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Using Computer Simulations as a Pre-Training Activity in a Hands-On Lab to Help Community College Students Improve Their Understanding of Physics

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The University of San Francisco

USING COMPUTER SIMULATIONS AS A PRE-TRAINING ACTIVITY IN A HANDS-ON LAB TO HELP COMMUNITY COLLEGE STUDENTS IMPROVE THEIR UNDERSTANDING OF PHYSICS

A Dissertation Presented
to
The Faculty of the School of Education
Learning and Instruction Department

In Partial Fulfillment
of the Requirements for the Degree
Doctor of Education

by
Blanca Pineda
San Francisco
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THE UNIVERSITY OF SAN FRANCISCO
Dissertation Abstract

Using Computer Simulations as a Pre-training Activity in a Hands-on Lab to Help Community College Students Improve Their Understanding of Physics

The purpose of this study was to investigate the effectiveness of using computer simulations as a pre-training activity to a hands-on lab to improve students' understanding of induction topics in physics. The computer simulation activity was compared to an overview presentation. Conceptual understanding and spatial ability were measured. A two-group descriptive repeated measures design was implemented with a convenience sample of 35 community college physics students in the Bay Area. Participants were randomly assigned to a simulation group (n = 17) or a presentation group (n = 18). A 30-item spatial ability assessment was given to all participants one week before the day of the experiment.

On the day of the experiment, the simulation group completed a 30-minute induction simulation activity while the presentation group received a 30-minute overview presentation. Both groups then completed a 90-minute hands-on lab. Before completing the simulation activity or receiving the overview presentation, an 18-item conceptual understanding test was given to all participants. The same test was given as a posttest after participants completed the simulation activity or received the overview presentation, and again as a second posttest after participants completed the hands-on lab.

Overall results suggest that the overview presentation was more effective in improving students understanding of induction topics in comparison to completing the simulation activity. However, both groups showed noticeable conceptual understanding gains. The simulations had a medium effect (d = 0.68) and the overview presentation had a large effect (*d* = 1.07) on conceptual understanding. Results also suggest that high spatial ability participants benefited more from the simulations while the low spatial ability participants benefited more from the overview presentation. Both male and females benefited similarly from the overview presentation. However, male participants seemed to have benefited more from the simulations.

Although the overview presentation was more effective in improving students understanding of induction topics, the 30-minute computer simulation activity still made a difference in student learning. This result can be seen as a positive finding suggesting that 30-minutes of working with simulations could help students improve their understanding of physics concepts even if they had not used the simulations before.

Blanca Pineda, Author	Mathew Mitchell, Chairperson, Dissertation Committee

This dissertation, written under the direction of the candidate's dissertation committee and approved by the members of the committee, has been presented to and accepted by the Faculty of the School of Education in partial fulfillment of the requirements for the degree of Doctor of Education. The content and research methodologies presented in this work represent the work of the candidate alone.

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Candidate Date

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Dr. Mathew Mitchell 11/17/15
Chairperson Date

Dr. Susan Prion 11/17/15
Date

Dr. Kevin Oh 11/17/15
Date

DEDICATION

This dissertation is dedicated to my parents Diana and Luis who have always supported and encouraged me to pursue my dreams.

Thank you mom and dad!

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CHAPTER 1

Statement of the Problem

Abstract concepts in college science are difficult to understand for many students, but having a clear understanding of basic abstract concepts is necessary to comprehend more advanced scientific phenomena (Tambade & Wagh, 2011). Traditional methods of teaching that utilize lectures and textbooks alone may not be sufficient in helping students gain a deeper understanding of these complex scientific concepts, such as learning about chemical bonding (Karacop & Doymus, 2013). Computer animations may help students gain a better understanding of these concepts (Aldahmash & Abraham, 2009; Luealamai & Panijpan, 2012).

Computer animations are graphic, dynamic representations that show movement, and are produced through drawings and other forms of visualizations. In addition, these can be generated through computer applications, and can also contain user interactivity where the learner takes control over the sequence of the animation (Betrancourt, 2010; Mayer & Moreno, 2002).

There are several reasons why students have difficulty understanding abstract concepts in college science including the cognitive demand that is placed on them in trying to interpret abstract phenomena (Fong, 2013; Höst, Schönborn, & Palmerius, 2012) as well as learning concepts that are difficult to visualize with static images from a textbook (Hoeling, 2011). In addition, students may come to the classroom with misconceptions about the concepts they are learning, making it even more difficult to have a clear understanding of the phenomena under study (Bell & Trundle, 2008; Karacop & Doymus, 2013; Kucukozer, 2008; Zacharia, 2007). Furthermore, traditional methods of teaching such as lectures, static illustrations, hand-held manipulatives (Craig, Michel, & Bateman, 2013; Luealamai & Panijpan, 2012), and textbooks (Bell & Trundle, 2008; Hoeling, 2011) when used as the primary source of instruction may not help students build strong models. Building strong models can help students enhance their conceptual of the abstract concepts they are learning (Karacop & Doymus, 2013).

There are several ways in which computer animations can help students enhance conceptual understanding of abstract concepts in science. First, students can create mental representations of the concepts they are studying by manipulating and interacting with the animations (Aldahmash & Abraham, 2009; Tambade & Wagh, 2011; White, Kahriman, Luberice, & Idleh, 2010), which in turn promotes conceptual understanding (Tambade & Wagh, 2011).

Second, learning with computer animations gives students the opportunity to become engaged by allowing them to be part of the learning process (Fraser, Pillay, Tjatindi, & Case, 2007), and allowing them to explore "what-if" scenarios, something that would be difficult to do without computer-based simulations (Zacharia & Anderson, 2003). Learning with computer animations also gives students the opportunity to visualize abstract concepts that could not be possible to see without the use of computer animations (Fong, 2013; Tambade & Wagh, 2011).

Third, research suggests that computer-based instruction that includes computer animations can be an effective instructional method that can help students visualize difficult concepts by promoting conceptual understanding, which is necessary to learn more advanced topics (Karacop & Doymus, 2013; Kulasekara, Jayatilleke, & Coomaraswamy, 2011; Tambade & Wagh, 2011). For example, understanding the photoelectric effect in physics is essential to understanding more advanced concepts in quantum mechanics (McKagan, Wieman, Handley, & Perkins, 2009). Research also suggests that when used as a supplement or in addition to other traditional instructional strategies, computer animations can help students enhance their understanding (Hoeling, 2011; Karacop & Doymus, 2013; Luealamai & Panijpan, 2012; Williamson et al., 2012).

It is important to emphasize that instructional design plays a key role when computer animations are used as part of instructional strategies. Well-designed multimedia instruction that segments difficult concepts can help students better understand science concepts by promoting engagement and self-reflection (Fong, 2013; Kulasekara et al., 2011). Instructional design that is grounded in effective instructional theories such as the Cognitive Theory of Multimedia Learning (CTML) (Mayer, 2010a) should be taken into account when choosing and designing instructional materials that include computer simulations (Adams et al., 2008; Hoeling, 2012). Computer simulations are representations of real or hypothesized concepts that allow users to explore what-if scenarios by controlling and adjusting different parameters within the computational representations (Clark, Nelson, Sengupta, & D'Angelo, 2009).

Research suggests that spatial ability is an important factor in determining conceptual knowledge when learning with computer simulations (Urhahne, Nick, & Schanze, 2009). Spatial ability is also associated with knowledge gains (Sanchez & Wiley, 2010) in various science fields. Thus, in the current study, spatial ability was measured to assess the relationship between participants’ spatial ability and knowledge change. Spatial ability as defined by Cohen and Hagerty (2007) is:

> The cognitive ability to understand, mentally encode and manipulate three-dimensional visuo-spatial forms. Component processes of spatial visualization include encoding a visuo-spatial stimulus, constructing a visual spatial image from perceptual input, mentally rotating an image, switching one’s view

perspective, and comparing a visual stimulus to an image in working memory (p. 179).

Figure 1 shows an example question from the Santa Barbara Solids Test (SBST) that was developed by Cohen and Hegarty (2007) and measures spatial ability. In this example, test takers choose the two-dimensional (2D) shape that results from cutting the three-dimensional (3D) object with a cross-section plane. The resulting 2D shape is a circle (the answer is c).

Figure 1. Example of Spatial Ability Test Question.

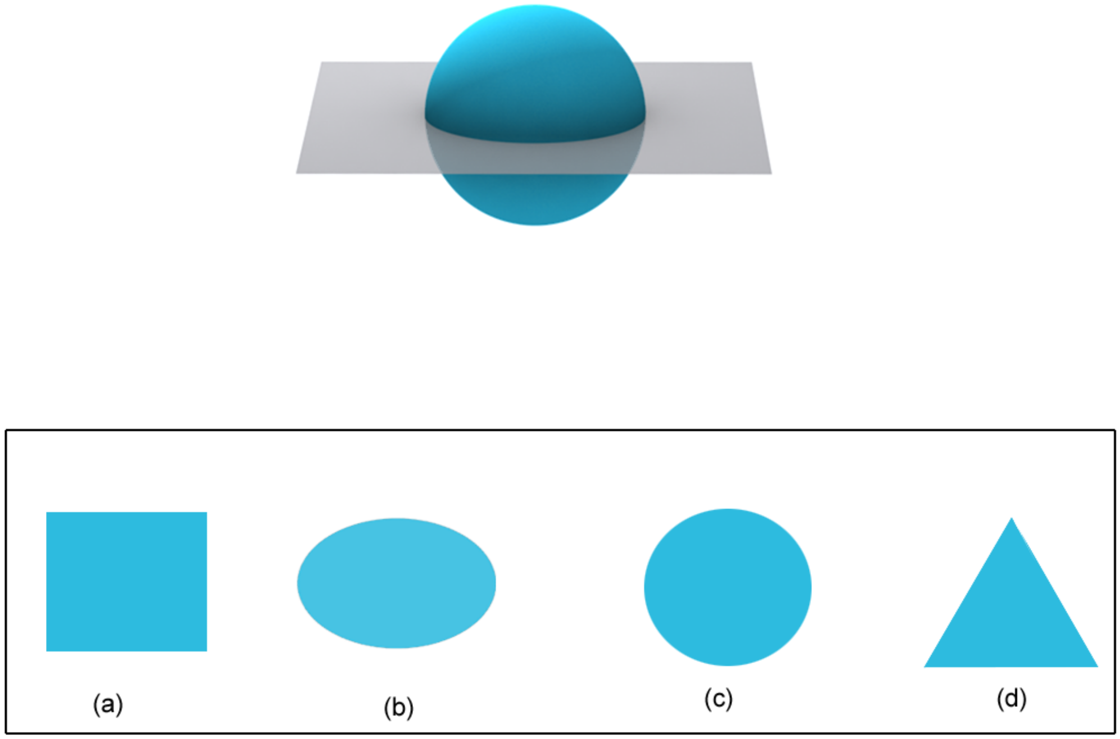


Figure 1. Example question from the Santa Barbara Solids Test (SBST). Adapted from "Sources of difficulty in imagining cross sections of 3D objects," by C. A. Cohen and M. Hegarty, 2007. In "Proceedings of the Twenty-Ninth Annual Conference of the Cognitive Science Society ,“ by D. S. McNamara and J. G. Trafton (Eds.), *Proceedings of the Twenty-Ninth Annual Conference of the Cognitive Science Society,* p. 179-184. Austin TX: Cognitive Science Society. And adapted from "Inferring Cross Sections of 3D Objects: A New Spatial Thinking Test," by C. A. Cohen and M. Hegarty, 2012, *Learning and Individual Differences, 22*(6), p. 868-874. Image used with permission from Dr. Cheryl Cohen.

Purpose of the Study

The purpose of this study was to investigate the effectiveness of enhancing learning with a computer simulation activity as pre-training before students completed a hands-on induction physics lab in comparison to having an overview presentation before completing a hands-on induction physics lab. Research suggests that spatial ability is an important factor when learning various science concepts such as chemistry and biology (e.g. Urhahne et al., 2009). However, researchers that investigated the effectiveness of computer animations for learning physics concepts have not taken into account the role that spatial ability plays in learning physics. Thus, this study also investigated the relationship between spatial ability and conceptual understanding when learning physics with computer simulations. Researchers also suggest that there are spatial ability and gender differences with undergraduate students when learning science concepts with computer animations (Sanchez & Wiley, 2010). Thus, this study also explored if there were gender differences and differences between high spatial ability students and low spatial ability students when learning about induction in physics with computer simulations.

Significance of the Study

This study used a two-group, descriptive, repeated measures design to compare mean differences among groups and correlations to assess the relationship between spatial ability and conceptual understanding stratified by gender.

There are two main reasons why this study is important for educational practice. First, results from this study can inform physics instructors and help them make better decisions about whether to implement the use of computer simulations or overview presentations in their practice as a pre-training activity to hands-on labs. Second, understanding if there are gender differences, and differences between high spatial ability students and low spatial ability students when learning about induction with computer simulations is important in helping instructors understand how their students learn and customize instruction based on their students' learning needs.

Theoretical Rationale

This study was grounded in Mayer's Cognitive Theory of Multimedia Learning (Mayer, 2010a). The Cognitive Theory of Multimedia Learning (CTML), is in part, based on Paivio's Theory of Dual Coding (Paivio, 1986). CTML is based on the assumption that humans process information through different channels (verbal and auditory), and humans can only actively process information a few items at the time for each channel, and learners must engage in cognitive processing to achieve meaningful learning (Mayer, 2010a; Mayer & Moreno, 2002; Mayer & Moreno, 2010b).

There are three kinds of cognitive processes: *extraneous processing*, this is the type of cognitive processing that is not required in order to make sense of new information and makes no contribution to someone's learning. *Essential processing* is the type of cognitive processing that is needed to be able to select new information and is "imposed" by how difficult the learning materials are. And *generative processing* is the type of cognitive processing that helps a learner organize new information in a clear structure in order to be able to integrate it to new knowledge, making a contribution to learning (Mayer & Moreno, 2010a, p. 153; 2010b, p. 133).

Given the complexity of achieving meaningful learning and the limited capacity learners have for cognitive processes (Mayer & Moreno, 2003), principles of instructional design based on the CTML were developed to guide instructional designers when creating multimedia learning environments (Betrancourt, 2010; Mayer & Moreno, 2003; Mayer & Moreno, 2010b).

These same principles were used as a guide to choosing the computer simulations that were used in the current study. Figure 2 illustrates the theoretical framework model for this study and how a combination of principles of multimedia instructional design can be used as a guide to choosing computer animations that can help reduce extraneous processing, manage essential processing, and promote generative processing, which in turn can lead to conceptual understanding.

Figure 2. Theoretical Framework Model for The Current Study Based on the Cognitive Theory of Multimedia Learning and Principles of Multimedia Design.

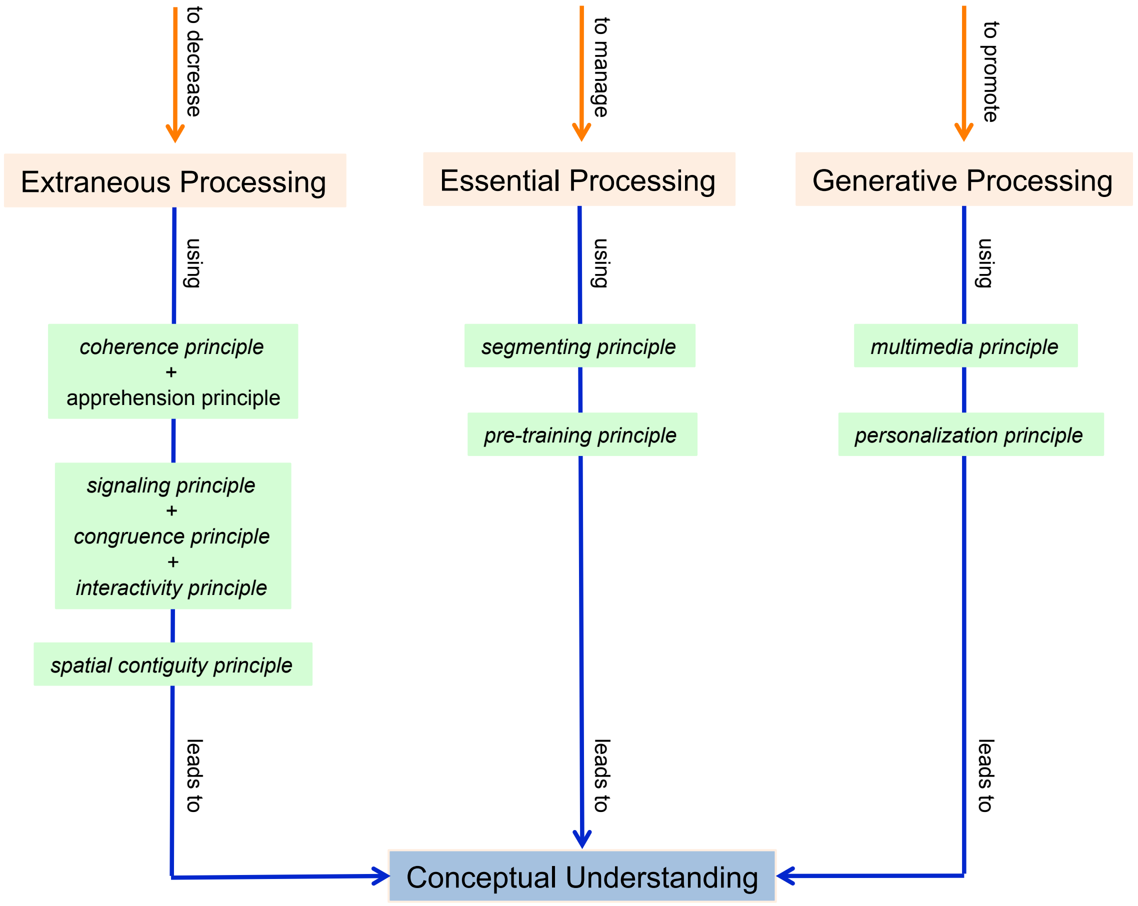


Figure 2. There are three main goals according to the Cognitive Theory of Multimedia Learning (CTML): reduce extraneous cognitive processing, manage essential cognitive processing, and promote generative cognitive processing (Mayer & Moreno, 2010b). This model shows that using principles of multimedia design as a guide to choosing computer animations can help reduce extraneous processing, manage essential processing, and promote generative processing – leading to enhanced conceptual understanding.

The goal of instructional design based on the CTML is to decrease extraneous processing, manage essential processing and promote generative processing (Mayer & Moreno, 2010b). The following principles of instructional design can help reduce extraneous processing: coherence, apprehension, signaling, congruence, interactivity, and spatial contiguity. The *coherence principle* states that eliminating extraneous materials such as unnecessary words, sounds and pictures is better because even though these extraneous materials may be interesting, these do not add anything to learning (Mayer, 2008, 2010c; Mayer & Moreno, 2002, 2003; Mayer & Moreno, 2010b). The *apprehension principle* states that the external characteristics of the animation should be easily understood by students, and features in the animation that are "cosmetic" in nature should be avoided for these do not add anything directly to student understanding (Betrancourt, 2010). The *signaling principle* states that highlighting materials that direct learners to essential information in a lesson promotes better transfer of information because providing signals helps learners reduce processing of extraneous information (Mayer, 2008, 2010c; Mayer & Moreno, 2003; Mayer & Moreno, 2010b).

The *congruence principle* states that depending on the phenomenon under study, events in an animation should be presented successively in order to allow students to form efficient mental models of what they are learning (Betrancourt, 2010). The *interactivity principle* states that students will have a better understanding of the information presented through an animation when they are given control over how fast or how slow they view the animation (Betrancourt, 2010). The *spatial contiguity principle* states that placing on-screen text near corresponding pictures is better than placing on-screen text farther from corresponding pictures on pages or screens in order to reduce unnecessary scanning, which in turn increases extraneous processing (Mayer, 2008, 2010c; Mayer & Moreno, 2002, 2003; Mayer & Moreno, 2010b).

The principles of instructional design that can help manage essential processing are the segmenting and pre-training principles. The *segmenting principle* states that presenting information that allows learners control what they are learning (user-paced segment) allowing time between sections is better than presenting the information in a continuous unit (Mayer, 2008, 2010b; Mayer & Moreno, 2003). Self-pacing is important because some learners may have difficulty with the pace of the lesson and therefore not engage in the necessary processing needed to engage in the material (Mayer, 2010b). The *pre-training principle* states that when learners have knowledge of names and characteristics of the main concepts prior to viewing a narrated animation, learners can decrease essential processing overload (Mayer, 2008, 2010b; Mayer & Moreno, 2003).

Finally the principles of generative processing are the multimedia and personalization principles. The *multimedia principle* states that learners can make better mental connections when both words and pictures (or animations) are used rather than words or pictures alone (Mayer, Griffith, Jurkowitz, & Rothman, 2008; Mayer & Moreno, 2002; Mayer & Moreno, 2010a). The *personalization principle* states that words in a conversational style are better than using words in a formal style because a conversational style encourages learner interest in the material promoting a deeper learning experience (Mayer et al., 2008; Mayer & Moreno, 2002; Mayer & Moreno, 2010a).

The purpose of this study was to investigate if the use of computer simulations as a pre-training activity to a hands-on lab could enhance conceptual understanding of abstract concepts in physics, in particular the concept of induction. To this end, the CTML was used as the framework for choosing the computer simulations that were used in the current study. It was hypothesized that choosing computer simulations that adhere to principles of multimedia design would help participants reduce extraneous processing, manage essential processing, and promote generative processing. Consequently, the computer simulations and the computer simulation instructional guide that were used in the current study were chosen based on the principles of multimedia design as a guide. These should help students enhance their understanding of abstract concepts in physics (figure 2).

Background and Need

Several concepts in physics are difficult for students to understand. Sahin and Yagbasan (2012) found that the concepts where pre-service teacher students have difficulty understanding include electromagnetic waves, inductance, Faraday's law, magnetic fields in magnetism, Gauss's law in electricity, motion, rotation and Newton's Laws in mechanics. Some of the reasons why students have difficulties understanding theses topics include: having trouble visualizing, difficulty solving problems, not being able to apply what they are learning into practice, and because the topic is being taught in a complex manner. The authors suggest that in order to help students have a better visualization of these concepts, learning should be supported with computer simulations.

A report by the American Institute of Physics on "Equipping Physics Majors for the STEM Workforce" indicated that to provide high-quality lab courses, faculty should provide lab experiences that include "modeling and simulations" (p. 5) among other experiences (Czujko, Redmond, Sauncy, & Olsen, 2014). Integrating computer animations can be an effective tool to help students enhance their conceptual understanding of various physics concepts (Dega, Kriek, & Mogese, 2013; Dilber, Karaman, & Duzgun, 2009; Karamustafaoglu, 2012; Kohnle et al., 2012). In a quasiexperiment to investigate the effectiveness of computer animations to promote conceptual change of electricity and magnetism, Dega et al. (2013) found that physics interactive simulations helped students promote conceptual change. Dilber et al. (2009) found that with conceptual change activities that included computer animations to learn about projectile motion concepts, students showed significant positive conceptual change in comparison to students who learned about the topic with traditional instruction.

Dilber et al. (2009) indicated that the benefits of computer animations included: making complex concepts more accessible, direct interaction that promotes an active student role, control of the pace and their learning, and being able to explore by changing the computer animation's characteristics so that they could immediately visualize what they were learning. Kohnle et al. (2012) also indicated that when using computer animations to learn about quantum physics, students found the computer animations to be helpful in improving their understanding of the topic. Moreover, Karamustafaoglu (2012) indicated that when learning about Simple Harmonic Motion (SHM), students who used computer animations had a better understanding of SHM in comparison to students who received traditional instruction, demonstrating that computer animations can be effective instructional tools that can help students develop a higher level of understanding.

In addition to promoting exploration, well-designed computer animations also promote engagement. In a qualitative study, Podolefsky, Perkins, and Adams (2010) investigated how the use of PhET (Physics Education Technology) simulations could enhance engaged exploration. PhET simulations are interactive and were built to promote teaching and learning of physics concepts (Perkins et al., 2010). In addition to physics PhET simulations, there are several other interactive simulations available through the PhET project website in subjects such as biology, chemistry, earth science and mathematics (PhET, 2015b). When using the “wave interference” PhET simulation, Podolefsky et al. (2010) found that students were able to build a conceptual framework about the topic because the simulation provided the necessary scaffolding to help students gain a better understanding of the topic (p. 10). Students also became engaged explorers, were able to view multiple representations, made connections, and arrived to an understanding of scientific ideas. Students were also able to pose and answer their own questions, allowing them to build conceptual knowledge and use the simulation in a manner in which a scientist would study a problem in a real-world setting.

These studies demonstrate how the use of computer animations can help students have a better understanding of physics concepts. This study is different because in addition to investigating how computer simulations can help students have a better understanding of physics, this study also investigated if computer simulations are effective pre-training tools that can be used before a hands-on induction physics lab.

Induction (also known as electromagnetic induction) was first discovered by Faraday in 1831 and is the process of moving a “current-carrying coil” or magnet back and forth through a loop of wire changing the magnetic field and generating an electric current in the loop of wire (Garg, 2012, p. 114). Research suggests that students have difficulties with the concepts related to electricity and magnetism with induction being one of the most difficult concepts for students to understand (Planinic, 2006). Students have difficulties with electricity and magnetism concepts because of the abstract nature of the different topics that cannot be visible such as electrons and fields (Chabay & Sherwood, 2006). This study investigated if computer simulations could help students enhance their understanding of induction topics.

Though there is research suggesting that incorporating computer simulations as a prior activity to completing an inquiry-based physics lab is effective in enhancing conceptual understanding when learning physics concepts (Zacharia & Anderson, 2003), this study is different in several ways. Zacharia and Anderson (2003) conducted a study to investigate if an interactive computer-based simulation, prior to completing an inquiry-based lab, was more effective than completing problems from a textbook prior to completing an inquiry-based lab. Thirteen postgraduate students participated in the study using a self-control design. Each student completed a total of twelve subtopics (six using the simulation, six completing the problems from the textbook) in mechanics, waves/optics, and thermal physics. Overall, results indicated that when students used the simulations to learn about the different subtopics, they had a greater conceptual change than when they solved problems from a book to learn about the different subtopics. This study built on Zacharia and Anderson (2003) by comparing the use of computer simulations as a pre-training activity to an overview presentation prior to completing a hands-on lab. In addition, the current study used a descriptive design that compared two groups, different from Zacharia and Anderson (2003) where they used a single-group self-control design, which the authors acknowledged to be a limitation because there could have been "contamination effects from using a self-control design" (p. 622).

Zacharia (2007) conducted a study to investigate the effectiveness of combining real experiments with virtual experiments in comparison to real experiments alone to learn about electric circuits in physics. The electric circuits module was broken into three components: behavior of simple electric circuits (Part A), measurements of currents and resistance (Part B), and measurement of voltage (Part C). The experimental group completed Parts A and B using the real experiments, and Part C with the virtual experiment. The comparison group completed all parts using the real experiments. Conceptual knowledge was measured before and after each part of the module. Results indicated that the experimental group outperformed the comparison group. The current study differs from Zacharia (2007) in that computer simulations were compared to an overview presentation prior to a hands-on lab. In addition, the current study investigated the relationship between spatial ability, conceptual understanding, and gender.

Research suggests that spatial ability is an important factor when learning science concepts with computer simulations. For example, Urhahne et al. (2009) conducted three different studies to investigate the effectiveness of three-dimensional simulations to enhance the learning of chemical structures. The authors found that spatial ability was a good predictor of conceptual knowledge in all three studies. The study above seems to demonstrate that spatial ability plays an important role when learning with computer simulations in chemistry and biology. However, research on spatial ability level (high or low) is not conclusive. There are studies suggesting that high spatial ability students have greater benefits when learning about biology with computer animations (Huk, 2006), while other studies suggest that low spatial ability students benefit more when learning about chemistry with virtual worlds (Merchant et al., 2013) and with segmented animated graphics (Fong, 2013). Other research suggests that spatial ability is related to structural and process knowledge when learning about biological processes with enriched pictures, but not with animations (Münzer, Seufert, & Brünken, 2009).

For example, Huk (2006) investigated the effectiveness of 3D computer animations that were built as part of a computer learning environment in order to help college and high school students' enhance their understanding of cell biology. Overall, results indicated that high spatial ability students benefited from learning about cell biology concepts with the 3D computer animations in comparison to low spatial ability students. Merchant et al. (2013), in a quasi-experimental pre-test posttest control group study, investigated if 3D virtual worlds in comparison to 2D static images could help undergraduate students have a better understanding of chemistry concepts and enhance students' spatial ability. When analyzing the data as a whole, overall results indicated that the 3D virtual worlds did not make a difference in enhancing students' spatial ability and chemistry understanding. However, when analyzing the data with the subgroups (gender and spatial ability), there were differences. Low spatial ability students performed better when learning about chemistry concepts using the 3D virtual world in comparison to high spatial ability students. In addition, overall results indicated that there were no statistically significant gender differences.

As demonstrated by these studies, most research that has investigated the effectiveness of computer animations and that also measure spatial ability has been conducted in science areas such as chemistry and biology. And even though there is research suggesting that there is a relationship between spatial ability and physics learning (Kozhevnikov & Thorton, 2006; Kozhevnikov, Motes, & Hegarty, 2007), these studies did not include computer simulations in their treatments and focused on kinematics topics, not induction topics. The current study investigated if there are spatial ability differences when learning with computer simulations about induction in physics. Measuring spatial ability in the current study allowed the researcher to compare if results were consistent with prior research suggesting that high spatial ability students benefit more from learning with computer animations, or if results were consistent with other prior research suggesting that low spatial ability students benefit more from learning with computer animations.

While Merchant et al. (2013) did not find gender differences when learning about chemistry with virtual worlds that included computer simulations, there is research suggesting that there are gender differences in spatial ability when learning science with computer animations (Falvo & Suits, 2009; Sanchez & Wiley, 2010). For example, Falvo and Suits (2009) investigated the effectiveness of molecular and macroscopic computer animations to enhance chemistry learning. In particular, the authors were looking at how "specific labels" and "diagrammatic arrows" in computer animations to learn about salt dissolution could help students have a better understanding of the concept. Ninety-one undergraduate students participated in this study. As demonstrated by previous research (Huk, 2006), participants with high spatial ability benefited more from the computer animations than low spatial ability students. However, female students benefited more from the computer animations than male students even though female students had lower spatial ability than male students.

The current study also investigated if there were gender differences when students used computer simulations as a pre-training activity to a hands-on lab, and compared if the findings were consistent with research indicating that there are no gender differences when learning with computer simulations, or with research indicating that there are gender differences when learning with computer simulations.

The role of community colleges

Overall, community colleges play an important role in educating students. In California, 31% of students at the University of California and 52% of California State University graduates started at a California community college during the 2013-2014 academic year (California Community Colleges Chancellor's Office, 2014). Furthermore, according to the National Science Board's science and engineering indicators for higher education, 49% of all science and engineering bachelor's degree recipients and 36% of all master's degree recipients in the United States from 2008 and 2009 attended a community college (National Science Board, 2014). In 2010 40% of engineering degree recipients and 39% of students receiving physical sciences and related sciences degrees attended a community college (American Association of Community Colleges, 2014). Because community colleges play an important role in educating students, the current study was conducted with community college students.

The role of physics

Physics also plays an important role in student success in engineering, physics, and other fields. For example, physics is a requirement for several majors when transferring to San Jose State University from a community college in California (San Jose State University, 2015). "Fundamentals of Physics" courses are a requirement as part of many majors in Aviation, Biological Sciences, Chemistry, Earth Sciences, Environmental Studies, Forensic Science, Geology, and Meteorology. Similarly, physics courses related to general "Mechanics" and "Electricity and Magnetism" are a requirement for majors in fields such as Applied Mathematics, various Engineering concentrations, and Mathematics (San Jose State University, 2015).

Given the important role that physics plays in the successful transfer of community college students to more advanced study, and given the complexity of learning several concepts in physics, it is important to investigate what instructional tools can help students enhance their understanding of physics concepts. Using computer simulations as instructional tools holds promise as effective methods for helping students enhance their understanding of physics concepts. More research is needed to investigate the effectiveness of computer simulations to help students understand physics concepts. It is unclear if learning with computer simulations can help students enhance their understanding of induction topics when used a pre-training activity prior to a hands-on lab, and if there are spatial ability differences in regards to high spatial ability and low spatial ability and gender differences.

Research Questions

1. What is the effect of computer simulations as a pre-training activity in physics on conceptual understanding scores?
2. What is the effect of spatial ability stratified as high and low on conceptual understanding scores when using computer simulations as a pre-training activity in physics?
3. Is there a gender difference on conceptual understanding scores when using computer simulations as a pre-training activity in physics?
4. What is the relationship between spatial ability and conceptual understanding scores when using computer simulations as a pre-training activity in physics?

Definition of Terms

Conceptual Understanding – For the purposes of this study, conceptual understanding is defined as knowledge measured using a conceptual understanding test. Conceptual understanding was measured with an 18-item multiple-choice conceptual knowledge test on induction topics that was created based on an “Electricity & Magnetism Tasks” book by Hieggelke, Maloney, O'Kuma, and Kanim (2005). Each correct item was scored as one point for a maximum total of 18 points. An increased score implies increased conceptual understanding.

Computer Animations – Graphical dynamic representations that show movement and are produced through drawings and other forms of visualizations. In addition, animations can be generated through computer applications and can also contain user interactivity where the learner takes control over the sequence of the animation (Betrancourt, 2010; Mayer & Moreno, 2002).

Computer Simulations – Computer representations of real or hypothesized concepts that allow users to explore what-if scenarios by controlling and adjusting different parameters within the computational representations (Clark et al., 2009).

Gender – Participants self-reported their gender.

Spatial Ability – "The cognitive ability to understand, mentally encode and manipulate three-dimensional visuo-spatial forms. Component processes of spatial visualization include encoding a visuo-spatial stimulus, constructing a visual spatial image from perceptual input, mentally rotating an image, switching one's view perspective, and comparing a visual stimulus to an image in working memory" (Cohen & Hegarty, 2007, p. 179). Spatial ability was measured using the Santa Barbara Solids Test (SBST). This is a 30-item multiple-choice test. Each correct answer was scored one point for a maximum of 30 points. Participants who scored 16 or more points, were considered high spatial ability, participants scoring below 16 points were considered low spatial ability.

Summary

Students have difficulties understanding abstract concepts in science for several reasons including cognitive demand that is placed on them (Fong, 2013) and learning concepts with static images that make it difficult to visualize abstract concepts (Hoeling, 2011). Computer simulations or animations have shown to be effective tools that can help students enhance their understanding of abstract concepts. In particular, computer animations can help students gain a better understanding of physics concepts (e.g. Dega et al., 2013). However, most of the research that investigates the effectiveness of computer simulations or animations has not taken into account spatial ability differences and gender differences when learning about induction topics in physics. The purpose of the current study was to investigate if using computer simulations as a pre-training activity to a hands-on lab could help students improve their understanding of physics concepts, in particular the concept of induction. Additionally, the purpose of the current study was to investigate if there were spatial ability and gender differences when learning about induction topics with computer simulations.

CHAPTER 2

Review of the Literature

The purpose of this study was to investigate the effectiveness of computer simulations as a pre-training activity for a hands-on laboratory experience. Simulations were compared to receiving an overview presentation as a pre-training activity. The review of the literature focused on five sections. The first section focused on an overview of the Cognitive Theory of Multimedia Learning (CTML) and the principles of multimedia learning that were derived from this theory. The second section reviewed studies on how the use of computer simulations helped students gain a deeper understanding of abstract physics concepts. The third section reviewed studies on how the use of computer simulations helped students enhance their understanding of other science concepts. The fourth section reviewed studies about the role that spatial ability plays when learning science concepts with computer simulations. The last section reviewed studies about the relationship of spatial ability and gender.

Cognitive Theory of Multimedia Learning

Mayer's Cognitive Theory of Multimedia Learning (CTML) is based on three assumptions. First, is based on the assumption that humans process information through different channels (verbal and auditory). Second, humans can only actively process information a few items at the time for each channel. And third, learners must engage in cognitive processing to achieve meaningful learning (Mayer, 2010a; Mayer & Moreno, 2002; Mayer & Moreno, 2010b). There are three kinds of cognitive processes: *extraneous processing*, this is the type of cognitive processing that is not required in order to make sense of new information and makes no contribution to someone's learning. *Essential processing* is the type of cognitive processing that is needed to be able to select new information and is “imposed” by how difficult the learning materials are. And *generative processing* is the type of cognitive processing that helps a learner organize new information in a clear structure in order to be able to integrate it to new knowledge, making a contribution to learning (Mayer & Moreno, 2010a, p. 153; 2010b, p. 133).

Achieving meaningful learning is a complex effort given the limited capacity that learners have for cognitive processes (Mayer & Moreno, 2003). The goal of the CTML is to reduce extraneous processing, manage essential processing, and to promote generative processing (Mayer & Moreno, 2010b). There are several principles of multimedia learning that can help meet these goals. In addition, there are several other principles specific to using computer animations and other more advanced principles. These principles can serve as a guide to help instructional designers when creating multimedia learning environments.

Principles of multimedia learning that can help reduce extraneous cognitive processing

Research suggests that there are five principles of multimedia learning that can serve as a guide for instructional designers in order to help them develop multimedia learning environments that can help learners reduce their extraneous cognitive processing. Table 1 summarizes these principles.

Table 1

Principles of Multimedia Learning That Can Help Reduce Extraneous Processing

Reference	Principle	Description
Mayer and Moreno (2002); Mayer and Moreno (2003); Mayer (2008); Mayer and Moreno (2010b); Mayer (2010c)	Coherence	Eliminate extraneous words, sounds, and pictures. Although some extraneous materials may be interesting, avoid them in order to reduce cognitive processing.

	Redundancy	Present words as narration and graphics rather than narration, on-screen text, and graphics. It is better to present just the narration of words, versus having words printed on the screen in addition to narrating the information.
	Signaling	Give cues that highlight the organization of essential material to promote better transfer of information. Providing a signal to process materials helps reduce processing of extraneous information.
	Temporal Contiguity	Present narration simultaneously with corresponding animation or words and pictures rather than successively.
	Spatial Contiguity	Place on-screen text near rather than far from corresponding pictures on pages or screens. It is important to reduce the need to scan for relevant information, placing words near graphics reduces unnecessary scanning

Note. The same references apply to all principles

Principles of multimedia learning that can help manage essential cognitive processing

Table 2 summarizes the principles of multimedia learning that instructional designers can use to develop instructional materials that can help learners manage their essential cognitive processing.

Table 2

Principles of Multimedia Learning That Can Help Manage Essential Processing

Reference	Principle	Description
Mayer and Moreno (2003); Mayer (2008); Mayer and Moreno (2010b); Mayer (2010b); Mayer (2010c)	Segmenting	It is better to present information to allow learners control what they are learning rather than having a continuous unit. It is better to allow time between sections of information that is being presented to the learner.
	Pre-training	It is better when students have knowledge of names and characteristics of the main concepts before the formal instruction begins.

Low and Sweller (2010); Mayer and Moreno (2002); Mayer and Moreno (2003); Mayer (2008); Mayer and Moreno (2010b); Mayer (2010b); Mayer (2010c)	Modality	It is better to present information with images and narration rather than images and on-screen text. Instead of providing too much text on-screen, convert this text to narration format.

Note. The same references apply to the segmenting and pre-training principles.

Principles of multimedia learning that can help promote generative cognitive processing

Table 3 summarizes the principles of multimedia learning that can help instructional designers develop multimedia based instructional materials that can help students in promoting their generative cognitive processing.

Table 3

Principles of Multimedia Learning That Can Help Promote Generative Processing

Reference	Principle	Description
Mayer and Moreno (2002); Mayer (2008); Mayer and Moreno (2010a)	Multimedia	Use both spoken text and pictures as animations or a series of still frames. Mental connections can be better built when both words and pictures are presented rather than words or pictures alone.
Mayer and Moreno (2002); Mayer (2008); Mayer and Moreno (2010a); Mayer (2010d)	Personalization	Use words in a conversational style rather than a formal style. Increasing learner interest encourages active cognitive processing and deeper learning.
Moreno and Mayer (2007); Mayer and Moreno (2010b)	Guided activity	Students learn better when they receive guidance and interact with an instructional agent that can help them guide their cognitive processes.
Moreno and Mayer (2007); Mayer and Moreno (2010b)	Feedback	Students learn better with positive feedback.
Moreno and Mayer (2007); Mayer and Moreno (2010b)	Reflection	Students learn better when they reflect upon correct answers while they are processing meaning.

Principles of multimedia learning specific to designing computer animations

In addition to the principles of multimedia learning that can help reduce extraneous processing, manage essential processing, and promote generative processing, Betrancourt (2010) proposed five principles of multimedia learning that are specific to designing multimedia environments that include animations. Table 4 summarizes these principles.

Table 4

Principles of Multimedia Learning Specific to Computer Animations

Reference	Principle	Description
Betrancourt (2010)	Apprehension	External characteristics of the animation should be easily understood by students, features in the animation that are “cosmetic” in nature should be avoided for these do not add anything directly to student understanding. This principle is similar to the coherence principle from table 1.
Betrancourt (2010)	Congruence	Depending on the phenomenon under study, events in an animation should be presented successively in order to allow students to form efficient mental models of what they are learning. This principle is similar to the segmenting principle from table 2.
Betrancourt (2010)	Interactivity	Learners will have a better understanding of the information presented through an animation when they are given control over how fast or how slow they view the animation. This principle is similar to the segmenting principle from table 2.
Betrancourt (2010)	Attention-guiding	Because animations are dynamic in nature and change rapidly, it is important to incorporate guidance to direct students to relevant parts of the animation through signals in verbal and graphic forms.
Betrancourt (2010)	Flexibility	Takes into account that not all students have the same level of knowledge. It is important to design animations that provide clear instructions with different options on how to start the animation

Additional principles of multimedia learning

Table 5 summarizes other principles of multimedia learning that can serve as a guide for instructors in order to develop effective instructional materials that can make a difference in student learning. The voice and image principles are related to social cues, which is an aspect of multimedia learning that encourages learners/instructors to be social partners and interact with a conversational and human voice style (Mayer, 2010e).

Table 5

Additional Principles of Multimedia Learning

Reference	Principle	Description
Ayres and Sweller (2010)	Split-attention	Information that comes from different sources must be integrated in order for the information to be mentally understood by learners.
Mayer (2010e)	Voice	Use a friendly human voice rather than machine voice.
Mayer (2010e)	Image	Avoid putting speaker's image on screen because the speaker's image hinders learning.

Advanced principles of multimedia learning

In addition to the several principles summarized in tables 1 to 5, there are eight additional advanced principles of multimedia learning that can serve as a guide for instructional designers that can help them develop instructional materials that can help students gain a better understanding of the content they are learning. Table 6 summarizes these principles.

Table 6

Advanced Principles of Multimedia Learning

Reference	Principle	Description
De Jong (2010)	Guided discovery	Multimedia learning environments that are discovery-based should incorporate guidance into their learning environment.

Renkl (2010)	Worked-out examples	Learners gain a deeper understanding of the materials they are learning when worked-out examples are provided at the beginning of their learning.
Jonassenm, Lee, Yang and Laffey (2010)	Collaboration	Learners perform better when online learning activities are provided.
Roy and Chi (2010)	Self-explanation	Learners engage in deeper learning when they are encouraged to provide explanations while they are learning.
Rouet and Potelle (2010)	Navigational	Learners perform better when navigation guidance is provided in "hypertext" learning environments. Hypertext is an electronic document made of multiple pages connected through links.
Shapiro (2010)	Site-map	Learners perform better when a map that shows where they are in the lesson and a map that supports their goals is provided in an online learning environment. A site map is "a graphical or linguistic representation of the organization of a hypertext" (p. 322).
Kalyuga (2010)	Prior knowledge	Principles of multimedia learning depend on the learner's prior knowledge. The same principles that may help novice learners may not help expert learners.
Paas, Van Gerven and Tabbers (2010)	Cognitive aging	Using more than one modality of instruction may be more efficient in helping older adults expand their working memory.

Using Computer Simulations can Enhance Physics Learning

This section will describe studies suggesting that computer simulations can help students gain a deep understanding of abstract concepts, explore "what if" scenarios, and visualize abstract concepts that would be difficult to visualize without the use of computer simulations.

Gaining deep understanding of abstract concepts

Research suggests that when computer simulations are used as part of an instructional strategy to learn about abstract concepts in physics, these can help students gain a deeper understanding of these concepts (Hoeling, 2012; Tambade & Wagh, 2011; Zacharia & Anderson, 2003).

Hoeling (2012) conducted a quasi-experimental pretest/posttest control group study to investigate if the use of an on-line learning module that was created specifically to help students learn about refraction and lenses within a physics unit (that incorporated interactive animations) had an effect on student learning. An Optics Module was created combining narrations and animation and/or graphics and each page on the module was limited to the essential information needed to learn the specific concept. In addition, the animations in the learning module gave students the opportunity to manipulate what was presented on the screen. The experimental group (n = 139) used the on-line learning module in addition to the textbook and lectures to learn about refraction and lenses while the control group (n = 35) learned about refraction and lenses using lectures and textbook alone. After the treatment, all students were given a posttest. Subsequently, participants in the experimental group completed a survey to assess their opinions about the amount of time they spent on the unit and how useful it was.

Overall, results indicated that the experimental group outperformed the control group from pretest scores to posttest scores. The experimental group went from 39%+-19% (pretest) to 76%+-16% (posttest) versus the control group, which went from 40%+-16% (pretest) to 52%+-20% (posttest), both groups were similar before the treatment. Survey results (given only to the experimental group) indicated that 87% of students agreed that the animations helped them have a better understanding of the material versus reading the textbook. In addition, approximately 80% of students indicated that they found the on-line module interesting versus reading the book chapters, and they liked working with the on-line module because it allowed them to learn about refraction and lenses with animations that were interactive, which in turn allowed them to explore different scenarios.

Despite the positive outcomes by Hoeling (2012), there were three main weaknesses. First, an alternative reason why the experimental group outperformed the control group could be that in addition to the on-line learning module with animations, students had the ability to read the book. Students were able to learn the same information from more than one source. Second, students were allowed to use the on-line module at their own pace, giving them the opportunity to view the animations as many times as they wanted. This was in comparison to the control group, which only had access to the face-to-face lectures one time and access to the textbook. Third, the researcher created the pretest instrument, reliability and validity information was not provided. Even though there are weaknesses, this study shows that a well-designed multimedia based learning module with animations can be an effective tool to help students gain a better understanding of physics concepts.

Tambade and Wagh (2011) conducted an experimental pretest/posttest control group study to investigate whether a computer-based environment with simulations and animations was a more effective method of learning electrostatics in physics, in comparison to traditional classroom instruction. Participants in the control group (n = 53) were exposed to traditional lectures to learn about electrostatics, while the participants in the experimental group (n = 53) used an Interactive Electrostatics Simulation Package (IESP) that included instruction built into the package. A 15-item multiple choice Electrostatic Concept Diagnostic Test (ECDT) was developed to measure content knowledge (KR20 = 0.70). Overall, results indicated that there were statistically significant differences between the control group and experimental group (t(52) = 10.20,

$p < .01$) in regards to conceptual understanding from the posttest scores ($d = 2.00$). The experimental group outperformed the control group indicating that the use of computer-assisted instruction with simulations and animations was a more effective tool to help students learn about electrostatics than traditional lectures alone.

Zacharia and Anderson (2003) conducted a self-control group study to investigate the effectiveness of using computer simulations presented before an inquiry-based lab experience could help students have a better understanding of mechanics, waves/optics, and thermal physics. Thirteen postgraduate pre-service science teachers participated in this study. Each student was assigned 12 sub topics covering concepts related to mechanics, waves/optics, and thermal physics. Students completed six of the sub topics using the simulation activity condition, and 6 of the sub topics using the non-simulation activity condition. The simulation and non-simulation activities were completed before the inquiry-based labs. All students received a reading assignment and a problem set from a textbook. For the simulation activity condition, students used computer simulations, and for the non-simulation activity condition, students studied additional problems and solutions from a textbook. Both activities lasted approximately 20 to 30 minutes. Semi-structured interviews were used to learn more about students' predictions and explanations of the different topics. A conceptual knowledge test developed by the researchers based on prior studies and was administered to students three times: as a pretest before the introductory activity, as a posttest after the introductory activity, and as a posttest after the inquiry-based lab in order to assess conceptual understanding.

Overall, results indicated that using the simulations helped students make acceptable scientific predictions and achieve conceptual understanding of the three physics concepts under study, in comparison to completing problems from a textbook.

Combining the simulation activities with the inquiry-based labs produced the greatest knowledge gains. It is important to note that students achieving enhanced knowledge gains could also be attributed to the self-control design that was implemented in the study. As the researchers indicated, the self-control design could have caused "contamination effects" (p. 622) because students were completing activities with the simulations and solving problems from the textbook. Nevertheless, results suggest that students were able to gain a deeper understanding of the concepts under study.

Research also suggests that when combining the use of virtual experiments that include simulations with more traditional lab experiments, students gained a deeper understanding of the material under study (Zacharia, 2007; Zacharia, Olympiou, & Papaevripidou, 2008).

Zacharia (2007) conducted a two-group pretest/posttest quasi-experimental study to investigate the effectiveness of using a combination of virtual experiments (VE) and real experiments (RE) in comparison to RE alone to enhance students' conceptual understanding of electric circuits. The virtual experiments were completed using a software package where students could manipulate the different parts of electric circuits. The real experiments used real materials from a physics lab. The same curriculum was used for both the experimental group (*n* = 45) and the comparison group (*n* = 43). To assess students' conceptual understanding of electric circuits, a conceptual test was administered before and after each part of the curriculum (there were three parts of the curriculum, part A, B and C), and before and after the study. The experimental group completed parts A and B using real experiments and part C using virtual experiments (combination RE and VE). The comparison group completed all parts using the real experiments (VE only).

Overall, results indicated that students who learned about electric circuits with the combination of virtual experiments and real experiments gained a better conceptual understanding of electric circuits in comparison to students who used real experiments ($F(1,85) = 10.6$, $p < .001$). Even more so, when comparing part C, students who used the virtual experiments gained a greater conceptual understanding of electric circuits in comparison to students who used the real experiments ($F(1,85) = 13.8$, $p < .001$). The researchers suggest that the virtual experiments allowed students the ability to do more experimentation by easily manipulating the parameters of the virtual environment.

Zacharia et al. (2008) obtained similar results in their two-group quasi-experimental study where they investigated the effectiveness of using a combination of virtual manipulatives and real manipulatives in comparison to using real manipulatives alone. In this case, the topic of study was heat and temperature, indicating that regardless of topic, the combination of virtual environments and real environments can help students enhance their understanding of various physics concepts.

Visualizing abstract phenomena

With the use of computer animations, students have the opportunity to conduct experiments and visualize abstract phenomena that could not be possible in a regular lab setting (Bayrak, 2008; Kohnle et al., 2010; Tambade & Wagh, 2011) or due to external factors that may be at play such as weather (Bell & Trundle, 2008).

Bell and Trundle (2008) conducted a study to investigate the effectiveness of using computer simulations to promote scientific conceptions of moon phases. Quantitative and qualitative methods were used in a single case pretest/posttest design ($n = 50$). During the study, a software package was used to collect data for 63 observations. The results indicated that 82% of the participants were able to scientifically understand the cause of moon phases and 80% were able to draw scientific shapes and sequences. The advantages of using the software were that participants were able to make more accurate observations in the simulated environment and in a shorter period of time because they did not have to worry about "weather conditions and obstructions from tall buildings, mountains, and trees" (p. 347). If the participants made these observations by going outside, unpredictable weather conditions or other manmade or natural factors could have made collecting data difficult and it would have taken much longer.

Kohnle et al. (2010) developed a series of animated visualizations to help students gain a better understanding of introductory and intermediate-level quantum mechanic topics. To assess the effectiveness of these animations, two animations (potential and finite well) were used as part of a 1-hour workshop with level 2 undergraduate quantum mechanics students. Six of the animations (probability current, time propagation of a Gaussian wave packet, the asymmetric well, comparison of the classical and quantum 1D simple harmonic oscillator, the 2D infinite well, and the successive energy measurements) were used in tutorial problems as part of level 3 quantum mechanics courses with undergraduate students. To measure conceptual knowledge, a multiple-choice 12-item survey was developed. The survey was administered to level 2 students ($n = 50$) as a pretest/posttest at the beginning and at the end of the semester. For the level 3 students ($n = 50$), the survey was administered in the middle of the second semester (level 3 students used the animations during the first semester).

Overall, results indicated that level 2 students made the greatest knowledge gains from pretest to posttest ($t(75.4) = 9.51$, $p < .0005$, two tailed). On average, students answered 2.8 questions on the pretest and 6.3 questions on the posttest. Level 2 students outperformed level 3 students on the questions related to potential and finite well, which was were the animations were used by level 2 students, but not level 3 students. These results indicate that using computer animations can help students have a better understanding of abstract concepts. However, it is important to note that the overall knowledge gains could be attributed to other factors because the use of the animations was only a small part of the overall semester instruction. Nevertheless, many students found a benefit from using the animations. For example, a student indicated “I was especially confused in visualizing solutions for the FDSW1 (1D finite-depth square well), but animations of the graphs really helped me understand the concepts.” (p. 1453).

Contradicting results

While the research has shown that using computer simulations is an effective way to enhance conceptual understanding of physics concepts, it is important to note that there were some studies that did not find statistically significant benefits when using computer simulations as part of an instructional strategy in physics (Darrah, Humbert, Finstein, Simon, & Hopkins, 2014; Finstein, Darrah, & Humbert, 2013; Martinez, Naranjo, Perez, Suero, & Pardo, 2011; Oh et al., 2012).

Finstein et al. (2013) in a three-group experimental study, investigated if students learning from virtual labs had the same knowledge gains as students learning with hands-on labs. The virtual labs were primarily comprised of simulations, but these also included videos, background theory, and post-lab questions. This study was conducted in two phases. In phase one, the researchers assessed the usability of four different labs using 50 high school participants. The labs included four physics concepts: Newton’s second law of motion, Hooke’s law, conservation of energy, and centripetal force. These labs were integrated into the regular classroom activity for three months in 2011. Students and teachers completed online surveys about their experiences using the different labs, and all students took a Force Concept Inventory at the beginning of the school year, and all students took pretests and posttests before and after each virtual lab respectively.

Overall results indicated that students significantly increased their knowledge of the four physics concepts previously outlined. It is important to note that it was expected that most students would show knowledge gains because the virtual labs included all the material they needed to know, and students did not receive any other type of instruction for the particular topic. However, phase one did verify that the virtual labs were useful.

In phase two of the study, Finstein et al. (2013) randomly assigned 168 high school students from Florida, Texas and West Virginia, to one of three groups based on five different labs in Spring 2012. Not all participants completed all labs. The Virtual Physics Lab (VPL) group learned about the physics concepts using the virtual lab that included simulations. The hands-on lab (HO) group learned about the different physics concepts using a traditional hands-on lab, and the supplemental group (SUPP) learned about the different concepts using the virtual labs as a supplement to the hands-on lab. The first lab was about learning the lenses concept (VPL, n = 78; HO, n = 55; SUPP, n = 35). The second lab was about learning refraction (VPL, n = 77; HO, n = 53; SUPP, n = 34). The third lab was about learning Ohm's Law (VPL, n = 78; HO, n = 55; SUPP, n = 35). The fourth lab was about learning about resistors (VPL, n = 68; HO, n = 55; SUPP, n = 35). The last lab was about learning the specific heat of metal (VPL, n = 22; HO, n = 11; SUPP, n = 20); all the participants in this lab were from one high school only, as opposed to the previous four labs that were comprised of students from the three different high schools.

To measure knowledge changes, all students took a Force Concept Inventory test at the beginning of the year to use as a baseline, in addition to taking a pretest and posttest before and after each lab respectively. Overall *t*-test results indicated that for most labs, there were no statistically significant differences between the VPL group and the HO group; only the second lab ($p < .05$) showed statistically significant results favoring the VPL group. When comparing the SUPP group and the HO group, results indicated that there were statistically significant results for the second lab ($p < .01$), the third lab ($p < .05$), and the fourth lab ($p < .01$) favoring the SUPP group. When comparing the VPL group with the SUPP group, only the fourth lab ($p < .01$) showed statistically significant results favoring the VPL group. These results are mixed and showed that both the virtual labs and the hands-on labs are almost equally successful methods that can be used when learning different physics concepts. On the other hand, the results also showed that when learning most of the physics concepts, using the virtual lab to supplement the hands-on lab was more effective to student learning than using the hands-on labs alone. However, as the researchers indicated, this finding could be attributed to the fact that students in the SUPP group completed each of the five labs two times.

Martinez et al. (2011) conducted a three-group quasi-experimental posttest study to compare the effectiveness of a hyper-realistic virtual environment in comparison to using schematic computer simulations and in comparison to a traditional laboratory experience. A total of 123 undergraduate college students participated in the study. The difference between the hyper-realistic environment (which also included the schematic simulations) and the schematic computer simulations is that in the hyper-realistic environment, the visual output was converted into a realistic visual. Both the hyper-realistic and schematic simulations treatments used interactive computer simulations. The hyper-realistic group ($n = 41$) used a hyper-realistic virtual lab to learn about formation images and optical aberrations. The schematic simulation group (*n* = 41) used computer simulations to learn about formation images and optical aberrations. The traditional group (*n* = 41) used a real laboratory optics machine to learn about formation of images and optical aberrations. Participants in all groups received the same theoretical background on formation of optical images. Each group then received four 3-hour sessions where they completed practice problems using their specific environment (hyper-realistic, schematic simulations, traditional lab). To measure learning changes, a 20 closed-response item test ($\alpha = .62$) was administered to each group after the treatment.

Overall, results indicated that the hyper-realistic group outperformed the traditional lab group ($t(80) = 2.08, p < .05$). There were statistically significant results when comparing the hyper-realistic group with the traditional lab. These results indicated that adding a realistic output to computer simulations can help students gain a better understanding of images and optical aberrations in physics. However, the schematic simulations without the realistic component did not make a statistically significant difference in student learning in comparison to the traditional lab.

Oh et al. (2012) in a two-group quasi-experimental designed study, and Darrah et al. (2014) in an experimental study; both found that the students in the treatment group did not outperform the students in the comparison group when learning about physics concepts using virtual labs in comparison to hands-on labs. Oh et al. (2012) had a total of 44 high school students from Singapore participating in their study. The treatment (*n* = 22) group received 12 one-hour lessons about the pressure unit; four different simulations were used in five of these 12 lessons. The comparison group did not use the simulations as part of the twelve lessons, and used a traditional “chalk-and-talk” approach. To measure a conceptual understanding of gas and liquid concepts, a 10-item multiple-choice test was administered as a pretest and posttest. In addition, a 7-item attitude survey was administered to the treatment group in order to measure students' attitudes towards using the simulations.

Results indicated that both the treatment ($t(22) = 5.72$, $p < .001$) and comparison ($t(22) = 3.23$, $p < .001$) groups showed statistically significant knowledge gains from pretest to posttest, indicating that both groups performed similarly with and without using the four simulations. However, after analysis of covariance analysis using the pretest as a covariate, results revealed that the comparison group outperformed the treatment group ($F = 4.74$, $p = .035$). Furthermore, results from the attitudes survey showed that students believed that the use of the simulations helped them gain a better understanding of pressure concepts.

Table 7 summarizes the physics research that was reviewed for this literature review. Overall the research suggests that computer animations or simulations can help students enhance their understanding of various physics concepts.

Table 7

Summary of Physics Studies That Use Animations or Simulations

Reference	Topic	Simulation Treatment	Comparison	Overall Results
Bell and Trundle (2008)*	Moon phases	Software package	No comparison	The majority of students were able to scientifically understand the cause of moon phases based on survey results.
Finstein et al. (2013)**	Lenses, refraction, Ohm's Law, resistors, heat of metal	Virtual labs that included computer simulations, one lab per topic	Virtual labs vs. hands-on labs vs. virtual labs as supplement to hands-on labs	Students who used the refractions virtual lab outperformed the hands-on lab students. There were no statistically significant differences for the other labs. When the virtual labs were used as a supplement to the hands-on lab, students had a better understanding of refraction, Ohm's Law, and resistors.
Hoeling (2012)	Refraction and lenses	On-line learning module with interactive animations	(On-line module + textbook + lecture) vs. (lecture + textbook)	Students who used the animations reported that the animations helped them gained better understanding of refraction and lenses.
Kohnle et al. (2010)	Quantum mechanics	Animated visualizations	Animated visualizations vs. regular course instruction	Students who used the animated visualizations made the greatest knowledge gains in comparison to students who did not learn with the animations.
Martinez et al. (2011)	Optics – formation images and optical aberrations	Hyper-realistic virtual labs and schematic simulations	Hyper-realistic virtual vs. schematic simulations vs. traditional lab	Students who used the hyper-realistic virtual environment had a better understanding of formation images and aberrations than students who used the schematic simulations or the traditional lab. There were no statistically significant knowledge gains from students learning with the schematic simulations in comparison to the traditional lab.

Reference	Topic	Simulation Treatment	Comparison	Overall Results
Oh et al. (2012)**	Gas and liquid	Computer Simulations	Computer simulations vs. “chalk-and-talk” approach	Students who used the simulations had similar knowledge gains from pretest to posttest as students who did not use the simulations. However, analysis of covariance using the pretest as a covariate revealed that students using simulations outperformed the students who did not use the simulations.
Tambade and Wagh (2011)	Electrostatics	Computer-based simulation package	(Computer simulation package) vs. (lecture)	Students who used the computer simulation package had better understanding of electrostatics.
Zacharia (2007)	Electric circuits	Virtual experiments	Virtual experiment + real experiment vs. real experiment	Students who learned with the combination of virtual experiments and real experiments gained a better understanding of electric circuits than students who learned about electric circuits with real experiments alone.
Zacharia and Anderson (2003)*	Mechanics, waves/optics, and thermal physics	Simulation activity	Animation activity vs. problems from a textbook vs. inquiry-based lab	Students who used the simulations had better knowledge gains than students completing problems from a textbook. Greater gains were found when combining the use of the simulation activities with the inquiry-based labs.
Zacharia et al. (2008)	Heat and temperature	Virtual manipulatives	Virtual manipulative + real manipulative vs. real experiment	Students who learned with the combination of virtual manipulatives and real experiments gained better understanding of heat and temperature then students who learned about electric circuits with real experiments alone.

Note. *Pre-service teachers. **High-school students. ***Graduate students. Everyone else were undergraduate students

Using Computer Simulations to Enhance Learning of Biology and Chemistry Concepts

In addition to physics, computer simulations can also help students enhance their understanding of abstract concepts in other science disciplines such as chemistry and biology.

Chemistry

Luealamai, Panijpan, and Ruenwongsa (2010) conducted a mixed methods quasi-experimental study with interviews to investigate if the use of a three-dimensional (3D) computer modules that incorporated animations could enhance student understanding of crystal lattice and the unit cell in chemistry. The computer module was compared to using a traditional lecture-based method. The computer module in addition to lectures was given to participants in the experimental group (*n* = 12), participants were able to play with the models as much or as little as they wanted. Participants in the traditional group (*n* = 12) only received instruction with lectures. Prior to the treatment, all participants completed a pretest and then after the treatment all students took a posttest. The pretest and posttest were used to measure achievement. The experimental group also answered a questionnaire to measure attitude towards learning, and then all students were interviewed.

Overall, results indicated that the experimental group made greater knowledge gains (36% to 75%) in regards to learning about crystal lattice and the unit cell than the control group (0% to 69%). In addition, participants in the experimental group indicated that they preferred to learn about crystal lattice and the unit cell from 3D simulations versus learning from the traditional setting and 2D and 3D illustrations. From the interviews, students in the control group indicated that learning from hand-held models helped them have a better understanding of the text materials. However, these models were not flexible enough to manipulate. The experimental group indicated that they liked using the hand-held models, but using the simulations allowed them to have a different view and make the atoms more easily visible. One of the weaknesses of this study was that the sample size was very small, it will be difficult to generalize the results. However, the interviews gave researchers great insight about why the 3D simulations were effective when learning about crystal lattice.

Karacop and Doymus (2013) in a quasi-experimental pretest/posttest control group study investigated the effectiveness of using a jigsaw cooperative learning technique and computer animations on academic achievement of students learning about chemical bonding. Participants were divided into three groups: the first experimental group (*n* = 36) used a jigsaw cooperative learning technique that fostered activity, content acquisition and explaining to learn about chemical bonding. The second experimental group (*n* = 39) used animations to learn about chemical bonding and the control group (*n* = 40) used traditional methods of learning. To measure scientific reasoning, spatial ability and understanding of chemical bonding, four different tests were used: Test of Scientific Reasoning (TOSR) ($\alpha = .63$), the Purdue Spatial Visualization of Rotations (PSVT:R) (*KR20* = .80), the Chemical Bonding Academics Achievement Test (CbAAT) ($\alpha = .83$), and the Particulate Nature of Matter in Chemical Bonding (CbPNMT), which was developed by the researchers for the purposes of the study.

Overall, results indicated that there were mean differences among the groups in regards to academic achievement (measured using the CbAAT) and understanding of chemical bonding after the treatment (measured using the CbPNMT). The participants in the animation (*m* = 102.95 for CbAAT, *m* = 59.04 for CbPNMT) and jigsaw cooperative (*m* = 93.89 for CbAAT, *m* = 41.18 for CbPNMT) learning groups outperformed those participants in the traditional teaching method group (*m* = 70.63 for CbAAT, *m* = 21.81 for CbPNMT). In addition, the computer animation group outperformed the jigsaw group, indicating that learning about chemical bonding can be better achieved when using animations.

Aldahmash and Abraham (2009) in an experimental pretest/posttest control group study investigated if there were any differences in using animations in comparison to using static images, the textbook, and lectures to help students have a better understanding of nucleophilic substitution and elimination reaction in chemistry. A computer instructional program was developed with animations and visual materials representing the reaction mechanisms of nucleophillic reaction. The control group (*n* = 71) was exposed to the static materials, while the experimental group (*n* = 71) was exposed to the animated visuals. Other than the type of visual, the materials in both versions were identical. The reference group (*n* = 101) was exposed to the regular course lectures and text readings. Results indicated that those students in the experimental group outperformed those students in the control group, scoring 10% higher in the posttest for content knowledge than the control group, which in turn scored 12% higher than the reference group. These results showed that when learning about chemical reaction phenomena, students benefited from using animations because they could see the reaction process taking place, they could manipulate it, and they could easily follow the entire process.

Biology

Kulasekara et al. (2011) conducted a mixed methods one-group (*n* = 42) study to investigate what students thought about the design on an interactive multimedia module that was developed to learn abstract microbial genetic processes. The Interactive Multimedia (IMM) learning package was developed to teach students about the "Recombination of Genes in Bacteria" (p. 114) and was used as a supplement to printed material that was already available. Participants were then given the opportunity to use the IMM learning package as often as they wished to supplement the printed materials. Students were observed while using the IMM package, and participants completed a questionnaire (*n* = 42) followed by participant interviews (*n* = 30).

Overall, results indicated that participants found the use of animations the most helpful component in using the IMM package to learn bacterial genetics because it helped them see the "live processes, which cannot be explained in face-to-face situations" (p 118). In addition, 100% of the participants who responded to the questionnaire indicated that audio narration, color graphics, animations, and the other media used in the IMM package, helped them learn the concepts more easily. Some of the weaknesses included a small sample size and the notion that researchers could have included a pretest and posttest to measure content knowledge, which could have been easily integrated into the study. Although researchers did gain useful information from students' perceptions, having an experimental component added to the study would have further validated the results as shown by other studies.

Urhahne et al. (2009) found mixed results in the three different studies that the authors conducted to investigate the use of three-dimensional simulations versus using two-dimensional illustrations to learn about chemical structures. The first two experiments presented in this study used a posttest experimental design with one treatment group and one comparison group for each experiment, pretest data and posttest data was also collected. Measurements included factual knowledge and conceptual knowledge, spatial ability, prior knowledge, domain-specific self-concept, and cognitive load. Participants were randomly assigned to either an experimental group or a comparison group. The third experiment used a 2x2 factorial design and participants were assigned to four different groups. The following is a detailed description of each of the experiments.

A total of 41 college freshman chemistry students participated in the first experiment, participants in the treatment group (*n* = 23) used 3D computer simulations to learn about chemical structures, and the students in the comparison group (*n* = 18) used two-dimensional illustrations to learn about chemical structures. The second study included a total of 155 tenth-grade students, the experimental group had 76 participants and the comparison group had 79 participants. The third study had a total of 51 first-year college students, participants were randomly assigned to one of four groups: 3D-simulations with life context (*n* = 14), 3D-simulations without life context (*n* = 13), 2D-illustraions with life context (*n* = 13), and 2D-illustrations without life context (*n* = 11).

Overall, results indicated that there were no statistically significant differences between the treatment group and comparison group for the first and third study with college students. For the second study, statistically significant results were found favoring the treatment group when it came to conceptual knowledge but not factual knowledge. There could be several explanations why results varied among all of the experiments. First, the sample size for the second study was larger than in the other two studies. Second, the unit with the 3D simulations to learn about chemical structures was adapted for tenth-graders, thus it is possible that the material was learned more efficiently with three-dimensional simulations than with two-dimensional models. Third, students had the support of the researcher for the second study while the treatment was taking place, while students in the other two experiments did not.

Table 8 summarizes the studies that were reviewed for this literature review. Most studies suggest that using computer animations helped students have a better understanding of various chemistry and biology concepts.

Table 8

Summary of Chemistry and Biology Studies That Use Animations or Simulations

Reference	Topic	Simulation Treatment	Comparison	Overall Results
Luealamai et al. (2010)	Chemistry	Three-dimensional (3D) computer module that included animations	3D computer module vs. lecture-based method	The 3D computer module group performed better than students on the lecture-based group. Using the 3D module gave students the ability to visualize different views of atoms.
Karacop and Doymus (2013)	Chemistry	Computer animations	Jigsaw cooperative learning vs. animations vs. traditional	Students in the animation group had a better understanding of chemical bonding in comparison to the other two groups.
Aldahmash and Abraham (2009)	Chemistry	Animated visuals	Animated visuals vs. static materials	Students in the animated visuals group had a better understanding of chemical reactions in comparison to the static materials group.
Kulasekara et al. (2011)	Biology	Interactive multimedia package (IMM)	No comparison	Using the IMM helped students gain a better understanding of bacterial genetics because they were able to see processes that could not be observed without the use of the IMM package.
Urhahne et al. (2009)*	Chemistry	Three-dimensional (3D) simulations	3D simulations vs. 2D illustrations	No statistically significant differences were found between the 3D simulations group and 2D illustrations groups for studies one and three. Students in the second study who learned about chemical structures using the 2D simulations had a better conceptual understanding of the concept.

Note. *High-school students for study one and three and undergraduates for study two. Everyone else were undergraduate students

Computer Simulations and Spatial Ability

Spatial ability plays an important role when learning various science concepts with computer simulations. However, overall research on spatial ability is inconclusive. Though some research suggests that students with low spatial ability (Merchant et al., 2013; Sanchez & Wiley, 2010) benefited more from learning with computer animations or simulations, other research suggests that high spatial ability students benefited more from learning with computer animations or simulations (Falvo & Suits, 2009; Fong, 2013; Huk, 2006). Other research also suggests that spatial ability was positively correlated to process and structure knowledge when learning with enriched static images, but not necessarily with animations (Münzer et al., 2009).

Fong (2013) conducted a 3x2 factorial experimental study that investigated the effectiveness of using segmented animated graphics to learn about electrolysis and aqueous solution in chemistry. A total of 171 high school students were randomly assigned to one of three conditions. All groups received the same learning content. The segmented animated graphics (SAG) group (*n* = 53) received the learning content with animated graphics that were presented in segmented sections and to proceed to the next section, students needed to click a button. The continuous animated graphics (CAG) group (*n* = 56) received the learning content where the animated graphics were presented in a continuous way. The multiple static graphics (MSG) group (*n* = 62) learned the content using a series of static graphics that contained explanatory text. Before all groups completed the treatments, all students were administered the Purdue Visualization of Rotation Test (ROT) to measure students' spatial ability level. To measure understanding of electrolysis, a 15-item multiple-choice test was developed by the researcher ($\alpha = .82$) and administered after each treatment.

Overall, results indicated that both low-spatial ability students and high spatial ability students performed significantly better when learning about electrolysis with SAG in comparison to the CAG and MSG groups (*F (2,167)* = 88.19, *p* = .00). Furthermore, students with high spatial ability outperformed students with low spatial ability in all conditions. High spatial ability students performed even better when they learned about electrolysis using animated segmented graphics. While low spatial ability students performed better with the SAG in comparison to the CAG and MSG, they did not outperform the high spatial ability students in the SAG group.

Sanchez and Wiley (2010) investigated the effectiveness of using computer animations to help students enhance their understanding of scientific concepts (earth science, physical science, and geology). In this experimental study, 96 undergraduate students were randomly assigned by gender (male; *n* = 48, female: *n* = 48) to three conditions: non-illustrated, static, and animated. The treatment was a volcano’s unit that contained text (non-illustrated), text and static images (static), and text with animated flash movies. To measure spatial ability, a paper folding task test was used. To measure learning, an essay response and a 20-sentence sentence verification task test was used. Cognitive ability was also measured using a general cognitive ability test called the OSpan.

Overall, results indicated that male students significantly outperformed female students in spatial ability but not in cognitive ability. Males had high spatial ability, and females had low spatial ability. Male students also outperformed females in the non-illustrative conditions and static conditions, but not on the animated condition. In particular, females (low spatial ability) learned the concepts of moving plates, plate subduction, and pressure better than male students in the animated condition. These results suggest that there were differences between male and female students and low spatial ability and high spatial ability when learning some science concepts. However, using computer animations can help eliminate these gender and spatial ability differences. Low spatial ability students (females) can benefit more from learning with computer animations.

In a three-group quasi-experimental study, Münzer et al. (2009) investigated the role of spatial ability when learning about cellular processes from a computer-based unit. Ninety-four graduate students were assigned to an animation condition (n = 34), or a static pictures condition (n = 31), or an enriched static pictures condition (n = 31). Prior knowledge was measured using a six multiple-choice and three open-ended questions test (α = .62). A paper-folding test was used to measure spatial ability. To measure learning, an eight-item structure knowledge test (α = .67) and a 14-item process knowledge test (α = .77) was administered after the treatments. Overall, results indicated that both, participants in the rich static and animations conditions enhanced their process knowledge gains in comparison to the static pictures condition. Furthermore, spatial ability was significantly related to process and structure knowledge in the enriched pictures condition, but not to the simulation condition.

Table 9 summarizes the research that was evaluated for this literature review. Most studies indicate that high spatial ability students benefited more from learning with computer animations or simulations in comparison to students with low spatial ability.

Table 9

Summary of Spatial Ability Studies That Use Animations or Simulations

Reference	Topic	Simulation Treatment	Comparison	Overall Results
Falvo and Suits (2009)	Molecular structures	Computer animations	Animations w/o labels vs. animations with specific labels vs. animations with diagrammatic arrows vs. animations with labels and arrows	High spatial ability students performed better than low spatial ability students. Female students performed better than male students regardless of spatial ability.
Fong (2013)**	Chemistry – electrolysis	Segmented animated graphics	Segmented animated graphics vs. Continuous animated graphics vs. multiple static images	High spatial ability students outperformed low ability students across all conditions. Low spatial ability students using the segmented animated graphics outperformed the other two groups, except for the high ability students using the segmented animated graphics.
Huk (2006)**	Cell biology	Three-dimensional a animations built into a computer learning environment	Learning environment with 3D animations vs. learning environment without 3D animations	High spatial ability students benefited from learning about cell biology concepts with computer animations in comparison to low spatial ability students.

Reference	Topic	Simulation Treatment	Comparison	Overall Results
Merchant et al. (2013)	Chemistry concepts	Three-dimensional (3D) virtual worlds	3D virtual worlds vs. 2D images	Low spatial ability students performed better when learning about chemistry concepts using the 3D virtual world in comparison to high spatial ability students.
Münzer et al. (2009)	Cellular processes	Animations	Animation vs. enriched static pictures vs. static pictures	Spatial ability was significantly related to process and structure knowledge in the enriched pictures condition, not in the simulation condition.
Sanchez and Wiley (2010)	Physical science concepts	Flash animations	By gender Non-illustrated vs. static vs. animated	There are differences between male and female students and low spatial and high spatial ability students when learning physical science concepts (favoring male students who had high spatial ability). Using computer animations can help eliminate these gender and spatial ability differences. Low spatial ability students (females) can benefit more from learning with computer animations.

Note. **High-school students. ***Graduate students. Everyone else were undergraduate students

Spatial Ability and Gender

Research on spatial ability and gender indicates that male participants outperform female participants in many fields including medicine (Langlois et al., 2013), STEM (Miller & Halpern, 2013), anatomy (Guillot, Champely, Batier, Thiriet & Collet (2007), and chemistry (Stieff, Ryu, Dixon & Hegarty 2012).

Langlois et al. (2013) investigated if there were gender differences in spatial ability on medical students entering a medicine residency program over a five-year period. To measure spatial ability, the Vandenberg and Kuse Mental Rotations Tests in two dimensions (MRTA) with 24-items and three dimensions (MRTC) with 24-items were used. A total of 214 medical students participated in this study, 131 female students and 83 male students. The Wilcoxon sign-rank test was used to make two group comparisons. Overall, results indicated that male students scored higher on both the MRTA test ($p < 0.0001$) and the MRTC test ($p < 0.0001$). These results indicate that overall male participants had higher spatial ability. However, the authors cautioned that even though male students performed better on the spatial ability tests, this does not mean that there were no individual female student who might have scored higher, or male students who might have scored lower. In fact, the frequency distributions of the spatial ability tests did show that some female students scored higher than male participants.

In a one-year longitudinal study, Miller and Halpern (2013) investigated if spatial ability training could improve spatial ability, narrow the gender gap, and improve Science, Technology, Engineering and Mathematics (STEM) outcomes among gifted STEM undergraduate students. A total of 77 students participated in the study, 28 females and 49 males. Students were randomly assigned to a training group or a control group. The training group (25 males, 14 females) received six two-hour spatial ability training over a period of six weeks, and the control group (24 males, 14 females) did not receive any training. Participants were tested for spatial ability before the training started, one week after the training ended, and 10 months later. In addition, other measures such as SAT scores, STEM course grades, and specific physics learning outcomes were collected.

Participants completed the Mental Cutting Test (MCT) to measure their spatial ability before the spatial ability training began (as a pretest) and one week after the spatial ability training ended (as a posttest). The MTC consisted of 25-items, only 10 items were used for the purposes of the study. The internal consistency of the MTC when administered as a pretest and posttest was acceptable ($\alpha = .74$ and $\alpha = .73$ respectively). Participants also completed additional spatial ability tests including a 24-item Mental Rotation Test (MRT) ($\alpha = .84$ and $\alpha = .67$ respectively), the Lappan Test ($\alpha = .62$ and $\alpha = .48$ respectively), and the Paper Folding Test (PFT) ($\alpha = .72$ and $\alpha = .70$ respectively) as a pretest and posttest.

Overall, results indicated that males outperformed female participants on the MCT, MRT, Lappan test, and SAT scores for math. There were no gender differences for the PFT, SAT scores for critical writing and writing. One week after the training, results indicated that participants in both the training and control groups made improvements on all spatial skills measures (MCT, PFT, MRT, Lappan). However, participants in the training group made greater improvements on the MCT and MRT. For the MCT, MRT and Lappan, gender differences became narrower. In regards to STEM course improvements, participants in the training group outperformed participants in the control group for the specific concept of Newtonian physics.

Ten months later, the longitudinal subsample included 55 participants. In addition to the MCT and MRT, a Novel Cross-Sections Test was administered and spatial working memory was measured. Results indicated that male participants outperformed female participants in the MRT and MCT, not the Novel Cross-Sections or Spatial Working Memory Tests. Overall, results indicated that participants in the training group made greater improvements in their spatial skills overtime in comparison to the control group. Although the spatial ability training seemed to have narrowed gender differences that may have existed. Also, the training group specifically outperformed the control group on the topic of Newtonian physics. However, the training group did not outperformed the control group when it came to other STEM related courses. Despite that the spatial ability training seemed to have helped students improve their spatial skills, it is important to note that most of the tests yielded either poor or acceptable internal consistency scores, suggesting that perhaps these tests should be piloted before using them in the study.

Guillot et al. (2007) investigated the relationship between spatial ability and mental rotation ability with functional anatomy learning. A total of 184 students enrolled in the anatomy program at Claude Bernard University participated in the study (130 males, 54 females). Three spatial ability assessments were used in the study. The first test was the Group Embedded Figures Test (GEFT), which consisted of 18 questions that evaluated the degree of dependence and independence of simple shapes. The second test was the Mental Rotations Test (MTR), which consisted of 24 three-dimensional items that students needed to rotate. The third test was the Gordon Test of Visual Imagery Control (GTVIC), which consisted of 12 items where students needed to rate the accuracy of a mental image on a “three-step scale” (p. 496). In addition to the spatial ability tests, participants completed a multiple choice anatomy test with 220 items. In addition, a comprehensive questionnaire to assess the time and preparation that students spent on the functional anatomy assignment was also given to students. Before the anatomy-learning module began, all participants completed the three spatial ability tests. After 14 hours of lectures and 14 hours of hands-on training in functional anatomy, students completed the anatomy test. After the experiment ended, 148 of the 184 participants completed the comprehensive questionnaire.

Overall, results indicated that there were statistically significant spatial ability differences between male and female participants favoring male students for the GEFT test ($F(1,182) = 4.03, p < .05$), the MRT test ($F(1,182) = 17.29, p < .0001$), and the anatomy test ($F(1,182) = 4.03, p < .05$). There were no statistically significant differences between male and females participants for the GTVIC spatial ability test. Results also indicated that there was a strong relationship between spatial ability and anatomy proficiency. More specifically, there was a strong relationship between mental rotation and anatomy proficiency, suggesting that mental rotation ability is an important factor in order to be proficient in anatomy learning. The authors suggest that mental rotation ability could be considered as a reliable predictor of anatomy success.

In their study to investigate the role of spatial ability and spatial strategy preferences to solve chemistry problems, Stieff et al. (2012) also found gender differences. A total of 103 first semester chemistry undergraduate students who were enrolled in a six-week organic chemistry course participated in the study. Gender information was reported for 90 participants only, 33 males and 57 females. To measure spatial ability strategy preferences, the authors developed a strategy choice questionnaire that consisted of six organic chemistry problems. In this questionnaire, students were asked to solve chemistry problems and then report what spatial ability strategy they used to solve the problems (spatial-imagistic, spatial-diagrammatic, and spatial-analytic algorithmic). The questions were displayed on large televisions in front of the classroom, and students used clickers to choose the appropriate responses. Students completed the survey two times, once right after the topic of canonical organic chemistry was introduced, and then again after the whole course ended (six weeks later) at the end of the last class. In addition, the Vandenberg Mental Rotation Test (MRT) and a modified version of the Guay's Visualization of Views Test (VoV) was administered to 91 students who volunteered to take these tests (out of the original 103 sample).

Overall, results indicated that students preferred to use spatial-imagistic strategies after the introduction of canonical organic chemistry (77.23%) and six weeks later after the course ended (58%) in comparison to the spatial-diagrammatic (18.08% and 27.83% respectively) and spatial-analytic (4.69% and 13.26% respectively) strategies. From the spatial ability test results, students were organized into three groups, high spatial ability, medium spatial ability, and low spatial ability. When analyzing the associations between spatial ability level and spatial ability strategy choice, results revealed that low spatial ability students used alternative strategies more times than high spatial ability students right after the introductory canonical organic chemistry lecture ($F(2,88) = 8.61$, $p = 0.05$). When results of the spatial ability tests were stratified by gender, results indicated that male participants outperformed female participants in both the mental rotation test ($t(83) < .001$) and the visualization of views test ($t(83) = .003$). In addition, further analysis revealed that female participants used alternative spatial strategies more frequently in comparison to male participants. After six-weeks of instruction, students use of alternative spatial strategies increased (diagrammatic and analytic) while spatial-imagistic strategies decreased. This result suggests that over time, students need less imagistic reasoning and rely more on "heuristics" to solve spatial related problems in organic chemistry (p. 858).

Table 10 summarizes the spatial ability and gender research that was evaluated in this review of the literature. Most studies indicated that male participants outperformed female participants in various spatial ability tests.

Table 10

Summary of Spatial Ability Studies That Focused on Gender Differences

Reference	Topic	Comparison	Overall Results
Guillot et al. (2007)	Functional anatomy	Relationship between spatial ability and anatomy learning	Male participants outperformed female participants in two of the three spatial ability tests, the Mental Rotations Test (MRT) and the Group Embedded Figures Test (GEFT). There were no gender differences in the Gordon Test of Visual Imagery Control (GTVIC). There was a strong relationship between mental rotation ability and anatomy proficiency.
Langlois et al. (2013)	Medical education	Spatial ability, male vs. female medical students	Male participants had higher spatial ability in comparison to female participants.
Miller and Halpern (2013)	Science, Technology, Engineering, and Mathematics (STEM)	Spatial ability training vs. no training	Spatial ability training improved spatial ability skills, narrowed gender differences, and improved physics scores one week after receiving the training. Spatial ability training did not improve scores of other STEM courses. Male participants outperformed female participants in many of the spatial ability measures, and these differences persisted 10 months after the training.
Stieff et al. (2012)	Organic Chemistry	Spatial ability strategy preference	Students preferred to use spatial-imagistic strategies after the introduction of canonical organic chemistry in comparison to spatial-diagrammatic and spatial-analytic strategies. After six-weeks of instruction, students use of alternative spatial strategies increased while spatial-imagistic strategies decreased. Male participants outperformed female participants in mental rotation ability and visualization of views ability.

Summary

Overall, the literature suggests that computer simulations can be effective learning tools when used as part of an instructional strategy in order to help students gain a deeper understanding of abstract physics concepts (e.g., Hoeling, 2012). Research also suggests that with computer simulations, students have the opportunity to visualize abstract concepts, which would be difficult to visualize without the use of computer simulations such as learning about quantum mechanics concepts in physics (Kohnle et al., 2010). In addition, computer simulations seem to be effective learning tools not only in physics, also in other fields such as chemistry (e.g., Karacop and Doymos, 2013) and biology (Kulasekara et al., 2011). The literature also suggests that spatial ability is an important factor when learning various science concepts with computer simulations. However, the research is not conclusive, while some studies indicate that low spatial ability students benefited more from computer simulations (e.g., Merchant et al., 2013), other research suggest that high spatial ability students benefited more from learning with computer simulations (e.g., Falvo & Suits, 2009). Furthermore, the literature also suggests that there were gender differences in students' spatial ability. Male students tend to score higher on spatial ability tests in comparison to female students in various science fields such as chemistry (Stieff et al., 2012).

CHAPTER 3

Methodology

This study investigated the effectiveness of computer simulations as a pre-training activity for a hands-on laboratory experience. Simulations were compared to an overview presentation as a pre-training activity. This study also explored the amount of spatial ability and gender differences when learning about induction with computer simulations, and explored the relationship between spatial ability, conceptual understanding and gender. Community college students participated in the study. The research questions that the current study aimed to answer are as follow:

1. What is the effect of computer simulations as a pre-training activity in physics on conceptual understanding scores?
2. What is the effect of spatial ability stratified as high and low on conceptual understanding scores when using computer simulations as a pre-training activity in physics?
3. Is there a gender difference on conceptual understanding scores when using computer simulations as a pre-training activity in physics?
4. What is the relationship between spatial ability and conceptual understanding scores when using computer simulations as a pre-training activity in physics?

Research Design

A two-group descriptive repeated measures design was used with a total of 17 participants in the simulation group and 18 participants in the presentation group. The Santa Barbara Solids Test (Cohen & Hegarty, 2007) was administered to all participants to measure spatial ability one week before the experiment took place in order to compare differences between the groups and to explore the relationship between students' spatial ability and conceptual understanding. The treatment for the simulation group consisted of completing an electromagnetic induction activity using the Faraday's Electromagnetic Lab PhET simulation (PhET, 2015a). The presentation group received an overview presentation about electromagnetic induction. After completing the simulation activity or the overview presentation, both groups then completed their scheduled hands-on lab. Before and after the treatment and hands-on labs for both groups, participants were given the same conceptual knowledge test (pretest and posttesst from Figure 3) to measure their understanding of induction. The physics instructor for the class provided the test questions. The dependent variable was conceptual understanding. Figure 3 shows the overall model that was used in this study.

Participants

A total of 35 students in one Bay Area community college participated in this study (17 in the simulation group and 18 in the presentation group). Students were enrolled during the Spring 2015 quarter in a general calculus-based physics course focusing on classical electricity and magnetism. Students were required to have completed a calculus-based course on classical Newtonian mechanics, and have already completed or be concurrently enrolled in an introduction to functions calculus based course.

A full-time physics instructor taught the calculus-based physics course and the labs. The instructor has been teaching at the institution where the current study took place since Fall 2003. The instructor has a Bachelors of Science and a Masters of Science degree in physics from two different universities in the United States. In addition to teaching calculus-based physics, the instructor also teaches different general physics courses or calculus-based physics courses throughout the academic year.

Figure 3. Overall Study Model

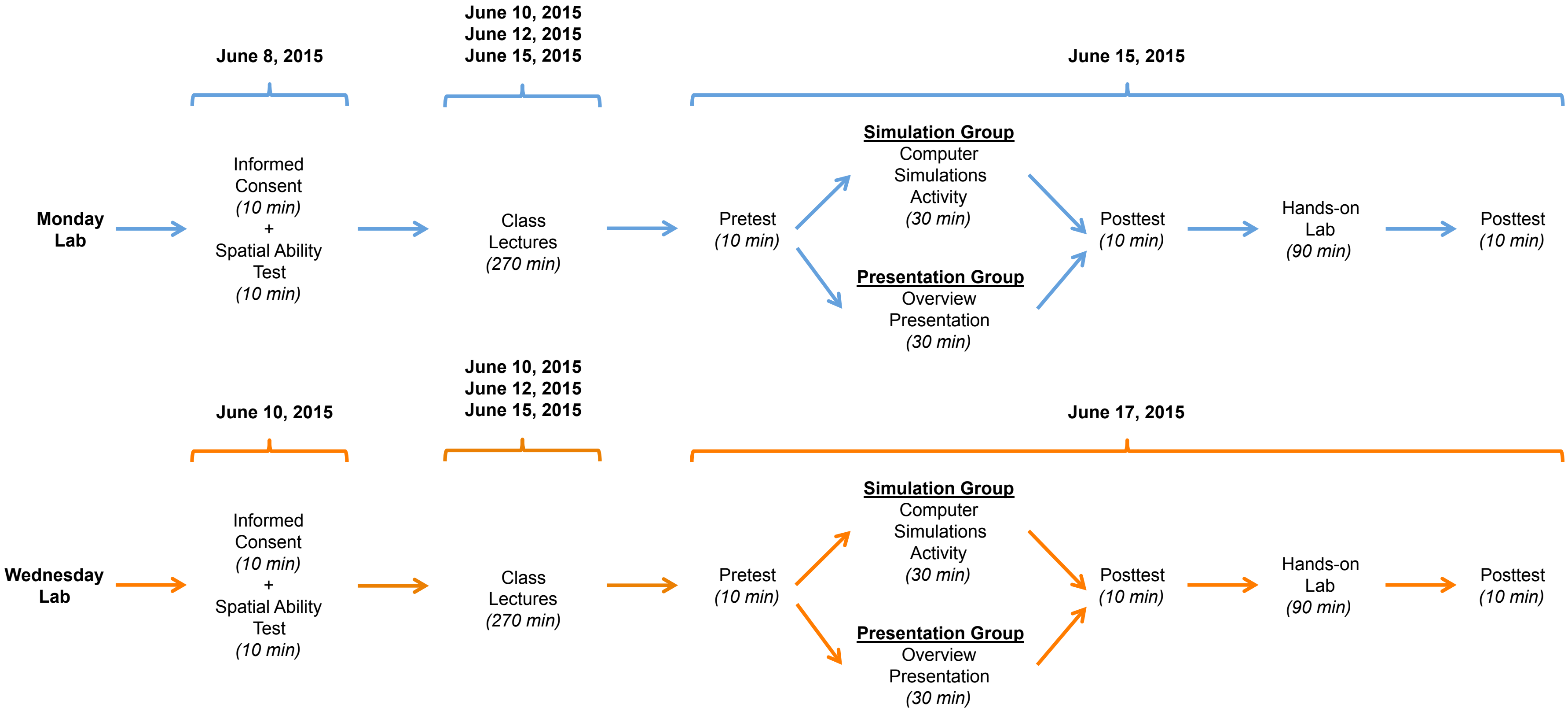


Figure 3. Model describing the sequence of study implementation with approximate timings. After students took the pretest on both the Monday lab and Wednesday lab, students were randomly assigned to a simulation group or presentation group. After the treatment, both groups came back together to take the first posttest, complete the hands-on lab, and then take the second posttest after the hands-on lab. All students received their regularly scheduled lectures on induction in between when the informed consent and spatial ability test were given and collected, and the day when the experiment took place.

Protection of Human Subjects

Institutional Review Board (IRB) approval was granted from the University of San Francisco's Internal Review Board for Protection of Human Subjects (IRBPHS) (Appendix A). Approval was also granted from the institution where the current study took place. The researcher requested informed consent from participants (Appendix B). In appreciation for their participation, students were entered to win a $50.00 Amazon gift card. Only students over the age of 18 were asked to participate in the current study. Students were asked to enter their initials and the day of their birthday on each of the different measures in order to track of each student's data throughout the data collection process (i.e. bsp18). Once all the information was collected and before conducting any analysis, student's initials were replaced by random numeric IDs in order to keep each student's information confidential once it was entered into the analyses software.

Instrumentation Description

The following is a description of the spatial ability test that was given one week before the treatment, and the conceptual knowledge test, which was given as a pretest and posttest the day of the experiment.

Spatial Ability Test (Appendix C) – For this study, the Santa Barbara Solids Test (SBST) that was developed by Cohen and Hegarty (2007) was administered. The SBST is a 30-item multiple-choice test that measures the "ability to identify the two-dimensional cross section of a three-dimensional geometric solid" (p. 873), which has indicated to be an important factor for learning in many STEM (Science, Technology, Engineering, and Mathematics) fields (Cohen & Hagerty, 2012). Figure 4 shows problem 1 of the SBST.

Figure 4. Problem 1 From the Spatial Ability Test

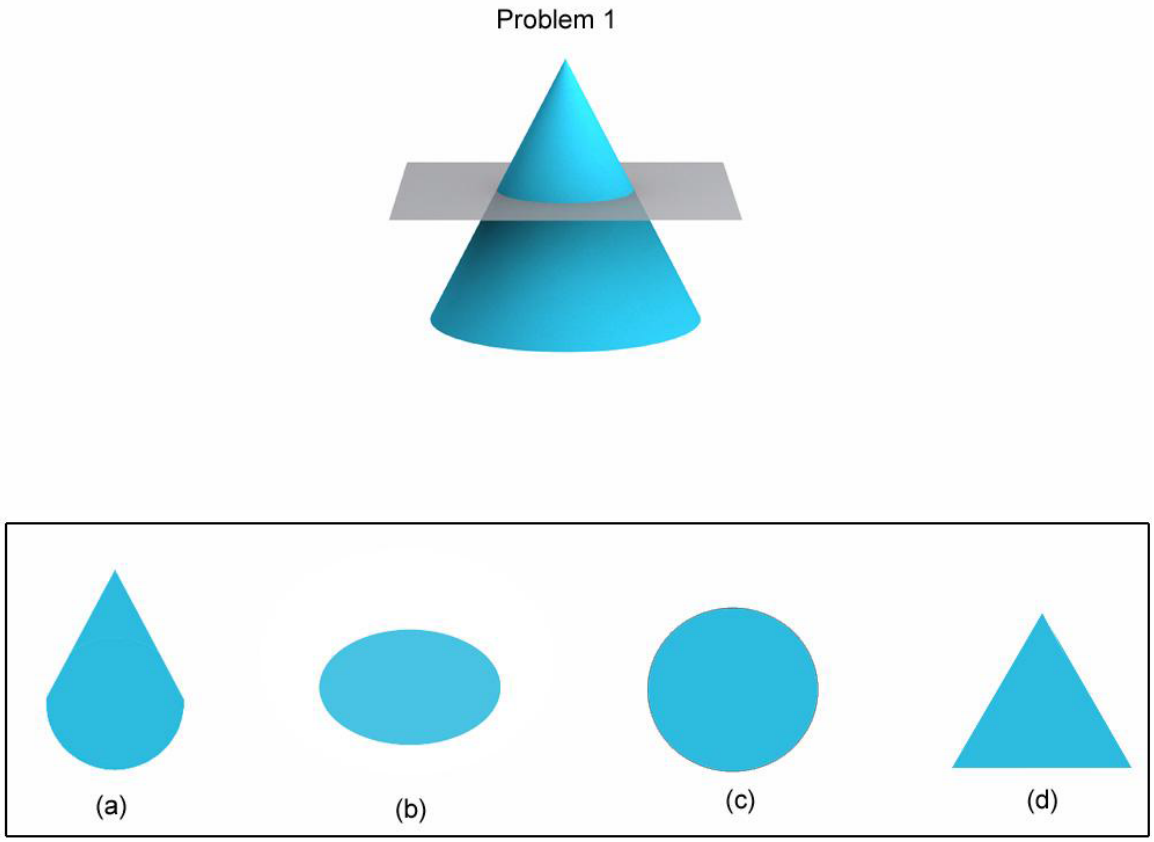


Figure 4. Problem 1 from the Santa Barbara Solids Test (SBST). Adapted from "Sources of difficulty in imagining cross sections of 3D objects," by C. A. Cohen and M. Hegarty, 2007. In "Proceedings of the Twenty-Ninth Annual Conference of the Cognitive Science Society ,“ by D. S. McNamara and J. G. Trafton (Eds.), *Proceedings of the Twenty-Ninth Annual Conference of the Cognitive Science Society,* p. 179-184. Austin TX: Cognitive Science Society. And adapted from "Inferring Cross Sections of 3D Objects: A New Spatial Thinking Test," by C. A. Cohen and M. Hegarty, 2012, *Learning and Individual Differences, 22*(6), p. 868-874. Image used with permission from Dr. Cheryl Cohen.

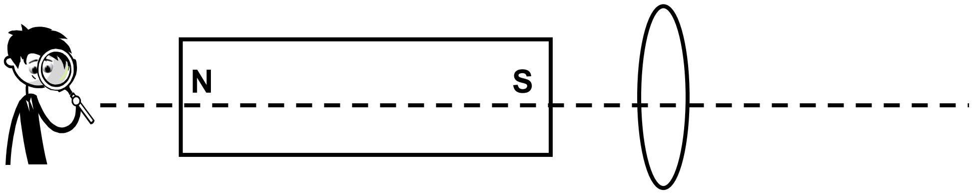
The SBST was highly reliable when administered in its paper-based form (α = .86) to 59 college students (Cohen & Hegarty, 2007) and when administered online to 223 college students (Cohen & Hagerty, 2012). The reliability for the online administration of the SBST was based on 29 items (α = .91); one item was eliminated from analysis due to researcher error. The SBST is composed of three sub-scales (Cohen & Hagerty, 2012), with 10 questions for the simple figures sub-scale (α = .79), 10 questions for the joined figures sub-scale ($\alpha = .80$), and 10 questions for the orthogonal figures sub-scale ($\alpha = .85$). Cohen and Hagerty (2012) indicated that the SBST could be used with high school and college students. The online version of this test takes approximately five minutes to complete. Participants in this study were given 10 minutes to complete as many questions from the test. The maximum number of points that a participant could earn was 29 points. The test was given one week before the experiment as shown in the current study's overall model (Figure 3). Each correct question was scored one point and any incorrect on unanswered question was given zero points. Participants scoring 16 points or above were considered high spatial ability while participants scoring below 16 points were considered low spatial ability.

Gender – Participants were asked to self-report their gender. On the spatial ability test, participants were asked to circle Male or Female. For the purposes of the current study, a dichotomous variable was needed.

Conceptual Knowledge Test (Appendix D) – This test was administered to measure an understanding of induction topics in physics. The test included 18 multiple-choice questions provided by the physics instructor for the class where the current study took place. The instructor obtained the questions from an "Electricity & Magnetism Tasks" book by Hieggelke et al. (2005). Figure 5 shows an example question from this conceptual test. This conceptual test was administered three times. The test was given as a pretest before the computer simulation activity for the experimental group, and before the overview presentation for the comparison group. The same test was then given as a posttest after the treatments (computer simulations or overview presentation), and then given again after all participants had completed a hands-on lab. Participants were given 10 minutes to complete as many questions from the test as they could. Each correct question was scored with one point and any incorrect on unanswered question was scored with zero points for a total of 18 possible points.

Figure 5. Example of Conceptual Test Question.

Initially, the magnet and the loop are not moving. Then, the loop starts to rotate around its center (denoted by the dotted line). The rotation is clockwise when viewed from the magnet side. What will be the direction of the induced current in the loop when viewed from the magnet side?



1. Clockwise
2. Counter Clockwise
3. No current

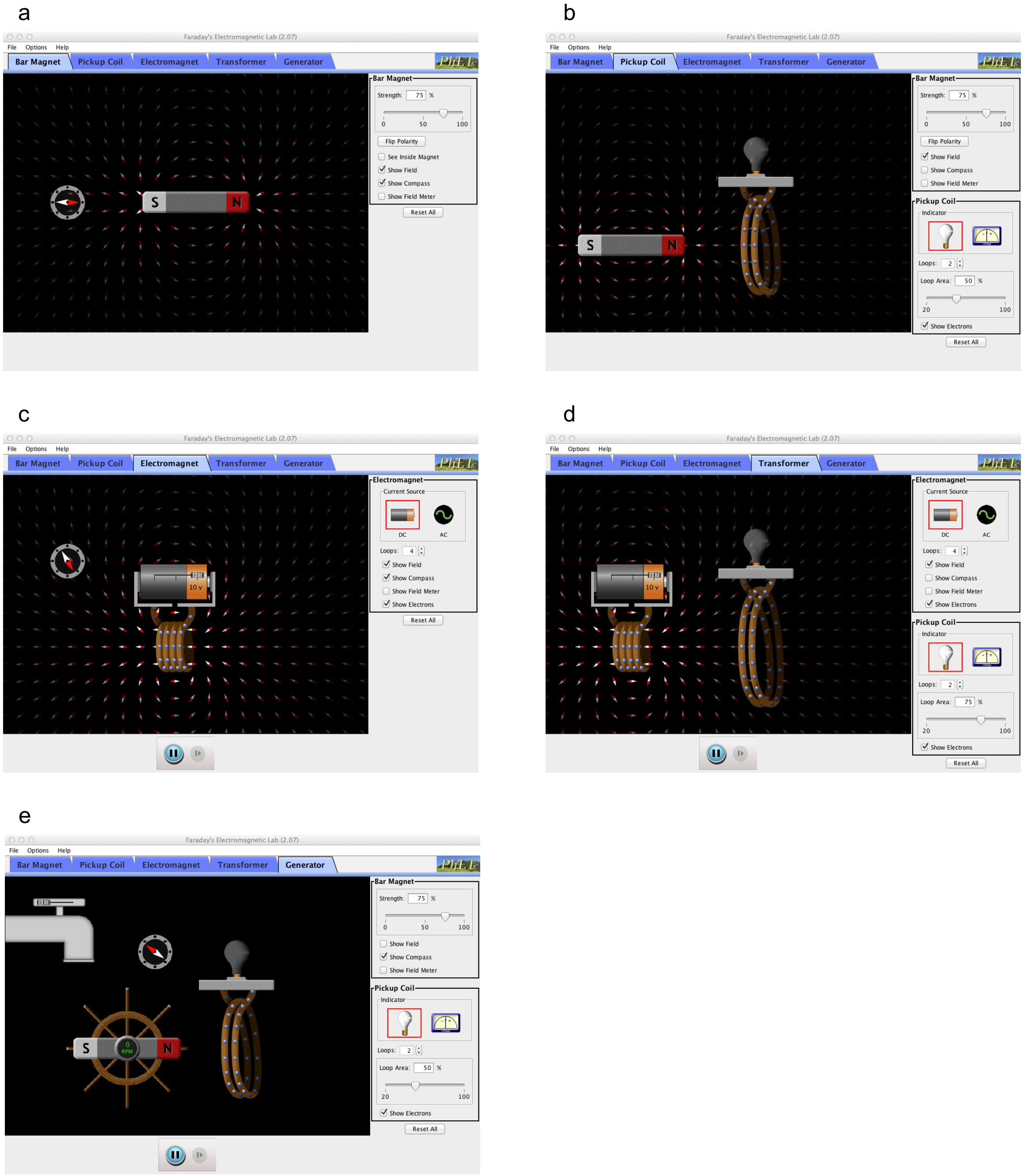
Figure 5. Conceptual test question from Hieggelke, C., Maloney, D., O'Kuma, T., & Kanim, S. (2005). *E&M TIPERs: Electricity & Magnetism Tasks*: Addison-Wesley.

Treatment Description

The following is a description of the PhET Faraday's Electromagnetic Lab computer simulation (PhET, 2015a) and the activity guide that was used to guide students in the simulation group. In addition, a description of the overview presentation that was given to the presentation group and a description of the hands-on lab that all students completed are also provided.

PhET Faraday's Electromagnetic Lab Simulation – These are a group of interactive simulations (Figure 6) that were built by the Physics Education Technology (PhET) project for teaching and learning of physics concepts (Perkins et al., 2010). The PhET project has built several interactive simulations available on their website not only for physics, also including subjects such as biology, chemistry, earth science and mathematics (PhET, 2015b).

Figure 6. Screenshots From The Faraday's Electromagnetic Lab Simulation



a
Bar Magnet
Strength: 75 %
0 50 100
☐ See Inside Magnet
☑ Show Field
☑ Show Compass
☐ Show Field Meter

b
Bar Magnet
Strength: 75 %
0 50 100
☑ Show Field
☐ Show Compass
☐ Show Field Meter
Pickup Coil
Loops: 2
Loop Area: 50 %
20 100
☑ Show Electrons

c
Electromagnet
Loops: 4
☑ Show Field
☑ Show Compass
☐ Show Field Meter
☑ Show Electrons

d
Electromagnet
Loops: 4
☑ Show Field
☐ Show Compass
☐ Show Field Meter
☑ Show Electrons
Pickup Coil
Loops: 2
Loop Area: 75 %
20 100
☑ Show Electrons

e
Bar Magnet
Strength: 75 %
0 50 100
☐ Show Field
☑ Show Compass
☐ Show Field Meter
Pickup Coil
Loops: 2
Loop Area: 50 %
20 100
☑ Show Electrons

Figure 6. The Faraday's Simulation lab contains five simulations: Bar Magnet (a), Pickup Coil (b), Electromagnet (c), Transformer (d), and Generator (e). Permission to use this simulation was given by PhET Interactive Simulations Project at the University of Colorado (PhET). Link: http://phet.colorado.edu.

Some of the advantages of using PhET simulations include conducting experiments that would not be possible to do without the use of the simulations due to the inability to visualize abstract concepts, impractical laboratory set-ups, or availability of real laboratory equipment (Wieman, Adams, Loeblein, & Perkins, 2010). PhET also provides easy user interactivity and the ability for students to get immediate feedback about what they are learning (Wieman et al., 2010).

The Faraday's Electromagnetic simulation that was used in the current study was a java-based program that was downloaded and installed in lab computers at the location where the experiment took place. The Faraday's Electromagnetic simulation is composed of five different simulations related to induction. Figures 6a-6b show screenshots of each of the five simulations.

Although not explicitly stated by the PhET project, these simulations adhere to the principles of multimedia design based on Mayer's Cognitive Theory of Multimedia Learning (Mayer, 2010a), which is the theoretical framework that was used in this study. Table 11 shows how the Faraday's Electromagnetic Lab simulation characteristics adhere to these principles. Because of the close alignment to Mayer's Cognitive Theory of Multimedia Learning, it was reasonable to assume that using these simulations would help students decrease *extraneous processing*, manage *essential processing*, and promote *generative processing*, which in turn would enhance understanding of the induction topics.

Table 11

Principles of Multimedia Design That Apply to the Faraday's Electromagnetic Lab Simulation

Principle	Simulation Characteristics
Coherence principle – eliminate extraneous materials that do not contribute to learning	The simulations did not contain any extraneous material that was not necessary and that did not contribute to learning.
Apprehension principle – external characteristics of the animation should be easily understood, features that are "cosmetic" in nature should be avoided	The simulations were easy to use and all the features that were part of the simulations were needed in order to effectively run the simulations. There were no "cosmetic" features that did not contribute to the use of the simulations.
Signaling principle – highlighting materials that direct learners to essential information helps learners reduce processing of unnecessary information	The simulations were used with an activity guide that highlighted the information students needed to go through with the different simulations.
Congruence principle – events in an animation should be presented successively in order to allow students to form efficient mental models of what they are learning	The simulation activities were presented in a sequential manner, as students went through the simulations, they were able to pause and reflect on what they were learning so that they could form effective mental representations.
Interactivity principle – students will have a better understanding of the information presented through an animation when they are given control over how fast or how slow they view the animation	Students were given an activity that guided them as they went through the simulations. However, they had control over how fast or slow they completed the activity in the allotted time.
Spatial contiguity principle – placing on-screen text near to corresponding pictures reduces unnecessary scanning	The text associated with the simulations was through control panels to the right of the simulations, which were closely placed with what was happening with the simulations.
Segmenting principle – present information that allows learners take control of what they are learning	The different simulations that were part of the Faraday's Electromagnetic Lab were presented in different screens by clicking on the different tabs, which in turn gave students control over the simulations.

Principle	Simulation Characteristics
Pre-training principle – learners should have knowledge of names and characteristics of the main concepts prior to viewing animations.	When students worked with the simulations, they had already received lectures on the topic of induction giving them enough knowledge to complete the simulation activity.
Multimedia principle – learners can make better mental connections when using both words and pictures (or animations) rather than using words or pictures alone.	Using the activity guide in conjunction to the simulations allowed students to make connections to the different topics they were learning.
Personalization principle –using words in conversational style encourages learners' interest in the material promoting	The activity guide that students were using to go through the simulations was written in a conversational style.

Figure 7. Computer Simulation Activity Guide Example

Move the bar magnet through the coil and observe the motion of the electrons in the forward arc of the coil loops.

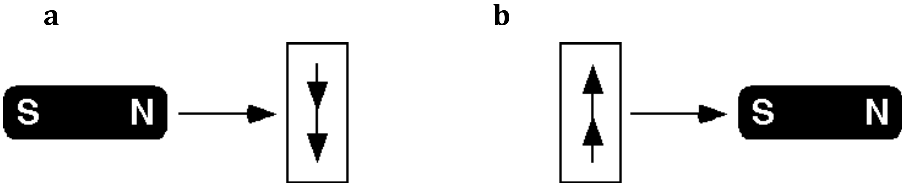


Figure 5

a. Magnet approaches from the left, north pole first; electrons **move downward (Figure 5a).**

b. Magnet departs to the right, south end last; electrons **move upward (Figure 5b).**

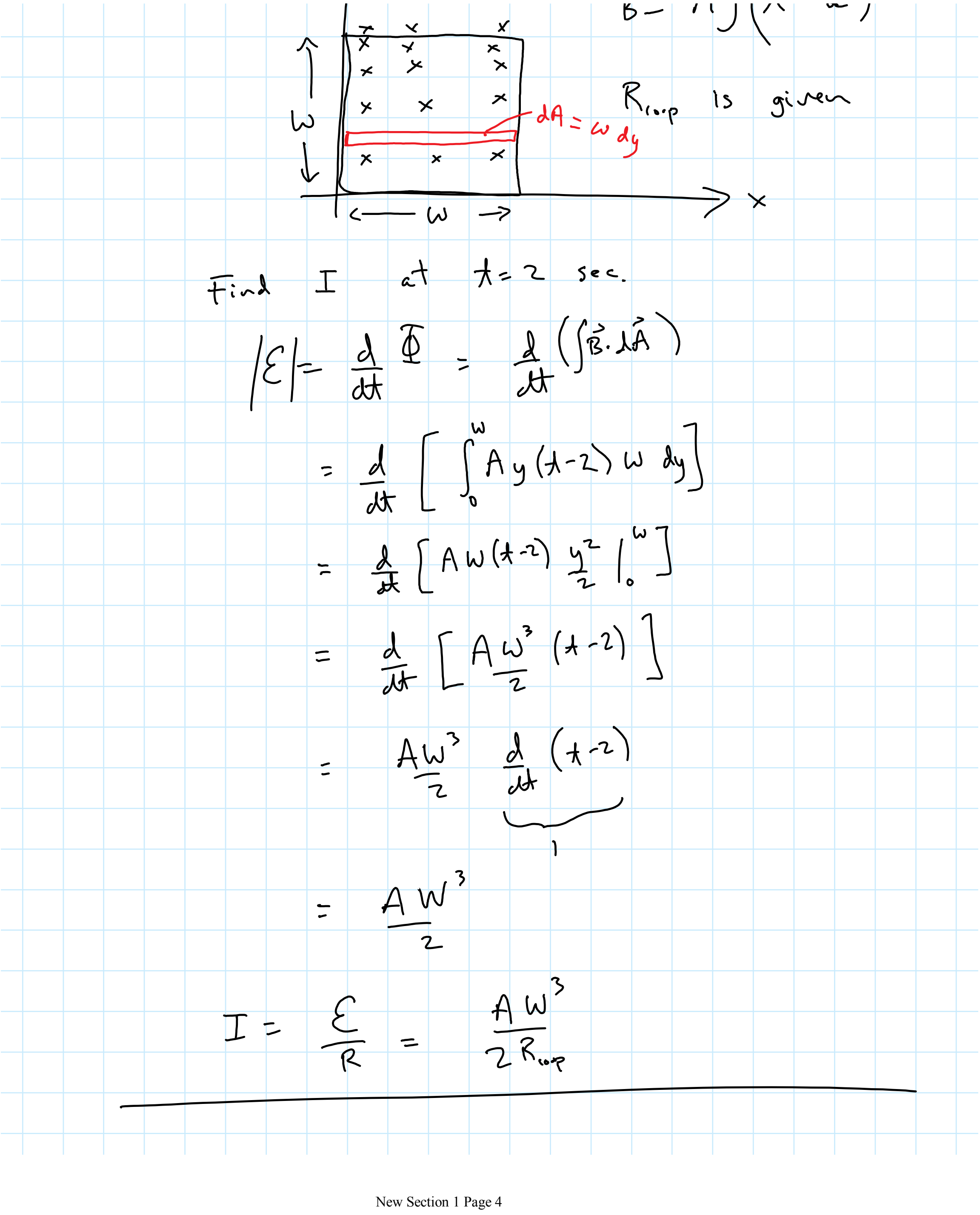
Figure 7. Electromagnetic induction example activity. Adapted from "Laboratory Manual: Activities, Experiments, Demonstrations & Tech Labs for Conceptual Physics, 12/E," by P. G. Hewitt, D. Baird. 2014, *Pearson Higher Education.*

Computer Simulation Activity Guide (Appendix E) – To guide students in their use of the simulations, students went through the simulations with an activity guide that was adapted from Hewitt and Baird (2014). This guide covered electromagnetic induction topics as part of the Faraday's Electromagnetic Lab simulations that included bar magnet, pick-up coil, electromagnet, transformer, and generator simulations. Figure 7 illustrates an example activity that students completed using the “Pickup Coil” simulation, which is part of the Faraday’s Electromagnetic Lab.

Overview Presentation (Appendix F) – The course instructor gave the students in the presentation group an overview of induction topics using a document camera, hand-drawn images, equations, and hand-drawn graphs. During this overview presentation, the instructor ended up with five pages of notes (Appendix F). The instructor went through the different problems from the overview presentation live. The instructor drew images and equations step-by-step while the instructor worked through and talked through the different examples. Throughout the presentation the instructor used arrows and sometimes color to highlight relevant information about a specific problem. During the presentation, the participants were able to ask questions and interact with the instructor.

The different concepts that the instructor went over during the overview presentation were presented in chronologically order. The instructor presented beginning induction concepts first and successively continued to present more advanced concepts. From reviewing these presentations notes, the instructor seemed to have incorporated several of the principles of multimedia design into the overview presentation (even though the instructor indicated to have no prior knowledge about these principles of multimedia design). Figure 8 shows an example of a problem that the instructor went over during the overview presentation (Appendix F, page 4). The whole figure represents one whole page of notes, the instructor wrote in large font taking over an entire page. The instructor also indicated that having grid paper as the background served as a guide that helped when drawings graphs and images that required lines, and when writing down equations so that the instructor would not write all over the place.

Figure 8. Example Problem From Overview Presentation



Find I at t = 2 sec.

$$|\mathcal{E}| = \frac{d}{dt}\Phi = \frac{d}{dt}\left(\int \vec{B}\cdot d\vec{A}\right)$$

$$= \frac{d}{dt}\left[\int_0^w A y (t-2) w \, dy\right]$$

$$= \frac{d}{dt}\left[A w (t-2) \frac{y^2}{2}\Big|_0^w\right]$$

$$= \frac{d}{dt}\left[\frac{A w^3}{2}(t-2)\right]$$

$$= \frac{A w^3}{2}\underbrace{\frac{d}{dt}(t-2)}_{1}$$

$$= \frac{A w^3}{2}$$

$$I = \frac{\mathcal{E}}{R} = \frac{A w^3}{2 R_{loop}}$$

New Section 1 Page 4

Figure 8. Example problem from the overview presentation notes on Appendix F. This example shows that hand-drawn images and equations were used as the instructor went over the problem. The whole figure represents one entire page of notes. The overview presentation consisted of a total of five pages.

It is important to note that after reviewing the overview presentation notes, it can be inferred that several principles of multimedia design were used as part of the instructor's pedagogical instructional practice. Table 12 shows how some of the principles of multimedia design apply to the presentation overview based on reviewing the presentation notes.

Table 12

Principles of Multimedia Design That Apply to the Overview Presentation

Principle	Overview Presentation Characteristics
Coherence principle – eliminate extraneous materials that do not contribute to learning	The instructor did not seem to include extra information that was not needed in order to explain the problems.
Apprehension principle – external characteristics of the animation should be easily understood, features that are "cosmetic" in nature should be avoided	Although this principle is specific to animations, it can also apply to the overview presentation. I fact, for participants this was a kind of animation because the instructor went over the problems step-by-step live during the overview presentation. The instructor did not seem to include extra features while going through the problems that were only "cosmetic" in nature. Everything that the instructor included had a purpose for student learning.
Signaling principle – highlighting materials that direct learners to essential information helps learners reduce processing of unnecessary information	The instructor highlighted relevant information when going through the problems. The instructor used arrows and sometimes color to point to the relevant information being explained.
Spatial contiguity principle – placing on-screen text near to corresponding pictures reduces unnecessary scanning	The instructor did place text and relevant numbers near the images that were drawn.
Pre-training principle – learners should have knowledge of names and characteristics of the main concepts prior to viewing animations.	When students received the overview presentation, they had already received lectures on the topic of induction giving them the opportunity to become familiar with the characteristics of the content.
Multimedia principle – learners can make better mental connections when	The instructor was using words and hand-drawn images to explain the different

using both words and pictures (or animations) rather than using words or pictures alone.	problems, in addition to equations when needed.
Personalization principle – using words in conversational style encourages learners' interest in the material promoting	The instructor seemed to have used a conversational style while going through the problems.
Temporal contiguity principle – present narration simultaneously with corresponding animation or words and pictures rather than successively	The instructor was narrating the steps as the instructor was making drawings and writing the equations and as the instructor explained the different concepts during the presentation.
Attention guiding principle – it is important to incorporate guidance to direct students to relevant parts of the animation through signals in verbal and graphic forms	The instructor did guide students to the relevant parts of the problems as the instructor was working though them. The instructor used arrows and sometimes color to highlight relevant parts of the problems in addition to using verbal cues.
Split-attention – information that comes from different sources must be integrated in order for the information to be mentally understood by learners	Any sources of information that the instructor used, seemed to have been effectively integrated into the presentation so that students could have a better understanding of the concepts.
Worked-out examples – learners gain a deeper understanding of the materials they are learning when worked-out examples are provided at the beginning of their learning.	The overview presentation was a series of worked-out examples where the instructor went through many of the concepts related to induction. The problems that the instructor went through clearly show the formulation of the problem, the steps to solve the problem, and the solution to the problem, which are key aspects of worked-out examples (Renkl, 2010). By going through the different problems, students can then apply the skills to solve problems on their own.

This overview presentation was anticipated to be a static already completed presentation that the instructor might have given several times. However, the instructor went over the content live and step-by-step. This overview presentation really became very close to an animated multimedia presentation that used several techniques based on the principles of multimedia learning.

Hands-on Lab (Appendix G) – All students who participated in the study completed a hands-on induction lab called “Induced voltage from a dropped magnet”. Appendix G gives a detailed description of the procedures of this hands-on lab.

Procedures Description

This study was conducted towards the end of the 2015 Spring quarter. Students participating in this study had already received approximately 37 hours of instruction and had also completed nine 3-hour labs covering various physics concepts that included electric fields and forces, electric potential, DC circuits, B-fields and forces, and induction. When students enrolled in the course, they were required to sign-up for a Monday lab or a Wednesday lab. All students attended two one-hour and 50-minute lectures (12:00pm – 1:50pm) and one 50-minute lecture (1:00pm – 1:50pm) per week, and one lab per week (either Monday or Wednesday, 3:00pm – 6:00pm). This study took place during lab 9 (informed consent and spatial ability test) and lab 10 (pretest, treatment, posttest1, posttest2). One week before the experiment, students in the Monday lab and Wednesday lab were asked to complete the informed consent, and take the spatial ability test. On the day of the experiment (on the Monday lab and Wednesday lab), students were randomly assigned to either the simulation group or presentation group. There were two simulation groups (one on Monday and one on Wednesday) and two presentation groups (one on Monday and one on Wednesday).

To randomly assign students to the simulation group or presentation group, the conceptual knowledge pretest was coded with a small blue dot (simulation group) or a red dot (presentation group) on the back of the last page of the test. After students completed the pretest, the researcher collected each test from each student. If the test had a blue dot, the student was asked to stay seated. If the test had a red dot, the student was asked to stand up and go outside with the instructor. Students that stayed seated in the lab completed the simulation activity, and the students that went outside the lab with the instructor, went to a nearby classroom and received the overview presentation.

After both groups received their treatments, both groups came together into one lab, took posttest1, then completed the hands-on lab, and then took posttest2. Between the day when the informed consent and spatial ability test was given and collected, all students received approximately 270 minutes of their regularly scheduled lecture instruction on induction topics (see Figure 3). Table 13 shows the detailed sequence of procedures.

The approximate total duration of the study was 1-hour and 20 minutes on Monday (labs 9 and 10) and 1-hour and 20 minutes on Wednesday (labs 9 and 10). The researcher was present throughout the duration of the study, administered and collected the different measurement tests, explained the treatment, instructed participants to go through the computer simulations using the activity guide, and kept track of timing. When the presentation group went to a nearby classroom to receive the overview presentation, the instructor kept track of the overview presentation. The researcher kept track of the simulation treatment and was available to answer any technical questions only, such as if the simulation closed by accident. The researcher did not intervene during the test taking, treatment, or hands-on lab phases.

Table 13

Detailed Treatment and Procedures

Approximate Duration (minutes)	Experimental Group	Comparison Group
	Monday June 8, 2015 (Lab 9)	Wednesday June 10, 2015 (Lab 9)
10	Researcher explained study, and requested informed consent from participants.	Researcher explained study, and requested informed consent from participants.
10	Participants took the Santa Barbara Solids Test (SBST), which measured spatial ability and asked for gender information.	Participants took the Santa Barbara Solids Test (SBST), which measured spatial ability and asked for gender information.
All students received 270 minutes of their regularly scheduled lectures on induction in between when the informed consent and spatial ability test was given and collected and the days when the experiment took place.		
	Monday June 15, 2015 (Lab 10)	Wednesday June 17, 2015 (Lab 10)
	Researcher arrived to lab approximately 15 minutes before lab started to install simulations on computers.	Researcher arrived to lab approximately 15 minutes before lab started to install simulations on computers.
10	Participants took the conceptual knowledge test on induction topics. Participants were randomly assigned to the simulation group or presentation group using this test, which was already coded as simulation or presentation, with a red dot or a blue dot.	Participants took the conceptual knowledge test on induction topics. Participants were randomly assigned to the simulation group or presentation group using this test, which was already coded as simulation or presentation, with a red dot or a blue dot.
	Instructions Participants in the simulation group stayed in the lab and were instructed to go to a lab computer where they found the simulation opened on the screen and the activity guide placed on top of the computer keyboard – each participant used one computer.	*Instructions* Participants in the simulation group stayed in the lab and were instructed to go to a lab computer where they found the simulation opened on the screen and the activity guide placed on top of the computer keyboard – each participant used one computer.

Approximate Duration (minutes)	Experimental Group	Comparison Group
	Monday June 15, 2015 (Lab 10)	Wednesday June 17, 2015 (Lab 10)
	Participants in the presentation group were instructed to go to a nearby classroom where they received an overview presentation by the course instructor about induction.	Participants in the presentation group were instructed to go to a nearby classroom where they received an overview presentation by the course instructor about induction.
30	Participants in the simulation group went through the simulations, participants in presentation group received overview presentation.	Participants in the simulation group went through the simulations, participants in presentation group received overview presentation.
10	Participants took a second conceptual knowledge test on induction topics.	Participants took a second conceptual knowledge test on induction topics.
90	Participants completed the hands-on lab on induction guided by the course instructor.	Participants completed the hands-on lab on induction guided by the course instructor.
10	Participants took a third conceptual knowledge test on induction topics (same test as pretest and posttest).	Participants took a third conceptual knowledge test on induction topics (same test as pretest and posttest).

Note: The researcher was present throughout the treatment and data collection process. The researcher gave and collected the tests from participants, and kept track of time. The instructor kept track of the 30-minute overview presentation.

Data Analyses

SPSS was used to analyze the quantitative data. To answer research question 1 (What is the effect of computer simulations as a pre-training activity in physics on conceptual understanding scores?), mean scores and standard deviations were used to compare conceptual understanding scores differences between the simulation group and presentation group before the treatment, after the treatment, and after the hands-on lab. Mean gain scores and standard deviations were used to calculate Cohen’s d effect sizes.

According to Cohen (1992), independent means and standard deviations can be used to calculate effect sizes, *d* = .20 is a small effect size, *d* = .50 is a medium effect size, and *d* = .80 is a large effect size.

To answer research question 2 (what is the effect of spatial ability stratified as high and low on conceptual understanding scores when using computer simulations as a pre-training activity in physics?), spatial ability scores were stratified as high or low for the simulation group and presentation group. Participants scoring 15 points and under were considered low spatial ability, participants scoring 16 points and over were considered high spatial ability. Then mean scores and standard deviations were used to compare conceptual understanding scores differences based on spatial ability stratified as high and low for both the simulation group and the presentation group. Mean gain scores and standard deviations were also used to calculate Cohen's *d* effect sizes.

To answer research question 3 (is there a gender difference on conceptual understanding scores when using computer simulations as a pre-training activity in physics?), conceptual understanding scores were stratified by gender. Mean scores and standard deviations were used to compare conceptual understanding differences for both the simulation group and presentation group. Mean gain scores and standard deviations were also used to calculate Cohen's *d* effect sizes.

To answer research question 4 (what is the relationship between spatial ability and conceptual understanding scores when using computer simulations as a pre-training activity in physics?), Pearson Moment Correlation Coefficients (*r*) was calculated to explore the relationships between spatial ability and conceptual understanding for both the simulation group and presentation group. According to Shavelson (1996), *r* = .30 or less represents a low correlation, *r* = .40 to .60 represents a moderate correlation, and *r*

= .80 or more represents a high correlation. In addition, according to Cohen (1992), *r* can be used as a measure of effect size; *r* = .10 represents a small effect size, *r* = .30 represents a medium effect size, and *r* = .50 is considered a large effect size.

Summary

The purpose of the current study was to investigate if the use of computer simulations as a pre-training activity could enhance students' understanding of induction in physics in comparison to an overview presentation prior to completing a hands-on lab. A convenience sample of community college students was used in this study. A two-group descriptive repeated measures design was implemented. One week before the experiment, students in both the experimental and control groups took a spatial ability test. On the day of the experiment, students took a 10-minute pretest to measure conceptual knowledge of induction in physics. Participants in the simulation group worked with the computer simulations using an activity that guided them as they went through the computer simulations. The presentation group received an overview presentation, and then both groups took the conceptual knowledge test on induction after the treatments (posttest1). Both groups completed their regularly scheduled hands-on lab and took another conceptual knowledge test (posttest2) after completing the lab. Mean differences were calculated to assess spatial ability differences and conceptual knowledge differences among groups before the treatment. After the treatment and after the hands-on lab, conceptual knowledge mean differences were also calculated. In addition, correlations were calculated to assess the relationship between spatial ability and conceptual understanding.

CHAPTER 4

Results

The purpose of this study was to investigate the effectiveness of computer simulations as a pre-training activity for a hands-on laboratory experience. Simulations were compared to an overview presentation. This study also explored if there were spatial ability and gender differences when learning about induction with computer simulations, and explored the relationship between spatial ability and conceptual understanding. A total of 35 community college students participated in this study (*n* = 17 for the simulation group, *n* = 18 for the presentation group). Table 14 shows the demographic information of participants stratified by group and by gender.

Table 14

Study Participants Stratified by Gender and Group

	Gender			
	Male	Female	Not Specified	Total
Whole Group	27	6	2	35
Simulation Group	12	3	2	17
Presentation Group	15	3		18

To answer the research questions, two measurements were used: (1) The Santa Barbara Solids Test (SBST) was used to measure participants spatial ability (Cohen & Hegarty, 2007). The total maximum number points that participants could earn on the SBST were 29 points. Participants scoring 15 points and under were considered low spatial ability (LS), participants scoring 16 points and over were considered high spatial ability (HS). (2) A conceptual knowledge test with 18 questions from an “Electricity & Magnetism Tasks” book by Hieggelke et al. (2005) was used to measure participants’ conceptual understanding of induction topics. The same test was given as a Pretest, Posttest1, and Posttest2 (all given the same day of the treatment). The Pretest was given to all participants before completing the computer simulation activity or receiving the overview presentation. Posttest1 was given after completing the 30-minute computer simulation activity or receiving the 30-minute overview presentation. Posttest2 was given to all participants approximately 90-minutes later after they completed the hands-on lab. The maximum number of points that a participant could earn was 18 points. Descriptive statistics were used to analyze the data. Below are the results organized by research question.

Research Question 1

What is the effect of computer simulations as a pre-training activity in physics on conceptual understanding scores?

Table 15 shows the results of the conceptual understanding scores before the treatment (simulation or overview presentation, Pretest), after the treatment (simulation or overview presentation, Posttest1), and after the hands-on lab (Posttest2) for each group independently.

Table 15

Conceptual Understanding Results Stratified by Group

	Simulation Group (*n* = 17)		Presentation Group (*n* = 18)	
	M	*SD*	*M*	*SD*
Pretest	9.52	4.09	10.61	4.77
Posttest1	11.29	3.14	13.06	3.21
Posttest2	11.64	3.18	13.50	3.11

Note. Pretest = before completing the computer simulation activity or receiving the overview presentation. Posttest1 = after completing the computer simulation activity or receiving the overview presentation. Posttest2 = after completing the computer simulation activity or the receiving the overview presentation and the hands-on lab. The highest score possible for all tests was 18 points.

Overall, the overview presentation had the greatest effect on changing participants' understanding of induction topics in comparison to completing the computer simulation activity when combined with the hands-on lab.

Mean differences suggest that the presentation group performed higher in all the tests, including before receiving any type of treatment. The presentation group scored 1.09 points higher than the simulation group on the Pretest, 1.77 points higher on Posttest1, and 1.86 points higher on Posttest2 (Table 15).

Effect sizes were calculated on knowledge gains (Table 16) to compare the effect of the computer simulation activity or the overview presentation within each group on conceptual understanding. These effects were interpreted according to Cohen (1992) where $d = 0.20$ is a small effect size, $d = 0.50$ is a medium effect size, and $d = 0.80$ is a large effect size. Effect sizes favored the presentation group (Table 16) suggesting that receiving the overview presentation before the hands-on lab had a large effect ($d = 1.07$) in comparison to the medium effect ($d = 0.68$) that the computer simulation activity had on participants' conceptual understanding.

Table 16

Conceptual Understanding Gains Stratified by Group

		Gain 1			Gain 2		
Group	*n*	*M*	*SD*	Cohen's *d*	*M*	*SD*	Cohen's *d*
Simulation	17	1.77	2.61	0.68	2.12	3.26	0.65
Presentation	18	2.44	2.28	1.07	2.89	2.49	1.16

Note. Gain 1 = difference between Pretest and Posttest1. Gain 2 = difference between Pretest and Posttest2.

Receiving the overview presentation in addition to completing the hands-on lab also had a large effect ($d = 1.16$) on enhancing participants' understanding of induction topics in comparison to the medium effect (d = 0.65) that the computer simulation activity had on participants' understanding (Table 16).

Although receiving the overview presentation in addition to completing the hands-on lab had the greatest effect on knowledge change (Table 16, *d* = 1.16), the hands-on lab alone did not seem to make a substantial additional contribution to participants' learning for both groups. The hands-on lab on the simulation group contributed an additional 0.35 mean gain points in comparison to the 1.77 mean gain points that the computer simulation activity contributed to learning (Table 16, difference between Gain 1 and Gain 2 for the simulation group). The hands-on lab for the presentation group contributed an additional 0.45 mean gain points in comparison to the 2.44 mean gain points that the overview presentation contributed to learning (Table 16, difference between Gain 1 and Gain 2 for the presentation group).

Research Question 2

What is the effect of spatial ability (stratified as high and low) on conceptual understanding scores when using computer simulations as a pre-training activity in physics?

Table 17 shows the mean and standard deviation for the spatial ability test stratified by group and spatial ability level. The simulation group had the lowest spatial ability participants, and the presentation group had the highest spatial ability participants. Table 18 shows the mean and standard deviation for the spatial ability test stratified by group, spatial ability level, and gender. For the simulation group, both male and female participants had very similar high spatial ability and only two male participants were low spatial. For the presentation group, two female participants had the highest spatial ability, and one female participant was low spatial. A little over half of the male participants had high spatial ability, the rest of the male participants had low spatial ability.

Table 17

Spatial Ability Scores Stratified by Group and Spatial Ability Level

	High Spatial Ability (*n* = 13)		Low Spatial Ability (*n* = 4)	
	M	*SD*	*M*	*SD*
Simulation	23.23	3.47	6.25	3.59
	High Spatial Ability (*n* = 10)		Low Spatial Ability (*n* = 8)	
	M	*SD*	*M*	*SD*
Presentation	25.40	2.01	10.75	1.98

Note. The maximum score was 29 points.

Table 18

Spatial Ability Results Stratified by Group and Gender

	Male				Female			
	High Spatial (*n* = 10)		Low Spatial (*n* = 2)		High Spatial (*n* = 3)		Low Spatial (*n* = 0)	
Group	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Simulation	23.30	3.92	8.50	0.71	23.00	1.72		
	Male				Female			
	High Spatial (*n* = 8)		Low Spatial (*n* = 7)		High Spatial (*n* = 2)		Low Spatial (*n* = 1)	
Group	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Presentation	25.13	2.17	10.71	2.14	26.50	0.71	11.00	

Note. The maximum score was 29 points. Overall the simulation group had a total of seventeen participants. Two participants did not specify their gender. This analysis was based on fifteen participants.

Mean differences for the simulation group suggest that the high spatial ability participants scored 0.38 points higher than the low spatial ability participants after using the computer simulations as a pre-training activity (Table 19). After completing the hands-on activity, the low spatial ability participants scored 0.79 points higher than the high spatial ability participants (Table 19). These results suggest that combining the simulations as a pre-training activity with the hands-on lab, helped low spatial ability participants have a better understanding of physics induction topics relative to the high spatial ability participants.

Table 19

Simulation Group Conceptual Understanding Results Stratified by Spatial Ability Level

	High Spatial Ability			Low Spatial Ability		
	N	*M*	*SD*	*n*	*M*	*SD*
Pretest	13	9.23	4.11	4	10.50	4.51
Posttest1	13	11.38	3.25	4	11.00	3.16
Posttest2	13	11.46	3.41	4	12.25	2.62

Note. Pretest = before completing the computer simulation activity. Posttest1 = after completing the computer simulation activity. Posttest2 = after completing the computer simulation activity and the hands-on lab.

Mean differences for the presentation group (Table 20) suggest that the low spatial ability participants scored 1.02 points higher than the high spatial ability participants after receiving the overview presentation as a pre-training activity (Table 20). In addition, after completing the hands-on activity, the low spatial ability participants scored 1.08 points higher than the high spatial ability participants (Table 20). These results suggest that combining the overview presentation as a pre-training activity with the hands-on lab, also helped low spatial ability participants gain a better understanding of physics induction topics relative to the high spatial ability participants.

Table 20

Presentation Group Conceptual Understanding Results Stratified by Spatial Ability Level

	High Spatial Ability			Low Spatial Ability		
	N	*M*	*SD*	*n*	*M*	*SD*
Pretest	10	10.00	4.88	8	11.37	4.84
Posttest1	10	12.60	3.24	8	13.62	3.29
Posttest2	10	12.70	3.50	8	14.50	2.39

Note. Pretest = before completing the computer simulation activity. Posttest1 = after completing the computer simulation activity. Posttest2 = after completing the computer simulation activity and the hands-on lab.

Effect sizes were calculated on knowledge gains to compare the effect of the computer simulation activity or the overview presentation within each group on conceptual understanding stratified by spatial ability level (Table 21).

Table 21

Conceptual Understanding Gains Stratified by Spatial Ability

		Gain 1			Gain 2		
Group	*N*	*M*	*SD*	Cohen's *d*	*M*	*SD*	Cohen's *d*
Simulation							
HS	13	2.15	2.76	0.78	2.23	3.61	0.62
LS	4	0.50	1.73	0.29	1.75	2.06	0.85
Presentation							
HS	10	2.60	2.59	1.00	2.70	2.54	1.06
LS	8	2.25	1.98	1.14	3.13	2.59	1.21

Note. HS = High spatial ability. LS = Low spatial ability. Gain 1 = difference between Pretest and Posttest1. Gain 2 = difference between Pretest and Posttest2. Cohen's *d* was calculated based on Gain 2.

Results suggest that the computer simulation had a medium effect ($d = 0.78$) on high spatial ability participants relative to the small effect that the simulations had on low spatial ability participants (*d* = 0.29) before completing the hands-on lab. However, completing the computer simulation activity followed by the hands-on lab had a large effect (*d* = 0.85) on low spatial ability participants relative to the medium effect (*d* = 0.62) that the simulations had on high spatial ability participants.

Results also suggest (Table 21) that the overview presentation had a similar large effect on high spatial ability participants (*d* = 1.00) and low spatial ability (*d* = 1.14) participants before completing the hands-on lab. The overview presentation followed to completing the hands-on lab also had a large effect on both the high spatial ability participants (*d* = 1.06) and low spatial ability participants (*d* = 1.21).

Even though the hands-on lab contributed to participants' learning, the hands-on lab did not seem to make a substantial difference in high spatial ability participants compared to the completing the computer simulation activity. The computer simulation contributed 2.15 mean gain points to learning in comparison to the hands-on lab, which contributed 0.08 mean gain points (Table 21, difference between Gain 1 and Gain 2 for the HS simulation group). However, the hands-on lab did make a greater difference on low spatial ability participants. The hands-on lab contributed 1.25 mean gain points (Table 21, difference between Gain 1 and Gain 2 for the LS simulation group) to learning in comparison to the 0.50 mean gain points that the computer simulation activity contributed to learning.

The hands-on also did not seem to make a substantial difference for high and low spatial ability participants who also received the overview presentation. The hands-on lab contributed 0.10 mean gain points (Table 21, difference between Gain 1 and Gain 2 for the HS presentation group) to high spatial ability learners in comparison to 2.60 mean gain points that the overview presentation contributed. Although the hands-on lab made a larger difference for low spatial ability participants, the difference was not substantial, the hands-on lab contributed 0.88 mean gain points (Table 21, difference between Gain 1 and Gain 2 for the LS presentation group) to learning in comparison to the 2.25 mean gain points that the overview presentation contributed to learning.

Research Question 3

Is there a gender difference on conceptual understanding scores when using computer simulations as a pre-training activity in physics?

Overall, female participants scored higher relative to male participants on all conceptual understanding tests for both the simulation group and presentation group. Mean differences for the simulation group (Table 22) suggest that female participants scored 5.16 points higher than male participants before completing the computer simulation activity. Female participants scored 3.42 points higher than the male participants after using the computer simulations (Table 22). And after completing the hands-on activity, female participants scored 3.25 points higher than the male participants (Table 22).

Table 22

Simulation Group Conceptual Understanding Results Stratified by Gender

	Male			Female		
	n	*M*	*SD*	*n*	*M*	*SD*
Pretest	12	8.17	3.13	3	13.33	4.04
Posttest1	12	10.58	2.87	3	14.00	2.65
Posttest2	12	10.75	3.05	3	14.00	2.65

Note. Overall the simulation group had a total of seventeen participants. Two participants did not specify their gender. This analysis was based on fifteen participants. Pretest = before completing the computer simulation activity. Posttest1 = after completing the computer simulation activity. Posttest2 = after completing the computer simulation activity and the hands-on lab.

Mean differences for the presentation group (Table 23) suggest that female participants scored 2.06 points higher than male participants before receiving the overview presentation. Female participants scored 2.33 points higher than the male participants after receiving the overview presentation (Table 23). And after completing the hands-on activity, female participants scored 1.80 points higher than the male participants (Table 23).

Table 23

Presentation Group Conceptual Understanding Results Stratified by Gender

	Male			Female		
	n	*M*	*SD*	*n*	*M*	*SD*
Pretest	15	10.27	5.05	3	12.33	3.06
Posttest1	15	12.67	3.37	3	15.00	1.00
Posttest2	15	13.20	3.32	3	15.00	1.00

Note. Pretest = before receiving the overview presentation. Posttest1 = after completing the overview presentation. Posttest2 = after completing the overview presentation and the hands-on lab.

Effect sizes were calculated on knowledge gains to evaluate gender differences when completing the computer simulation activity or receiving the overview presentation within each group for conceptual understanding (Table 24). Results suggest that the computer simulation had a large effect (d = 0.92) on male participants relative to the small effect (d = 0.32) that the simulations had on female participants before completing the hands-on lab. Completing the computer simulation activity followed by the hands-on lab had a medium effect (d = 0.73) on male participants relative to the small effect (d = 0.32) that it had on female participants.

Table 24

Conceptual Understanding Gains Stratified by Gender

		Gain 1			Gain 2		
Group	*N*	*M*	*SD*	Cohen's *d*	*M*	*SD*	Cohen's *d*
Simulation							
Male	12	2.42	2.64	0.92	2.58	3.55	0.73
Female	3	0.67	2.08	0.32	0.67	2.08	0.32
Presentation							
Male	15	2.40	2.32	1.03	2.93	2.58	1.14
Female	3	2.67	2.52	1.06	2.67	2.52	1.06

Note. Gain 1 = difference between Pretest and Posttest1. Gain 2 = difference between Pretest and Posttest2. Cohen's *d* is calculated based on Gain 2.

Results (Table 24) also suggest that the overview presentation had a similar large effect on male participants (*d* = 1.03) and female participants (*d* = 1.06) before completing the hands-on lab. Receiving the overview presentation followed by the hands-on lab also had a similar large effect on male participants (*d* = 1.14) and female participants (*d* = 1.06).

The hands-on lab did not seem to make a substantial difference for both male and female participants in both the simulation group and presentation group. The hands-on lab contributed 0.16 mean gain points (Table 24, difference between Gain 1 and Gain 2 for male simulation group) to male learners and zero mean gain points to female participants in comparison to 2.42 mean gain points that the computer simulation activity contributed to male learners and 0.67 mean gain points that the computer simulation activity contributed to female learners.

For the presentation group, the hands-on lab contributed 0.53 mean gain points (Table 24, difference between Gain 1 and Gain 2 for male presentation group) to male learners and zero mean gain points to female participants in comparison to 2.40 mean gain points that the overview presentation contributed to male learners and 2.67 mean gain points that the computer simulation activity contributed to female learners.

Research Question 4

What is the relationship between spatial ability and conceptual understanding scores when using computer simulations as a pre-training activity in physics?

Pearson Product Moment Correlation Coefficient (*r*) results suggest that there was a negative weak relationship between participants' spatial ability and conceptual understanding scores (Table 25). These results were interpreted according to Cohen 1992, where *r* can be used as a measure of effect size; *r* = .10 represents a small effect size, *r* = .30 represents a medium effect size, and *r* = .50 is considered a large effect size.

Table 25

Intercorrelations for Spatial Ability Scores on Conceptual Understanding

Group	*n*		Pretest	Posttest1	Posttest2
Simulation	17	Spatial Ability	-.26	.01	-.16
Presentation	18	Spatial Ability	-.20	-.16	-.29

Note. Pretest = before receiving the overview presentation. Posttest1 = after completing the overview presentation. Posttest2 = after completing the overview presentation and the hands-on lab.

As participants' spatial ability increased, their conceptual understanding seemed to decrease (Table 25) for both the simulation group and the presentation group. The association of spatial ability and conceptual understanding when completing the computer simulation activity and the hands-on lab was small (*r* = -.16). The association of participants' spatial ability with conceptual understanding when receiving the overview presentation and the hands-on lab was also small (*r* = -.29).

Summary

Overall results suggest that the overview presentation made a greater contribution to participants' learning in comparison to the computer simulation activity. The overview presentation followed by the hands-on activity had a large effect on participants' learning of induction topics in comparison to the medium effect that completing the computer simulation activity had on participants understanding of induction topics. However, the hands-on lab alone did not seem to make a substantial contribution to learning to participants in both groups.

When results were stratified by spatial ability level, the computer simulation activity seemed to have had the greatest effect on high spatial ability participants, while the overview presentation had the greatest effect on the low spatial ability participants. In addition, the hands-on lab seemed to have made the greatest contribution to low spatial ability learners who only received a small benefit from completing the computer simulation activity. However, the hands-on lab did not seem to make a substantial difference on both high and low spatial ability participants who received the overview presentation, the overview presentation alone seemed to have been more beneficial to their learning.

Results also suggest that there were gender differences when learning with computer simulations or receiving an overview presentation. Although both male and female participants benefited more from receiving the overview presentation, male participants benefited more from completing the computer simulation activity in comparison to the female participants who seemed to have benefited more from the overview presentation. The hands-on lab seemed to have made a small contribution to male participants' learning and made no contribution to female participants' learning. It is important to note that, overall, most female participants had a high spatial ability.

Finally, there seemed to be a small negative relationship between participants' spatial ability and conceptual understanding. As participants' spatial ability increased, their conceptual understanding of induction topics decreased.

CHAPTER 5

Discussion

The purpose of this study was to investigate the effectiveness of using computer simulations as a pre-training activity to a hands-on lab to improve participants' understanding of induction topics in physics. First, an overview of induction and a summary of the study will be provided. Second, limitations of the study will be discussed. Third, conclusions of the study will be discussed. Last, the research and educational implications will be discussed.

Overview of Induction

Induction (also known as electromagnetic induction) was first discovered by Faraday in 1831, it is the process of moving a "current-carrying coil" or magnet back and forth through a loop of wire changing the magnetic field and generating an electric current in the loop of wire (Garg, 2012, p. 114). Students who participated in this study were introduced about the topic induction towards the end their electricity and magnetism calculus-based course. Based on the regularly scheduled lecture notes from the course instructor (Appendix H), the instructor used hand-drawn images, equations, hand-drawn graphs, and problems from the "Electricity & Magnetism Tasks" book by Hieggelke, Maloney, O'Kuma, and Kanim (2005) to teach students about induction topics. The lesson on induction concluded with a hands-on lab.

Research suggests that students have difficulties with the concepts related to electricity and magnetism. Induction is one of the most difficult concepts for students to understand because they are not familiar with "magnetic flux", which involves having an understanding of "field lines" and "fluid flow" (Planinic, 2006, p. 1146). In addition, students have difficulties with electricity and magnetism concepts because of at least two reasons. The first reason is because many of the topics themselves are abstract in nature, such as the concepts of electrons, fields, flux and potential (Chabay & Sherwood, 2006). The second reason is because students need to think and visualize in three dimensions, which in many cases, they may have not experienced before (Chabay & Sherwood, 2006, p. 329).

Based on the instructor's lecture notes (Appendix H), what seems to make learning about induction spatially difficult is that students need to be able to visualize and make sense of the direction of electrons and field lines from two-dimensional drawings. There seems to be no research about the spatial challenges of learning induction concepts. There is research suggesting that there is a relationship between spatial ability and solving kinematic related problems (Kozhevnikov et al., 2007) and the authors even suggest that spatial visualization might be useful in other physics domains. For example, when solving problems related to electricity and magnetism that deal with invisible phenomena such as electric or magnetic field lines and electric currents (Kozhevnikov et al., 2007, p. 576). However, no empirical evidence is given. Research is needed that investigates the relationship between spatial ability and electricity and magnetism topics. And in particular, research is needed that investigated if the concept if induction is spatially challenging.

Summary of the Study

There are several reasons why students have difficulty understanding abstract scientific phenomena including: the cognitive demand in trying to interpret abstract concepts (Fong, 2013; Höst et al., 2012), difficulty visualizing from static textbook images (Hoeling, 2011), and difficulty building models utilizing traditional methods of teaching such as lectures, and hand-held manipulatives alone (Craig et al., 2013; Sutha

Luealamai & Panijpan, 2012). Research suggests that computer simulations can help students enhance their understanding of abstract phenomena in several ways including: helping students build mental representations (Aldahmash & Abraham, 2009; Tambade & Wagh, 2011; White et al., 2010), explore what if scenarios (Zacharia & Anderson, 2003), and visualizing concepts that would not be possible without the use of computer animations (Fong, 2013; Tambade & Wagh, 2011).

Previous studies have investigated the effectiveness of using computer simulations as a pre-training activity to a lab experience (Zacharia, 2007; Zacharia & Anderson, 2003). The current study built on those previous studies by comparing the computer simulations to an overview presentation rather than comparing the use of simulations with completing textbook problems. The overview presentation in the current study was a stronger comparison than simply completing problems from a textbook. The overview presentation in the current study is not the typical lecture where the instructor presents several slides to students about different concepts. The implementation of the overview presentation was closer to a multimedia presentation partly because the instructor used a document camera; the instructor was able to write down images, words and formulas in real time. As a consequence, the instructor was able to employ several of the principles of multimedia learning that are based on the Cognitive Theory of Multimedia Learning (CTML) making it more of an animated multimedia presentation for participants. Also making it a very strong competitor with the computer simulations. In addition, the current study employed a two-group repeated measures descriptive design, different from Zacharia and Anderson (2003) where they employed a single-group self-control design, which the authors recognized to be a limitation because of the "contamination effects from using a self-control design" (p. 622).

The current study also investigated the role of spatial ability on conceptual understanding and if there were any gender differences. Research suggests that spatial ability plays a key role when learning scientific concepts in biology (Huk, 2006) and chemistry (Merchant et al., 2013). Prior research also suggests that there is a relationship between spatial ability and physics learning (Kozhevnikov & Thornton, 2006; Kozhevnikov et al., 2007). The relationship between spatial ability and physics when learning with computer simulations does not seem to have been studied, particularly when learning the concept of induction. Thus, the current study also investigated the role of spatial ability when learning physics concepts with computer simulations, in particular the concept of induction. Research on gender differences when learning scientific concepts with computer animations is not conclusive. Some research suggests that there are gender differences (Falvo & Suits, 2009), other research suggests that there are no gender differences (Merchant et al., 2013). Thus the current study ivestigated if there were gender differences when learning about physics concepts with computer simulations.

The current study used a two-group descriptive repeated measures design with a convenience sample of 35 participants who were randomly assigned to a simulation group, or a presentation group. Seventeen participants completed a 30-minute simulation activity, while 18 participants received a 30-minute overview presentation prior to completing a 90-minutes hands-on lab activity. There were two measures in the current study. First, the Santa Barbara Solids Test (Cohen & Hegarty, 2007, 2012) was used to measure participants' spatial ability one week before the treatment began. Second, a conceptual knowledge test with questions from an "Electricity & Magnetism Tasks" book by Hieggelke et al. (2005) was given to students as a pretest before completing the computer simulation activity or the overview presentation, the same test was given again approximately 30-minutes later as posttest1 after the treatments, and again given as posttest2 approximately 90-minutes later after the hands-on lab (pretest→30-minute treatment→posttest1→90-minutes hands-on lab→posttest2). Descriptive statistics were used to analyze the results. Before the day of the experiment, all participants received approximately 270 minutes of their regularly scheduled lecture on induction topics (instructor lecture notes on Appendix H).

Mean gain changes and effect sizes suggest that receiving the overview presentation made the greatest difference on participants' conceptual understanding of induction topics in comparison to completing the computer simulation activity. Mean gain changes and effect sizes also suggest that high spatial ability participants benefited more from completing the computer simulation activity, while low spatial ability participants benefited more from receiving the overview presentation. In addition, male participants seemed to have benefited more from completing the computer simulation activity, while female participants benefited more from receiving the overview presentation. Furthermore, the hands-on lab alone seemed to have made the greatest difference for low spatial ability students, making a small contribution overall. The section on the discussion of the research questions will discuss the results of the current study in detail.

Limitations

Issues related to sample, design and content validity of the conceptual understanding measurement used limited the current study. Although participants were randomly assigned to the simulation group or presentation group, the convenience and size of the sample makes it difficult to generalize the results to other college student population taking physics courses. Testing effect is another limitation in the current study because the same test that was given as a pretest, was again given as a posttest after the treatments, and again given as a follow-up posttest after the hands-on lab. Seeing the measurement as a pretest could have given participants the opportunity to practice or memorize the questions, attributing any knowledge changes to having taken the same test multiple times, not as a consequence of the treatment (Pedhazur & Pedhazur-Schmelkin, 1991). Future research should use different versions of conceptual understanding measurements to ensure that participants are not exposed to the same questions more than one time.

Another limitation in the current study was that validity and reliability information was not available for the conceptual understanding test that was used to assess participants' knowledge changes. Although the questions from this test have been used by the physics instructor of the students who participated in this study, and these questions came from the "Electricity & Magnetism Tasks" book by Hieggelke et al. (2005), no reliability of validity information was available. Future studies using this instrument should conduct a pilot study and obtain reliability and content validity information, or use an instrument that has been thoroughly validated.

It is important to note that when reviewing the instructor's lecture notes (from the regularly scheduled lectures on induction that all students received), it was found that the instructor went over all of the same conceptual knowledge test questions that were used in the pretest and the posttests during the experiment. The question prompts were the same and the possible answers were also the same (in multiple choice format) as in the conceptual knowledge test. The only difference seemed to be that the instructor presented and went over the questions in a different order than from the conceptual knowledge test.

For example, the first question that the instructor went over during the lecture was question number thirteen on the conceptual knowledge test that was used in the current study.

The instructor went over these questions two days before the experiment took place. For example, the instructor went over the questions on a Friday, and participants did not take the pretest and posttests until the following Monday and Wednesday, which were the days when the actual treatments were administered (computer simulation activity or overview presentation). Although all participants presumably went to the lecture and received the same information, the instructor going over the same exact questions as the conceptual knowledge test (that was used as the pretest and posttests in the current study) did not seem to have made a substantial difference in the overall participants' conceptual understanding mean scores. Group mean scores were well below the maximum 18-point score that was possible for the conceptual knowledge test. The pretest mean score for the simulation group was 9.52 and the pretest mean score for the overview presentation group was 10.61.

Discussion of Research Questions

Research question 1

The first research question was about the effect of the computer simulations as a pre-training activity on conceptual understanding. As a pre-training activity alone, results suggest that the overview presentation made a greater knowledge gain contribution to participants' learning relative to the computer simulation activity. This result is not consistent with other research suggesting that computer simulations are more effective than lectures. For example, in Tambade and Wagh (2011) study, participants who used a computer simulation package had a better understanding of electrostatics in comparison to participants who received lectures. There could be two reasons why results from the current study were different from Tambade and Wagh (2011).

First, participants in the current study were exposed to the computer simulations for only 30-minutes in comparison to the 3-hours that participants in Tambade and Wagh (2011) study spent working with the simulations. These results suggest that possibly giving more time to participants in the current study would have allowed them to have more practice working with the simulations allowing them to obtain greater knowledge gains in comparison to receiving the overview presentation.

Second, it is possible that computer simulations are more effective when learning some physics concepts such as electrostatics in Tambade and Wagh (2011) study, and not as effective when learning other concepts such as induction. There is research suggesting that computer simulations have been used as learning tools with concepts related to electricity and magnetism, more specifically the topics of potential and energy, and electromagnetic induction (Dega et al., 2013). Dega et al., (2013) focused on comparing two conceptual change models, cognitive conflict and cognitive perturbation. Participants in Dega et al., (2013) study used the computer simulations as the tools to learn about potential and energy and electromagnetic induction. However, the authors were interested in the impact of the method of conceptual change, not comparing the use of simulations to another teaching method such as a lecture as the current study did (Dega et al., 2013).

This result is also different from other research suggesting that the use of computer simulations as pre-training activities before an inquiry-based lab were more effective when compared to learning from textbook problems alone (Zacharia & Anderson, 2003). One reason why the result from the current study is different from

Zacharia and Anderson (2003) is because the overview presentation (used in the current study) is a stronger teaching activity relative to solving problems from a textbook. With an overview presentation participants can engage with the instructor and ask questions. In addition, the overview presentation that was used in the current study was not the typical lecture. The overview presentation employed several of the principles of multimedia learning and the content was developed live with step-by-step explanations, which made it more of an animated multimedia presentation, rather than static slides that are presented to students.

When combining the overview presentation followed by the hands-on activity, this combination had a large effect on participants' learning of induction topics in comparison to the medium effect that completing the computer simulation activity had on participants' understanding of induction topics. Overall, it seems that because participants did not have enough time to get familiar and practice, the computer simulations imposed an additional difficulty to their learning. With the computer simulations participants had to learn about changing the parameters of the simulations and moving objects around on the screen in order to be able to complete the different simulation activities.

According to the Cognitive Theory of Multimedia Learning (CTML), there are three kinds of cognitive processes: *extraneous processing*, this is the type of cognitive processing that is not required in order to make sense of new information and makes no contribution to someone's learning. *Essential processing* is the type of cognitive processing that is needed to be able to select new information and is "imposed" by how difficult the learning materials are. And *generative processing* is the type of cognitive processing that helps a learners organize new information in a clear structure in order to be able to integrate it to new knowledge, making a contribution to learning (Mayer &

Moreno, 2010a, p. 153; 2010b, p. 133). The goal of CTML is to decrease *extraneous processing*, manage *essential processing*, and promote *generative processing*. The computer simulation activity made it more difficult for participants to decrease their *extraneous processing,* and manage their *essential processing*. Presumably all participants did not have any prior exposure to simulations before the day they used them. Instead, they had to become familiar with the simulations by manipulating the parameters that they had to change and moving objects around while also reading the simulation activity guide in a in a very limited amount of time. The whole process could have made it difficult for participants to generate new learning.

It is important to emphasize that a likely reason why participants in the current study who received the overview presentation performed better than the participants who completed the computer simulation activity is because of the quality of the overview presentation instruction. When analyzing the overview presentation notes (appendix F), the overview presentation is not the typical lecture where the instructor presents slides and students sit and listen. The instructor used several effective techniques that are based on the principles of multimedia learning. For example, the instructor did not add extra information to the presentation that was not needed in order to make a clear explanation of the content (coherence principle). The instructor also did not include any “cosmetic” features to the presentation that were not necessary for student learning, everything the instructor included in the presentation had a purpose (apprehension principle).

The instructor used a document camera to go over the different problems that were explained during the overview presentation. With the document camera (which used a grid background as a guide) the instructor was able to hand-draw images, graphs, and write and solve equations live. In addition, the instructor was able to highlight relevant information with arrows and sometimes with red color during the presentation (signaling principle, attention guiding principle), and placed text and relevant numbers close to the images that were drawn during the presentation (spatial contiguity principle). Furthermore, as the instructor was explaining the different problems live and step-by-step, the instructor used words and hand-drawn images (multimedia principle, temporal contiguity principle), and the instructor used a conversational style (personalization principle) when explaining the problems during the presentation. And most importantly, the presentation itself was a series of worked-out examples where the instructor formulated the problems, then solved the problems step-by-step, and provided the solution live as the overview presentation took place (worked-out-example principle).

It can be inferred that because the instructor used techniques that are based on these principles of multimedia learning, the overview presentation became an even better learning experience for participants than completing the computer simulation activity (which was also chosen using principles of multimedia learning). The overview presentation was able to help participants organize the information they were learning in a clear structure and were able to integrate it into new knowledge, making a contribution to their overall learning (generative processing).

Table 26 summarizes and compares the principles of multimedia learning that were used as a guide to choose the computer simulation package that was used in the current study with the principles of multimedia learning that seemed to have been employed in the overview presentation.

Table 26

Principles of Multimedia Learning That Apply to the Simulations and Overview Presentation in the Current Study

Principle	Simulation	Overview Presentation
Coherence	X	X
Apprehension	X	X
Signaling	X	X
Congruence	X	
Interactivity	X	
Spatial contiguity	X	X
Segmenting	X	
Pre-training	X	X
Multimedia	X	X
Personalization	X	X
Temporal contiguity		X
Attention guiding		X
Split-attention		X
Worked-out examples		X

Note. Full description of each principle is located on chapter 3 tables 11 and 12.

Using the principles of multimedia learning in a non-multimedia environment has important implications for learning. This result seems to suggest that principles of multimedia learning cannot only serve as a guide for designing or choosing multimedia-based environments for learning (which can also include computer simulations), but these principles can also serve as a guide to create effective learning environments in a presentation and lecture setting that does not require fancy multimedia tools.

It is also important to note that the hands-on lab alone did not make a substantial contribution to participants' learning in both groups. One explanation is that participants were very familiar with the conceptual knowledge test (posstest2), since it was given for the third time after the hands-on lab. Some participants seemed to have taken very little time to complete the third test, suggesting that they were fatigued and did not pay careful attention when answering the questions again.

Research question 2

The second research question was in regards to the effect of spatial ability stratified as high and low on conceptual understanding. Results suggest that the computer simulation activity had the greatest effect on high spatial ability participants, while the overview presentation had the greatest effect on the low spatial ability participants. This result is consistent with research suggesting that high spatial ability students benefited more from learning with computer simulations (Falvo & Suits, 2009; Fong, 2013; Huk, 2006) than learning with more traditional approaches. While the computer simulation activity did not seem to have imposed an additional difficulty to learning for high spatial ability participants, the simulations did impose a difficulty to low spatial ability participants.

The concept of induction itself may have imposed a difficulty to low spatial ability participants in addition to completing the computer simulation activity. Induction seems to be one of the most difficult topics for students to understand when learning concepts related to electricity and magnetism (Planinic, 2006). One explanation is that the abstract nature of electricity and magnetism makes it difficult to visualize when learning topics such as electrons and fields (Chabay & Sherwood, 2006). However, no explanation is given in regards to the amount of spatial ability, if any, that is necessary to help students learn about induction topics. There seems to be no research about the spatial ability challenges when learning about induction. Future research should investigate what are the spatial ability challenges that are imposed on students when learning about induction topics.

Research question 3

The third research question explained if there were gender differences when using computer simulations as a pre-training activity. Results suggest that there were gender differences when learning with computer simulations or receiving an overview presentation. Overall both male and female participants benefited more from receiving the overview presentation. However, male participants seemed to have benefited more from completing the computer simulation activity, in comparison to the female participants who seemed to have benefited more from the overview presentation.

It is important to note that overall most female participants had high spatial ability scores. This finding is very interesting because there is research suggesting that female students tend to be low spatial ability (e.g., Langlois et al., 2013; Miller & Halpern, 2013). This finding is not consistent with research suggesting that low spatial ability female students benefited more from learning with computer animations compared to high spatial ability male students (Sanchez & Wiley, 2010). Overall, mean scores suggest that female participants constantly scored higher on all conceptual understanding test administrations for both the simulation group and the presentation group. This is an important finding because most research suggests that male students usually perform better in science related fields. In the current study the female participants were the ones performing better. It is important to note that there were only six female participants in the current study, results should be taken with caution and cannot be generalized.

Research question 4

The fourth research question was about the relationship between spatial ability and conceptual understanding. There seems to be a very small negative relationship between participants' spatial ability and conceptual understanding. This result is not consistent with research suggesting that there is a significant relationship between spatial ability and physics (Kozhevnikov et al., 2007).

As participants' spatial ability increased, their conceptual understanding seemed to decrease. It is unclear why there is a negative relationship between spatial ability and conceptual understanding of induction. One possible explanation is that the concept of induction does not require students to have increased spatial ability and instead of helping participants gain a better understanding of induction, having a high spatial ability actually hinders their learning. There seems to be no research about the relationship between spatial ability and conceptual understanding when learning about induction with computer simulations or overview presentations. Future research should investigate if the concept of induction is spatially challenging.

Conclusions

In the current study, the overview presentation made the greatest difference in helping students enhance their understanding of inductions topics. Participants in the computer simulation group seemed to have had trouble managing the difficulty that was imposed on them (*essential processing*) when using the simulations, which according to the CTML, effectively being able to manage the difficulty that is imposed by the learning materials, can promote *generative processing* (Mayer & Moreno, 2010b). One reason why the simulations might have had imposed a greater difficulty on participants' learning could be the lack of time and familiarity with the simulations. Participants had a limited amount of time to learn how to use the simulations. Although participants had an activity guide that helped them go through the simulations step-by-step, participants still had to learn a new tool, having to become familiar with buttons and moving objects, which presumably they were not familiar with before.

Research suggesting that computer simulations are effective when learning physics concepts have allowed their participants to spend more than 30-minutes working with the simulations. For example, in the Zacharia et al. (2008) study, participants spent approximately 9-hours working with simulations (virtual manipulatives) giving them more time to practice and become more familiar with the simulations. It is important to note that in the current study the simulations also yielded knowledge gains, although not as much as those receiving the overview presentation.

A second reason why the overview presentation made a greater difference in participant learning is because the overview presentation was not the typical lecture where the instructor goes through slides from a pre-prepared static presentation. The instructor employed several of the principles of multimedia techniques to go over the problems that were presented to the participants during the overview presentation. In addition, by the instructor going over the problems in the overview presentation in a live and step-by-step format while verbally explaining the problems, made the overview presentation more of an animated multimedia presentation for participants, which in turn helped them gain a better understanding of induction.

When stratified by spatial ability, as expected, high spatial ability participants seemed to have benefited more from using the computer simulations, similar to other research suggesting that high spatial ability students benefit more from using computer simulations (Fong, 2013). One interesting finding in the current study is that female participants benefited more from receiving the overview presentation; yet, these female participants had high spatial ability. This result suggests that gender plays an important role in learning not only with computer simulations, but also with more traditional methods of learning (such as the overview presentation). And this gender role may depend not only on spatial ability, but it may also be dependent on the topic that is being learned. It is important to note that only six females participated in the current study.

The current study contributed to the body of knowledge in four ways. First it provides a different perspective to prior research suggesting that computer simulations are more effective than receiving a traditional lecture because the overview presentation that was compared to the computer simulations was not a typical lecture; in the current study, it was more of an animated multimedia presentation. Second, results from the current study seem to suggest that lecture presentation techniques that are closely aligned with the principles of multimedia design can be very effective in helping students gain a better understanding of the topics they are learning. Third, even implementing a short 30-minute computer simulation activity or overview presentation prior to a hands-on lab, can help students enhance their understanding of the topics they are learning. And fourth, although the female sample in the current study is small (*n* = 6), the current study revealed that most female participants were high spatial ability, contrary to prior research suggesting that females tend have low spatial ability.

Research Implications

The current study suggests that receiving an overview presentation as a pre-training activity was more effective than completing a computer simulation activity prior to a hands-on lab. This finding is different from other research suggesting that computer simulations (virtual labs) as pre-training activities to a real laboratory experience were more effective than other methods of instruction that included solving problems from a textbook (Zacharia & Anderson, 2003). However, it is important to note that even though receiving the overview presentation overall made the greatest impact (large effect on knowledge gains) on participants' learning, the computer simulation activity also made a difference in student learning (yielding a medium effect on knowledge gains). Using computer simulations in a classroom environment should not be completely disregarded. Given that the computer simulation activity in the current study was only 30 minutes and that participants were not as familiar with the simulations as with the overview presentation, this can be seen as a positive finding. This result suggests that even 30 minutes of using a computer simulation can help students enhance their understanding of physics concepts even if they had not been exposed to the simulations before.

Future research should include exposure to computer simulations for longer periods of times so that participants can become familiar with the simulation and see if longer exposure to the simulations yields greater knowledge gains similar to Tambade and Wagh, 2011, Zacharia and Anderson (2003), and Zacharia et al. (2008) where participants used the simulations for more than 30-minutes over a longer period of time. One way to enhance exposure to the computer simulations is to include a simulation activity for each lab in a physics course. For example, if there are a total of ten hands-on labs, include a 30-minute simulation activity for each hands-on lab.

In the current study, one of the reasons why participants in the overview presentation performed better than participants who completed the computer simulation activity is because in the overview presentation the instructor employed several of the principles of multimedia learning in the presentation. Future studies should investigate the effectiveness of using computer simulations to enhance learning when compared to effective overview presentations that use principles of multimedia learning that are based on the Cognitive Theory of Multimedia Learning, and compared to overview lectures that do not employ any type of cognitive multimedia technique.

In the current study, it was interesting to see that high spatial ability participants scored very high (*M* = 23.23 simulation group, *M* = 25.40 presentation group) and low spatial ability participants scored very low (*M* = 6.25 simulation group, *M* = 10.75 presentation group) on the spatial ability test. Future studies should investigate why there is such a difference in participants' spatial ability given that all students were enrolled in the same advanced physics course and presumably all students should have scored high on the spatial ability test. One explanation for such a difference could be that some students did not get a chance to finish the test in the allotted time. According the validity and reliability paper for the Santa Barbara Solids Test (SBST) that was used in the current study, participants completed the test in less than 5 minutes (Cohen & Hegarty, 2012). In the current study, participants were given 10 minutes to complete the test; this allotted time should have been sufficient to complete all the questions.

In the current study, there was also a small negative relationship between spatial ability and conceptual understanding when learning about induction topics with computer simulations or with the overview presentation. This finding seems to suggest that the concept of induction may not be spatially difficult. Future research should investigate not only what is the relationship between spatial ability and induction with a larger sample size that would allow the researcher to make more robust statistical analyses, but also investigate if the concept of induction is actually spatially challenging.

The current study also suggests that female participants have high spatial ability, different from Sanchez and Wiley (2010) and Falvo and Suits (2009) where female participants were low spatial ability. Given the very small female sample that was included in the current study, and the research suggesting that female students tend to be low spatial ability (e.g., Langlois et al., 2013; Miller & Halpern, 2013), more research is needed that investigates the effectiveness of using computer simulations stratified by gender and spatial ability in physics to see if females tend to be higher spatial ability particularly in comparison with females in other science fields.

In addition, the current study suggests that the hands-on lab alone overall made a small contribution to participants' learning in comparison to the overview presentation or the computer simulation activity. This finding can be attributed to the participants' fatigue of taking the conceptual knowledge test a third time after the hands-on lab. However, future studies should include an additional control group that looks at the impact of the hands-on lab alone on learning and compare it to using the simulations or receiving the overview presentation (simulation vs. presentation vs. hands-on lab).

Adding a qualitative aspect to future research should also be taken into account. Future research should employ a mixed methods design in order to incorporate qualitative aspects such as interviews with participants to dig deeper and investigate what participants find useful about using the computer simulations or receiving an overview presentation. In addition, future research should collect more demographic information such as grades from previous courses, participants' age, and experience with computer simulations to see what is the effect of these additional variables on participants' conceptual understanding.

The small sample of the current study makes if difficult to generalize the results, future studies should include a larger sample with a more even number of male and female participants. The larger sample would allow the researcher to perform more robust statistical analyses. Future studies should also ensure that reliability and validity information is obtained for all the measurements used.

Educational Implications

Even though the current study suggests that the computer simulation activity was not as effective as the overview presentation in enhancing participants' understanding of induction topics, participants still learned. Using computer simulations in the classroom should not be discounted. For example, participants who might have missed a lecture or lab can use the simulations to help them catch up on what they missed. If computer simulations will be used, instructors are encouraged to use the principles of multimedia design (Betrancourt, 2010; Mayer & Moreno, 2003) to guide them in choosing the simulations in order to obtain the greatest benefit from using the simulations.

In the current study, the overview presentation helped participants enhance their understanding of induction. Instructors should take into account that even a short 30-minute overview presentation could make a difference in participants learning, and try to incorporate it before their hands-on labs.

The principles of multimedia learning are key guides that should be taken into account when designing or choosing multimedia-based learning environments (that can also include computer simulations). These multimedia principles should also be taken into account when designing presentations where instructors may not have all the necessary tools to create more sophisticated multimedia learning environments, such as computer software to create interactive computer simulations. Using the principles of multimedia learning as guides to designing presentations that use simple tools such as overhead projectors or document cameras can make a difference in the quality of the presentation. In the current study, the fact that the overview presentation was not the typical lecture and it was more of an animated multimedia presentation (because the instructor delivered the content of the presentation live and in a step-by-step format), it seemed to have made a difference in student learning. Instructors are encouraged to design their lectures and presentations taking into account some or all of the principles of multimedia learning. A handout with a summary of the Cognitive Theory of Multimedia Learning (CTML) and the list of principles of multimedia learning that are derived from this theory is provided on Appendix I. This handout can serve as a resource for instructors that could help them guide them when choosing or designing multimedia learning environment or when creating presentations.

Summary

The purpose of the current study was to investigate the effectiveness of using computer simulations as a pre-training activity to a hands-on lab in comparison to an overview presentation with community college physics participants. Conceptual understanding and spatial ability were measured to assess knowledge gains and to assess the role of spatial ability on conceptual understanding.

The current study suggests that the overview presentation made the greatest difference in participants learning, different from other research suggesting that computer simulations were more effective as pre-training activities (Tambade & Wagh, 2011). One likely reason why the overview presentation was more effective is because the overview presentation was not the typical lecture. The overview presentation was more of an animated multimedia presentation that employed several techniques that were based on principles of multimedia learning.

High spatial ability participants benefited more from using the computer simulations, consistent with other research suggesting that high spatial ability participants benefited more from using computer simulations (Falvo & Suits, 2009). Male participants also benefited more from the computer simulation activity while the female participants benefited more from the overview presentation, suggesting that the overview presentation did not impose an additional difficulty to female participants' learning. There was also a negative relationship between spatial ability and conceptual understanding, suggesting that spatial ability might have not been an important factor in helping participants gain a better understanding of induction topics in physics.

The research implications are related to addressing the findings and limitations of the current study. Additional research should include longer exposure to computer simulations and also include an additional control group so that simulations can be compared to an overview presentation and to a hands-on lab alone. Furthermore, more research is needed on the role of spatial ability and gender in physics. Future research should also include a larger sample and a thoroughly validated conceptual knowledge instrument.

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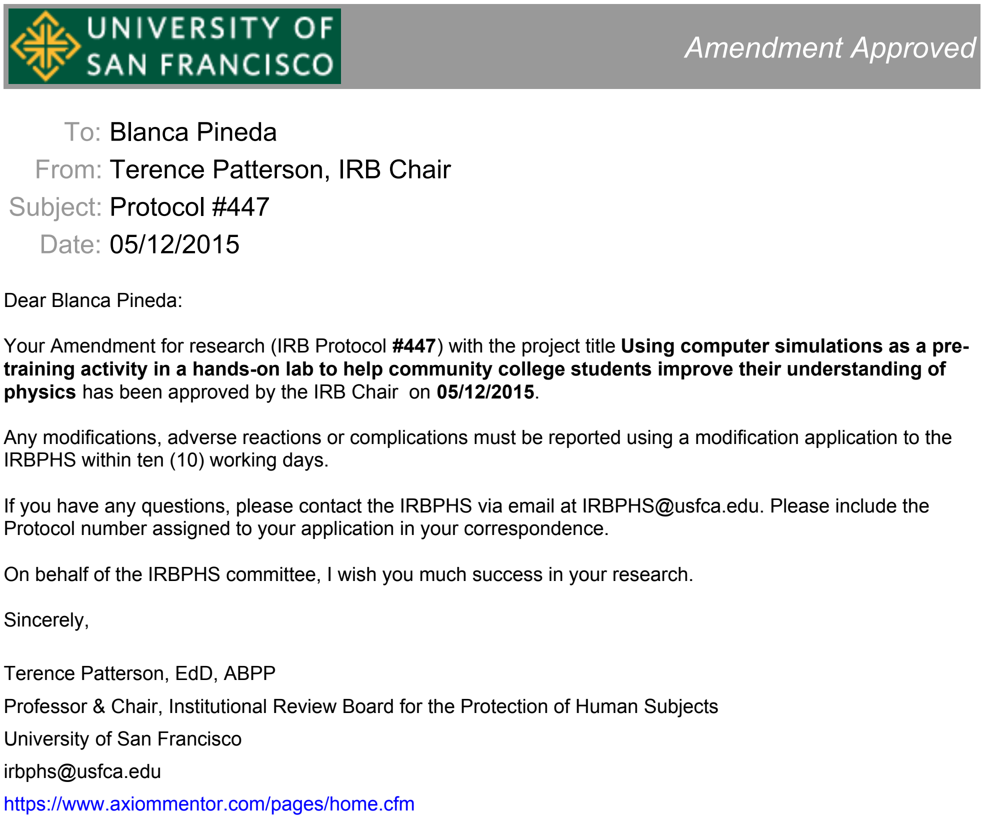
APPENDIX A

University of San Francisco IRB Approval



UNIVERSITY OF
SAN FRANCISCO

Amendment Approved

To: Blanca Pineda
From: Terence Patterson, IRB Chair
Subject: Protocol #447
Date: 05/12/2015

Dear Blanca Pineda:

Your Amendment for research (IRB Protocol **#447**) with the project title **Using computer simulations as a pre-training activity in a hands-on lab to help community college students improve their understanding of physics** has been approved by the IRB Chair on **05/12/2015**.

Any modifications, adverse reactions or complications must be reported using a modification application to the IRBPHS within ten (10) working days.

If you have any questions, please contact the IRBPHS via email at IRBPHS@usfca.edu. Please include the Protocol number assigned to your application in your correspondence.

On behalf of the IRBPHS committee, I wish you much success in your research.

Sincerely,

Terence Patterson, EdD, ABPP
Professor & Chair, Institutional Review Board for the Protection of Human Subjects
University of San Francisco
irbphs@usfca.edu
https://www.axiommentor.com/pages/home.cfm

APPENDIX B

Informed Consent

UNIVERSITY OF
SAN FRANCISCO
CHANGE THE WORLD FROM HERE

CONSENT TO PARTICIPATE IN A RESEARCH STUDY

Below is a description of the research procedures and an explanation of your rights as a research participant. You should read this information carefully. If you agree to participate, you will sign in the space provided to indicate that you have read and understand the information on this consent form. You are entitled to and will receive a copy of this form.

You have been asked to participate in a research study entitled **"Using computer simulations in physics"** conducted by **Blanca S. Pineda**, a doctoral student in the **School of Education, Department of Learning and Instruction at The University of San Francisco**. The faculty supervisor for this study is **Dr. Matthew Mitchell**, a professor in the **School of Education, Department of Learning and Instruction at the University of San Francisco.**

WHAT THE STUDY IS ABOUT:

The purpose of this study is to investigate the effectiveness of different kinds of physics activities.

WHAT WE WILL ASK YOU TO DO:

During this study, you will be asked to do the following:

During Lab 9

- Read and sign this informed consent form.
- Take a 10-minute multiple-choice Spatial Ability test (called the Santa Barbara Solids Test (SBST)).

During Lab 10

- Complete a 10-minute multiple-choice assessment.
- You will be assigned to one of two groups. If you are assigned to group 1, you will stay in the lab and complete a 30-minute activity. If you are assigned to group 2, you will go to a nearby classroom and complete a different 30-minute activity.
- Complete a second 10-minute multiple-choice assessment.
- Complete your regular scheduled hands-on lab on induction guided by your instructor, which will last approximately 100 minutes.

- Complete a final 10-minute multiple-choice assessment.

DURATION AND LOCATION OF THE STUDY:

Your participation in this study will be approximately 20 minutes at the beginning of lab 9, and approximately 1 hour during lab 10. Note that the time when you will be completing your scheduled hands-on lab is not counted as study time since you will have to complete this lab as part of your course.

POTENTIAL RISKS AND DISCOMFORTS:

We do not anticipate any risks or discomforts to you from participating in this research. If you wish, you may choose to withdraw your consent and discontinue your participation at any time during the study without penalty.

BENEFITS:

You will receive no direct benefit from your participation in this study. The anticipated benefit of this study is to understand how different activities can be valuable when learning physics topics.

PRIVACY/CONFIDENTIALITY:

Any data you provide in this study will be kept confidential unless disclosure is required by law. In any report I publish, I will not include information that will make it possible to identify you or any individual participant. For all forms you will be asked to write your initials and the day you were born (e.g. bsp18) in order to keep track of the multiple measurement documents and signed consent forms. After the data is collected, but before it is entered into the analysis software, your initials and day you were born will be replaced by random numeric IDs. This means your initials and day you were born will be crossed out with a black marker. Only the random numeric ID will remain in all measurement documents. All measurement documents and consent forms will be kept in a locked box. They will be destroyed approximately three years after the day of this study. Only the researcher (Blanca Pineda) will have access to the files.

COMPENSATION/PAYMENT FOR PARTICIPATION:

You will be entered to win a $50 Amazon Gift Card for your participation in this study. If you choose to withdraw before completing the study, you will be removed from the drawing.

VOLUNTARY NATURE OF THE STUDY:

Your participation is voluntary and you may refuse to participate without penalty or loss of benefits. Furthermore, you may skip any questions or tasks that make you uncomfortable and may discontinue your participation at any time without penalty or loss of benefits. In addition, the researcher has the right to withdraw you from participation in the study at any time.

OFFER TO ANSWER QUESTIONS:

Please ask any questions you have now. If you have questions later, you should contact Blanca Pineda at (408) 505-2167 or bspineda@usfca..edu. If you have questions or concerns about your rights as a participant in this study, you may contact the University of San Francisco Institutional Review Board at IRBPHS@usfca.edu.

I HAVE READ THE ABOVE INFORMATION. ANY QUESTIONS I HAVE ASKED HAVE BEEN ANSWERED. I AGREE TO PARTICIPATE IN THIS RESEARCH PROJECT AND I WILL RECEIVE A COPY OF THIS CONSENT FORM.

Initials: ______________

PARTICIPANT'S SIGNATURE _DATE_

APPENDIX C

Santa Barbara Solids Test (SBST)

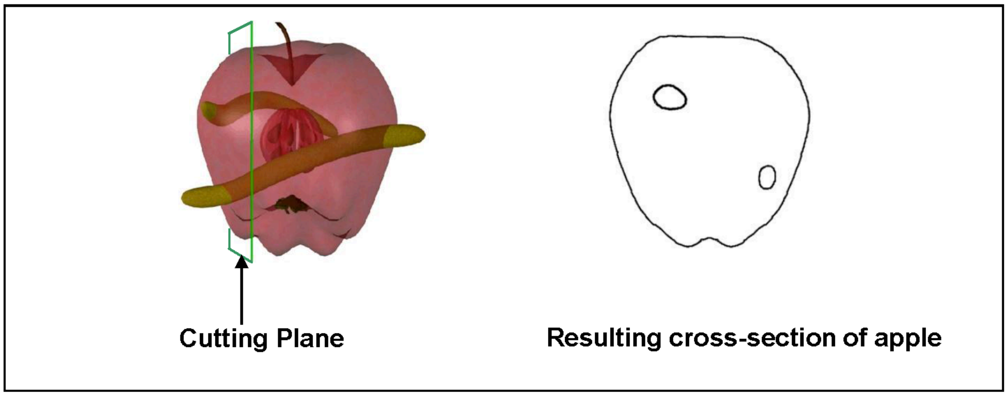
To use this test, request permission from authors (Cohen & Hegarty, 2007).

Cross Section Test

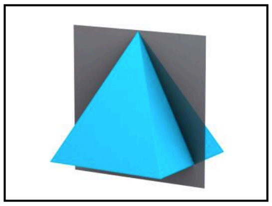
This is a test about **cross-sections**. A cross-section is the 2D shape that results when a cutting plane intersects an object.

You've seen many examples of cross-sections in everyday life. For example, when you slice an apple from top to bottom, the resulting cut surface is a cross-section of the apple.

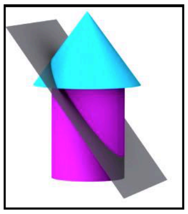
The picture below shows an apple with some worms inside. Note that the cross section on the right shows both the apple and the shapes and locations of the sliced worms inside the apple.



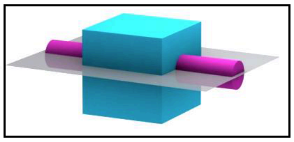
In this multiple choice test, you will be asked to identify the cross sections of three types of figures:



Single object



Attached objects

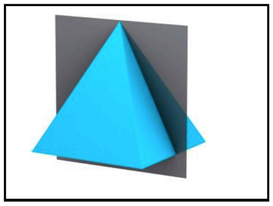


Nested objects
(one object is inside another)

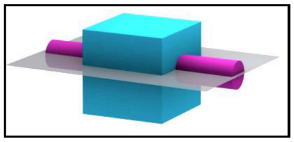
Here are some important things to remember:

- All figures are solid (not hollow) objects.
- The objects are about 6-8 inches tall. Imagine that they are on the table in front of you.
- Attached figures are “glued together” at their edges.
- Nested objects consist of one object inside another. In the nested object above, the cylinder extends all the way through the cube. If you sliced this figure, you would see the cylinder inside the cube.

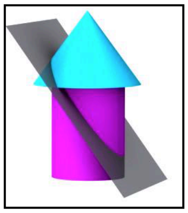
The cutting planes, shown in grey, will have different orientations.



Vertical Plane



Horizontal Plane



Oblique Plane

You will see three types of cutting planes: horizontal, vertical, and oblique.

For each type of cutting plane, try to imagine the cross section that would result if you faced the cutting plane head-on, as if you were looking at your reflection in a mirror.

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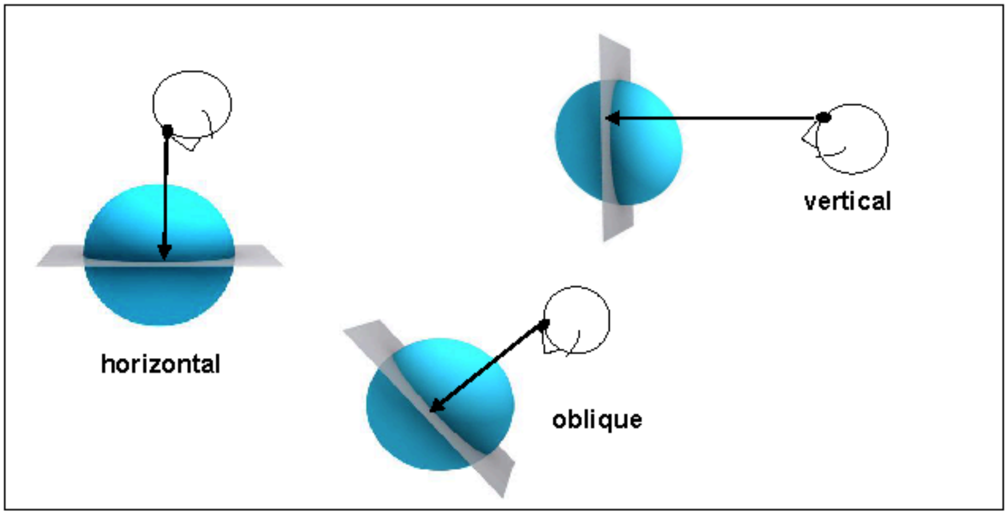
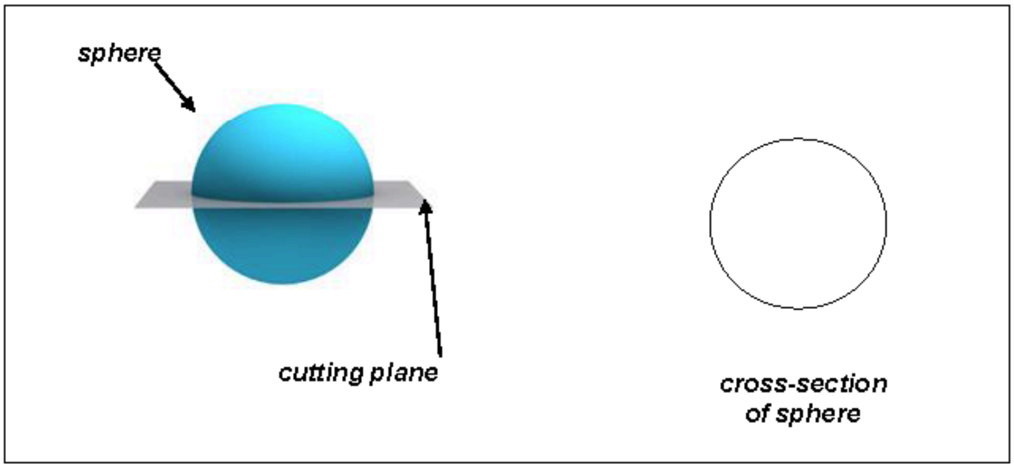
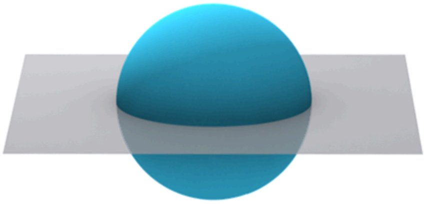


You should also assume that the objects are 6-8 inches tall, and that they are sitting on the desk in front of you.

In the example below, the cutting plane would produce the cross section on the right.



Sample Problem



(a)

(b)

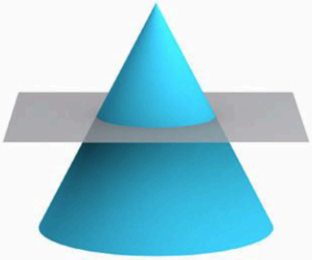
(c)

(d)

Instructions:

Circle the cross-section you would see when the grey cutting plane slices the object. Imagine that you are facing the cutting plane head-on, as if you were looking in a mirror. Make your choice based on the shapes of the possible answers, not their sizes.

Problem 1



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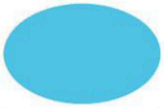

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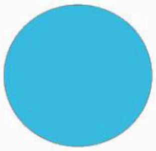

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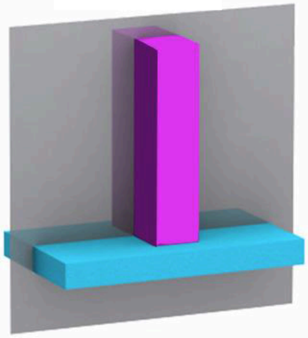

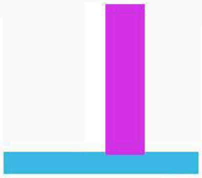

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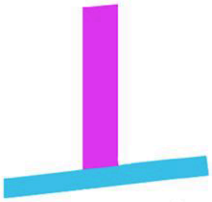

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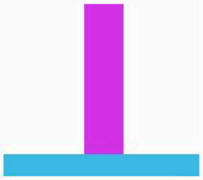

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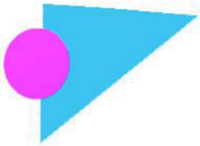
Problem 3



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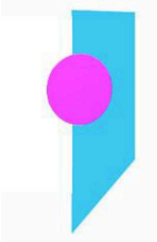

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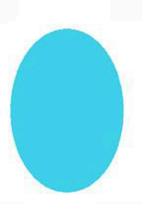
Problem 4



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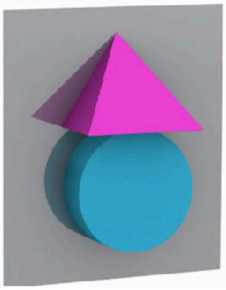
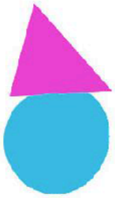
Problem 5





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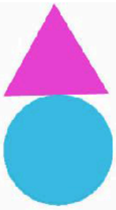

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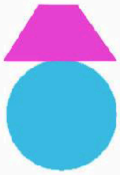

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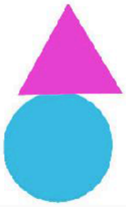

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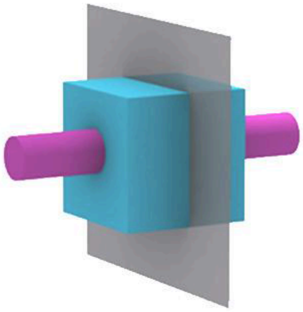

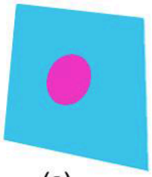

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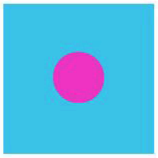

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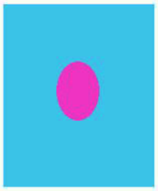

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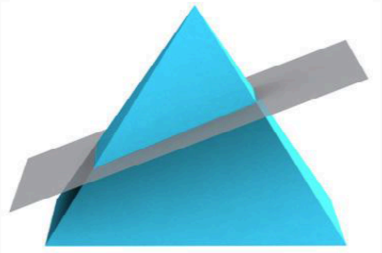

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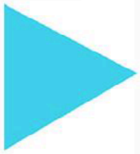

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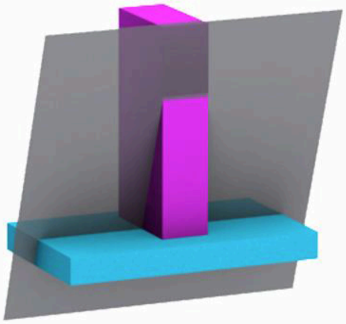
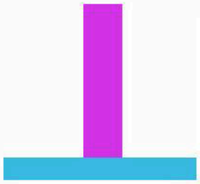
Problem 8





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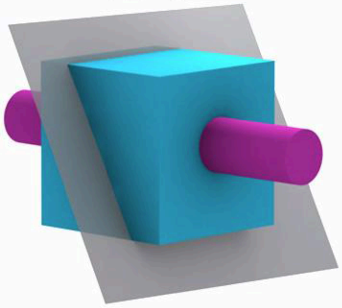
Problem 9



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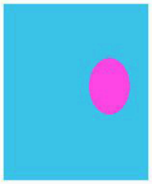

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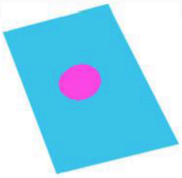

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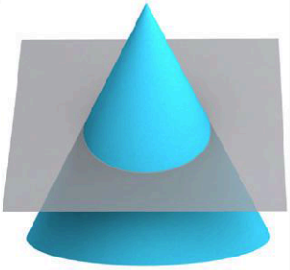
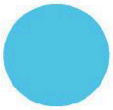
Problem 10





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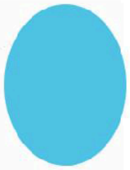

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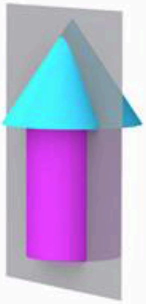


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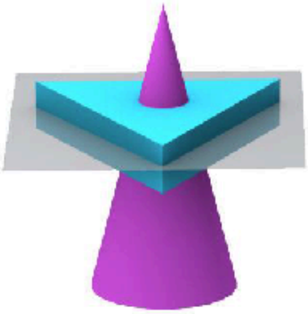
Problem 12

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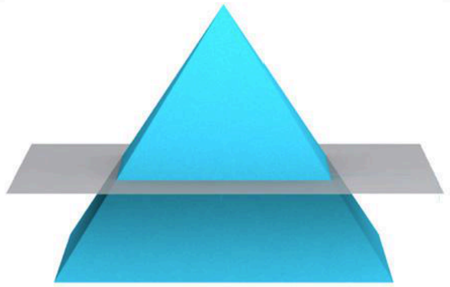
Problem 13

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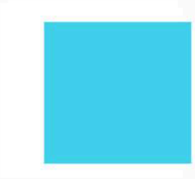
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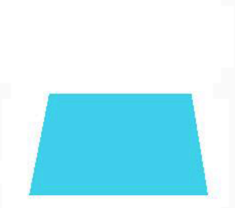
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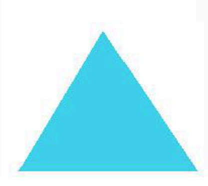
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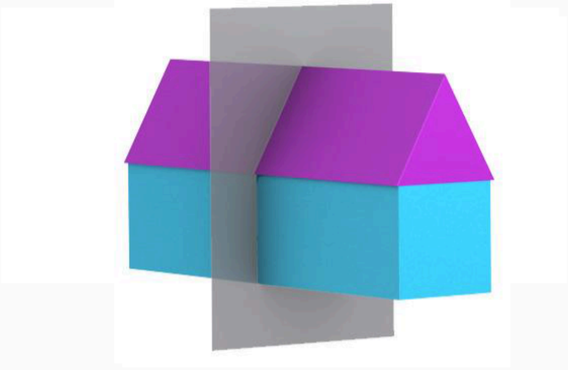
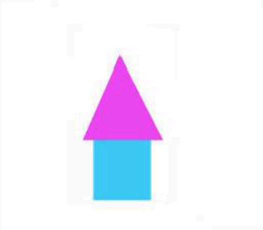
Problem 14

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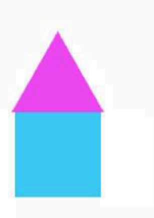
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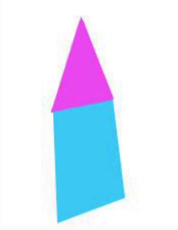
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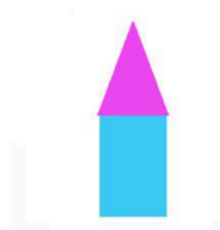
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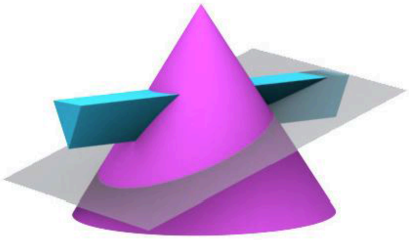
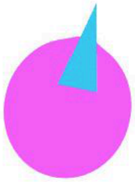
Problem 15



(a)

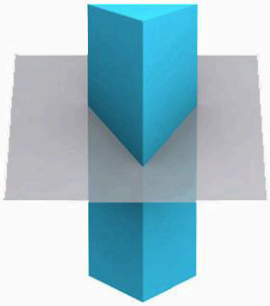
(b)

(c)



(d)

Problem 16



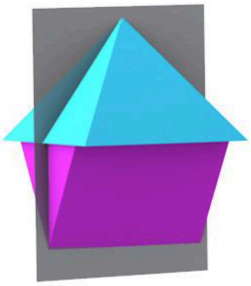
(a)

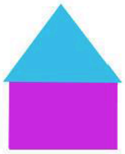
(b)

(c)

(d)

Problem 17

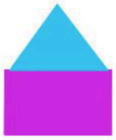




(a)

(b)

(c)



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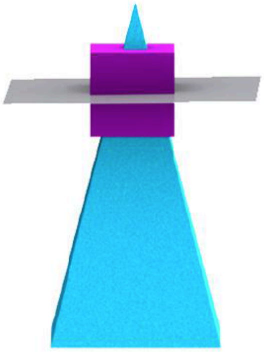
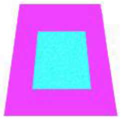
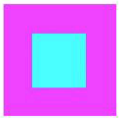
Problem 18





(a)

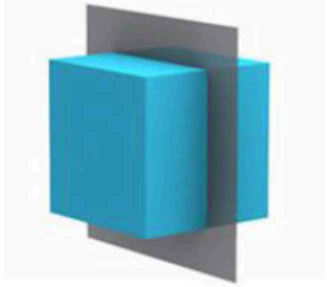


(b)

(c)

(d)

Problem 19



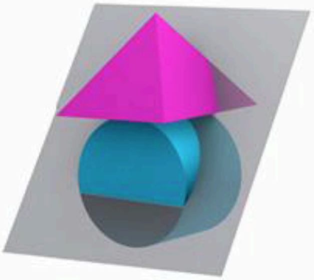
(a)

(b)

(c)

(d)

Problem 20



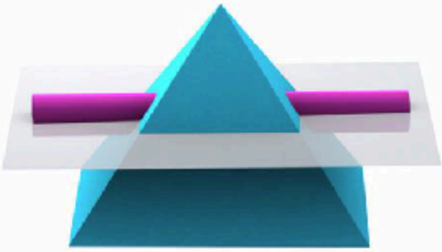
(a)

(b)

(c)

(d)

Problem 21



(a)

(b)

(c)

(d)

Problem 22

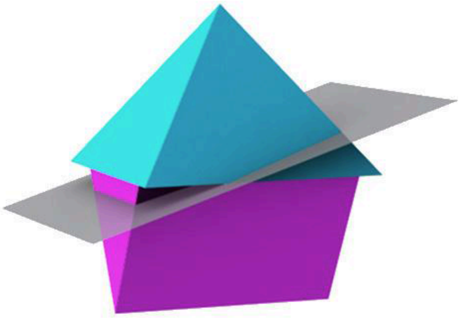
(a)

(b)

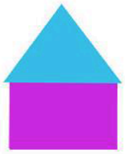
(c)

(d)

Problem 23




(a)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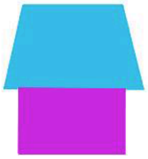
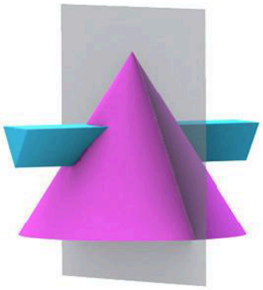
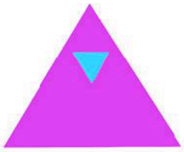

(c)


(d)

Problem 24




(a)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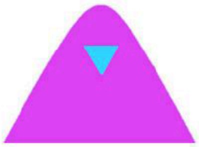
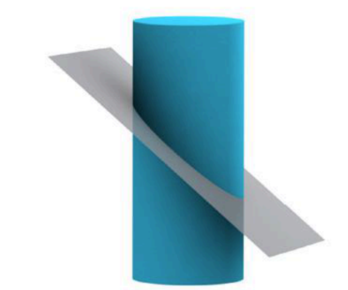
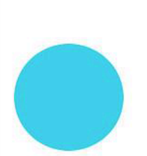

(c)


(d)

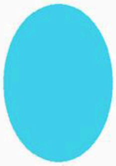
Problem 25





(a)

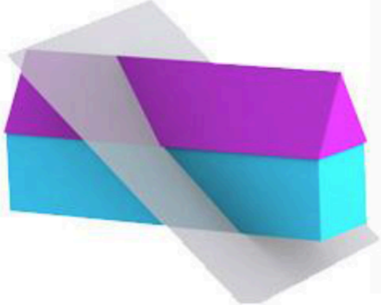
(b)

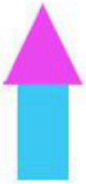


(c)

(d)

Problem 26





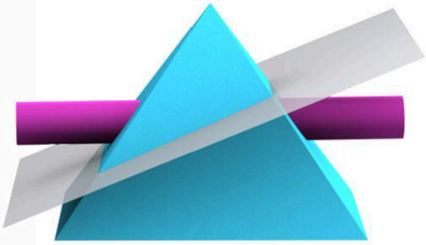
(a)

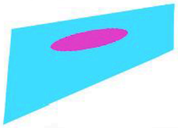
(b)

(c)

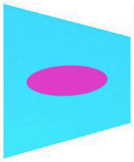
(d)

Problem 27





(a)



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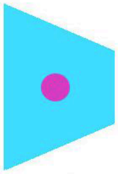

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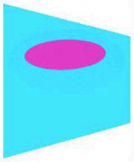
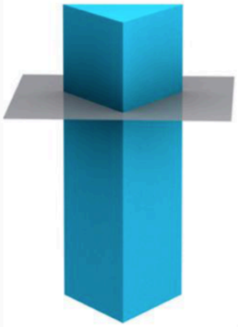


(d)

Problem 28



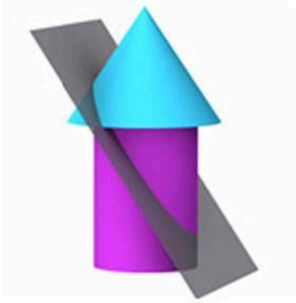
(a)

(b)

(c)

(d)

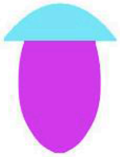
Problem 29



(a)

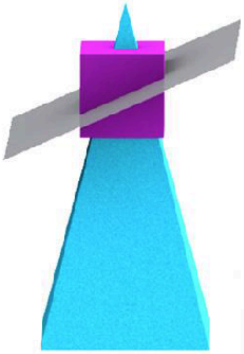
(b)

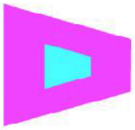
(c)



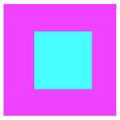
(d)

Problem 30



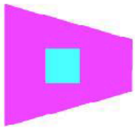


(a)



(b)

(c)



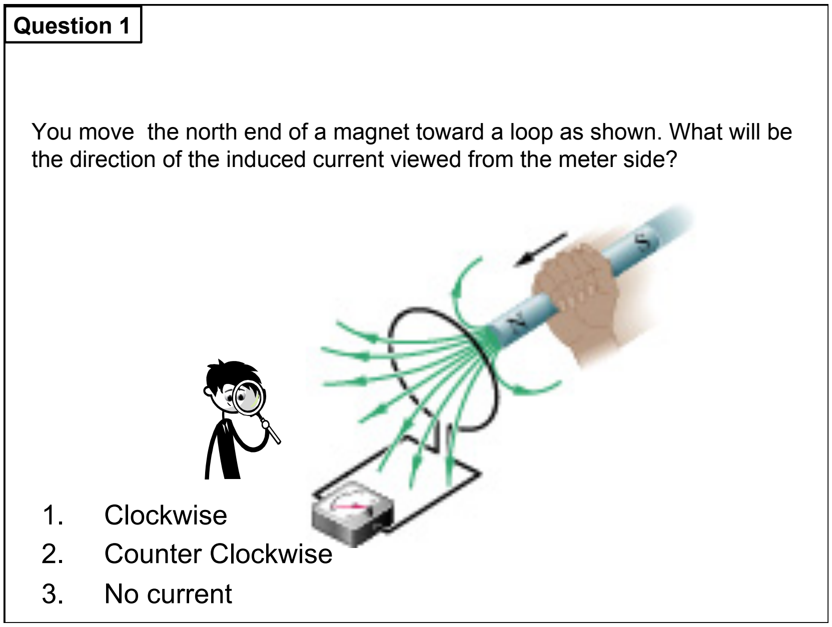
(d)

End of exercise

APPENDIX D

Conceptual knowledge Test

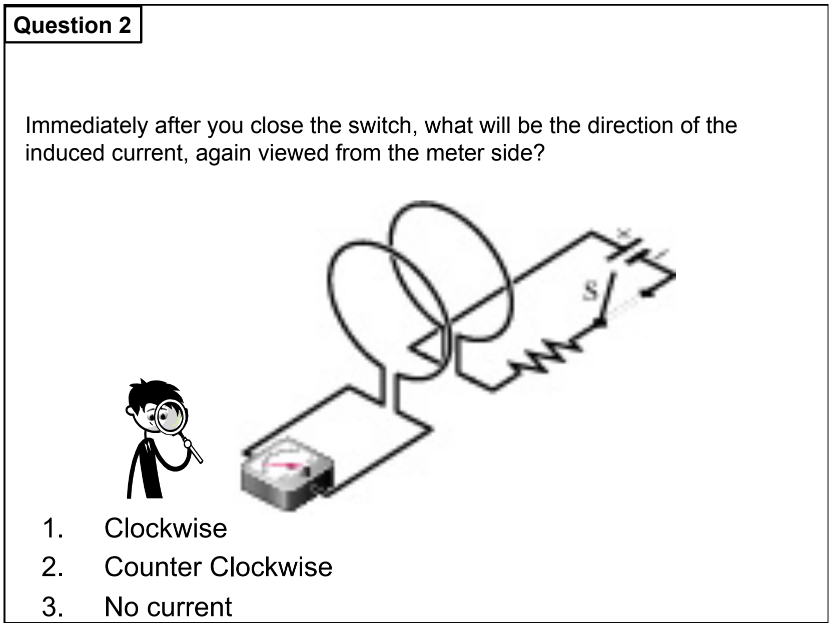
Adapted from Hieggelke et al. (2005)



Question 1

You move the north end of a magnet toward a loop as shown. What will be the direction of the induced current viewed from the meter side?

1. Clockwise
2. Counter Clockwise
3. No current



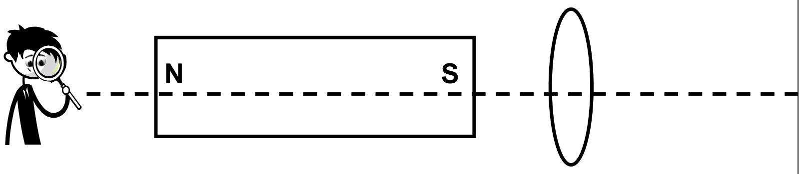
Question 2

Immediately after you close the switch, what will be the direction of the induced current, again viewed from the meter side?

1. Clockwise
2. Counter Clockwise
3. No current

Question 3

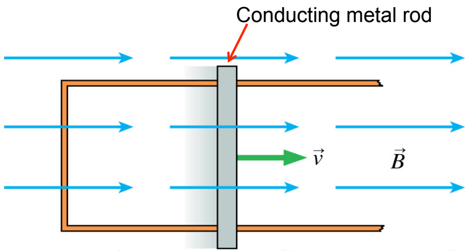
Initially, the magnet and the loop are not moving. Then, the loop starts to rotate around its center (denoted by the dotted line). The rotation is clockwise when viewed from the magnet side. What will be the direction of the induced current in the loop when viewed from the magnet side?



1. Clockwise
2. Counter Clockwise
3. No current

Question 4

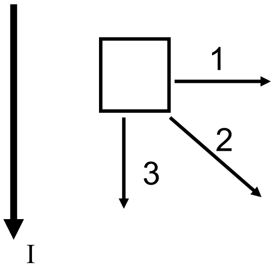
Is there an induced current in this circuit? If so, what is its direction?



1. Yes, clockwise.
2. Yes, counterclockwise.
3. No.

Question 5

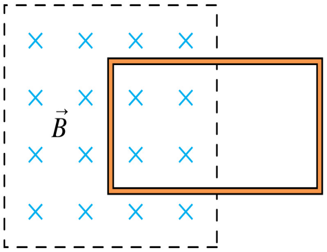
A rectangular loop could move in three directions near a straight long wire with current I. In which direction can you move the rectangular loop so the loop has an induced current in the loop?



A. 1only.
B. 1 and 2 only.
C. 2 only.
D. 1 and 3 only.
E. 2 and 3 only.
F. 1, 2, and 3.
G. None of the above.

Question 6

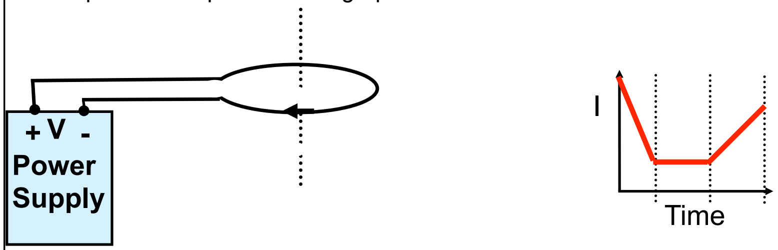
A conducting loop is halfway into a magnetic field. Suppose the magnitude of the magnetic field begins to increase rapidly in strength. What happens to the loop?



1. The loop is pushed upward, toward the top of the page.
2. The loop is pushed downward, toward the bottom of the page.
3. The loop is pulled to the left, into the magnetic field.
4. The loop is pushed to the right, out of the magnetic field.
5. The tension in the wires increases, but the loop doesn't move.

Question 7

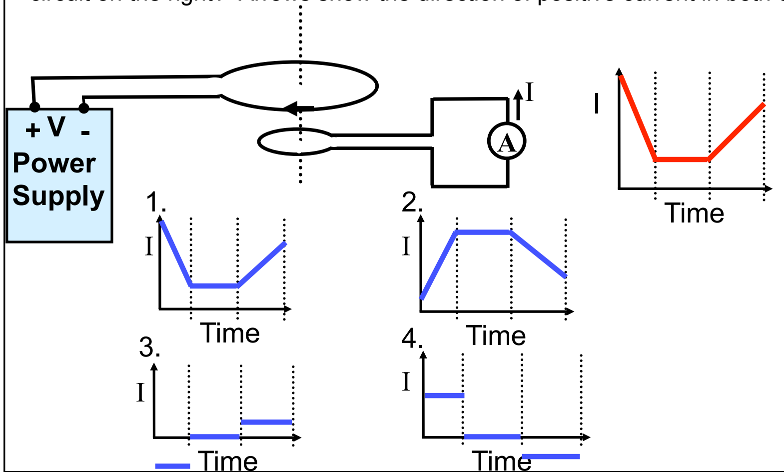
The current through the top coil varies with time as shown on the right. Which description corresponds to the graph shown?



1. The current first decreases at a constant rate, then it stays constant, and finally increases at a constant rate.
2. The current first increases at a constant rate, then it stays constant, and finally decreases at a constant rate.
3. The current first stays constant, then it increases, and finally increases more.
4. The current first decreases, then it increases, and finally increases more.
5. None of the above.

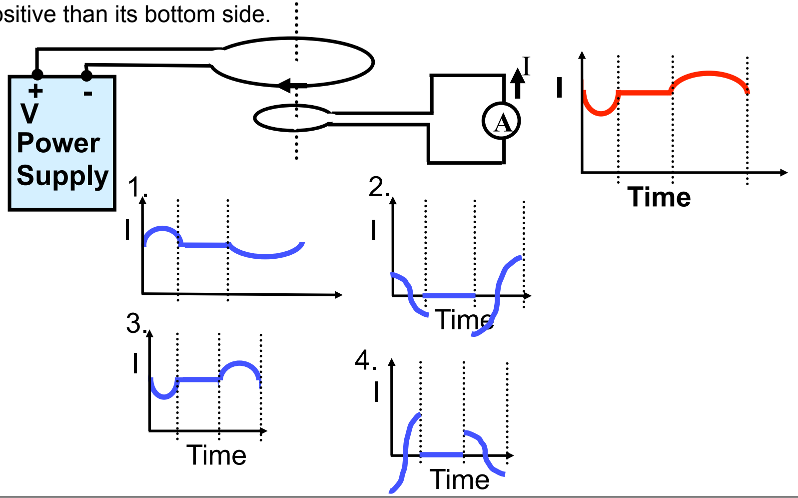
Question 8

The current through the top coil varies with time as shown on the right. Which of the following curves gives the correct current versus time in the secondary circuit on the right? Arrows show the direction of positive current in both coils.



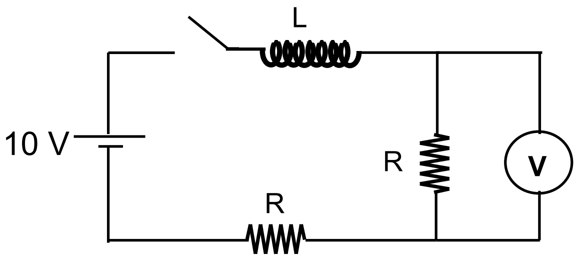
Question 9

Another pattern for current versus time is shown on the right. Which of the following qualitatively shows the ***ammeter reading current*** in the secondary. It is hooked up so that it reads ***positive current*** when its top side is more positive than its bottom side.



Question 10

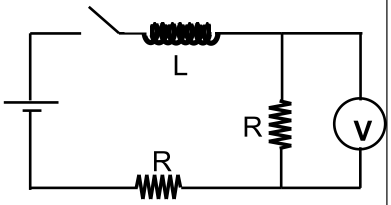
What is the value of the voltmeter ***just after*** the switch is closed? Both resistors have the same value.



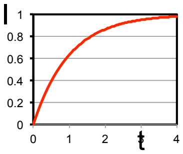
1. 0 V
2. 3.33 V
3. 5 V
4. 10V
5. None of the above

Question 11

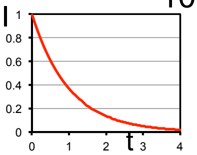
Which of the following graphs correctly shows the current passing through the resistance as a function of time? (The time when the switch is closed is defined as t=0.)



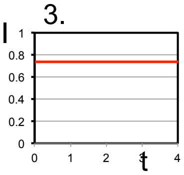
1.



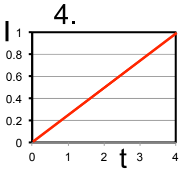
2.



3.



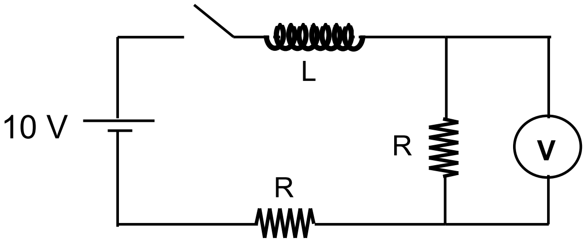
4.



5. None of the above

Question 12

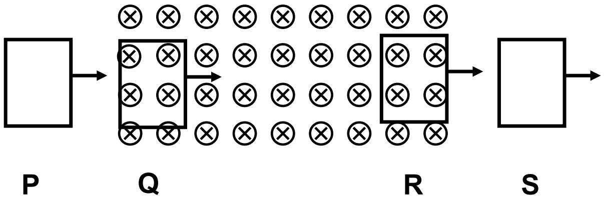
What is the value of the voltmeter reading ***a long time after*** the switch has been closed? Remember that there are ***two*** resistors with the same value.



1. 0 V
2. 3.33 V
3. 5 V
4. 10V
5. None of the above

Question 13

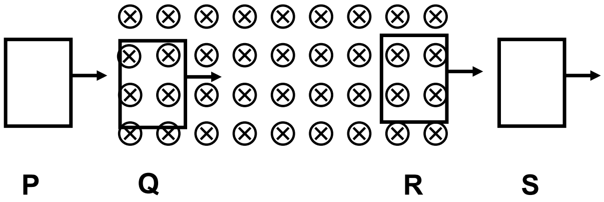
Consider coil positions P, Q, R and S. A uniform magnetic field is confined to the region shown, and a loop moves to the right with a uniform speed. What happens to the magnitude of the current in the loop between positions P and Q?



1. Increases
2. Stays the same
3. decreases
4. Can not say for sure

Question 14

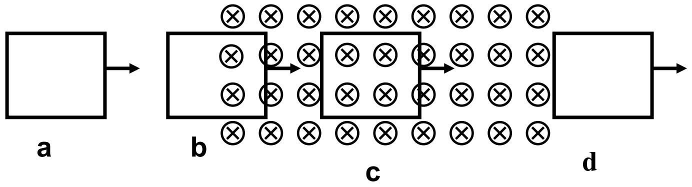
Consider coil positions P, Q, R and S. A uniform magnetic field is confined to the region shown, and the loop moves to the right. What happens to the magnitude of the flux through the loop between positions Q and R?



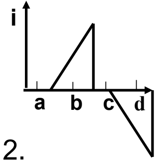
1. Increases
2. Stays the same
3. decreases
4. Can not say for sure

Question 15

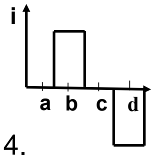
Which of the following graphs best represents the current in the loop as it moves at constant speed from position a to position d?



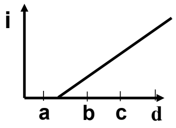
1.



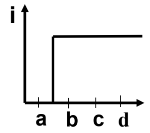
3.



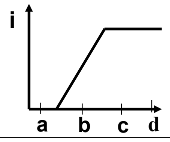
2.



4.

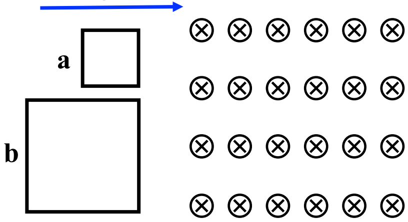


5.



Question 16

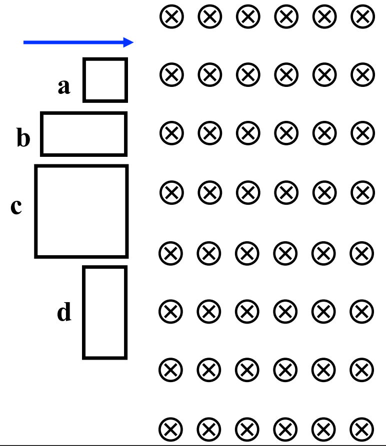
The figure shows two wire loops, with edge lengths of L and 2L, respectively. Both loops will move through a region of uniform magnetic field B at the *same constant velocity*. Rank them according to the EMF induced ***just as their front edges enter the B field region***.



1. a>b
2. a=b
3. a<b
4. Depends on the magnitude of their common velocity
5. Depends on the magnitude of the B field.

Question 17

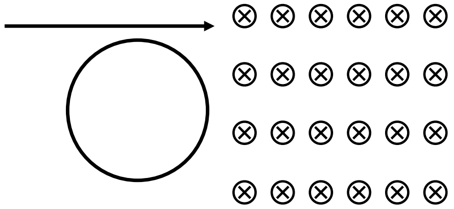
The figure shows four wire loops, with edge lengths of either L or 2L. All four loops will move through a region of uniform magnetic field B at the same constant velocity. Rank them according to the EMF induced ***just as they enter the B field region***.



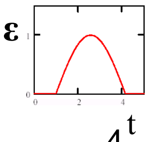
1. a<b<d<c
2. a<b=d<c
3. a<b<c<d
4. a=b<c=d
5. a=b<d<c

Question 18

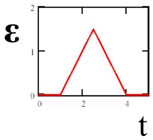
A circular wire loop moving at constant velocity enters a long region of uniform magnetic field B. Which one of the graphs describes the emf ε in the loop as a function of time t?



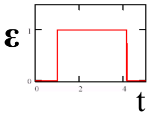
1.



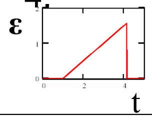
2.



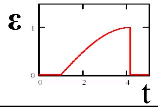
3.



4.



5.



APPENDIX E

Computer Simulation Activity Guide

Adapted from Hewitt and Baird (2014)

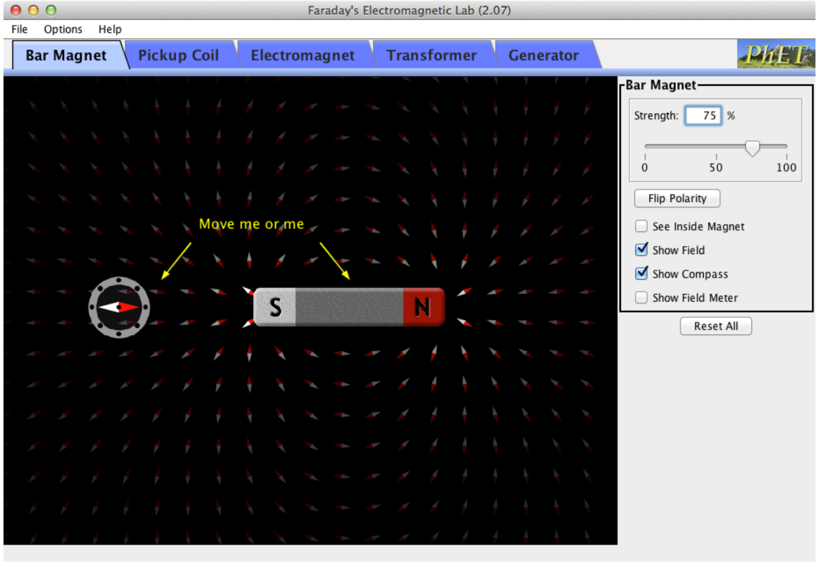
Computer Animation Activity Guide

Electromagnetic Induction: Generators and Alternating Current

Faraday’s Electromagnetic Lab

Please complete the steps below to go through the Faraday’s Electromagnetic Simulation.

The simulation should now be showing in your computer screen (**Figure 1**).



Strength: 75 %

☐ See Inside Magnet

☑ Show Field

☑ Show Compass

☐ Show Field Meter

Figure 1

BAR MAGNET TAB

The simulation should be opened to the **Bar Magnet** tab. You should see a bar magnet, a compass, and a compass needle grid.

1. Center the bar magnet horizontally on the fourth or fifth row from the top. Set the large compass just below the bar magnet at its midpoint. It's okay for the two objects to be touching. See **Figure 2**.

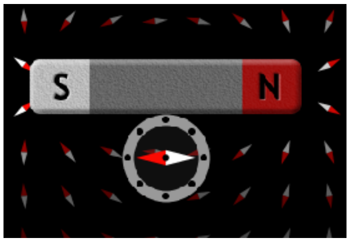
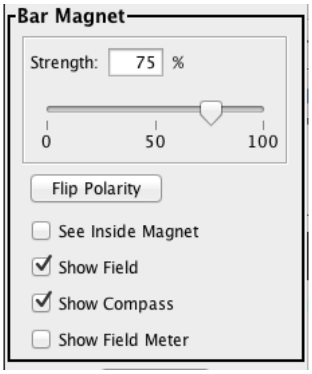


Figure 2

2. If the compass needles (in the grid or in the large compass) are to be thought of as arrows indicating the direction of the bar magnet's magnetic field, each one should be visualized as pointing **__“redward” __“whiteward”.**

3. Using the on-screen slider in the **control panel** (**Figure 3**), run the strength of the bar magnet up and down. How does the simulation show the difference between a strong magnet and a weak magnet?



Bar Magnet

Strength: 75 %

☐ See Inside Magnet

☑ Show Field

☑ Show Compass

☐ Show Field Meter

Figure 3

4. How does the strength of the magnetic field change with increasing distance from the bar magnet and how does the simulation show this?

5. With the magnet at its strongest, reverse it's polarity using the on-screen "**Flip Polarity**" button in the control panel. What are the ways in which the simulation reflects this polarity reversal?

6. Describe the behavior of the compass during a polarity reversal (magnet initially at 100%)
   a. When the compass is touching the bar magnet at its midpoint.

   b. When the compass is far from the bar magnet (touching the bottom of the simulation window), but still on a perpendicular bisector of the bar magnet.

   c. When the compass is far from the bar magnet and the magnet's strength is set to 10%.

7. Around the exterior of the bar magnet, the direction of the magnetic field is from its ________ pole to its _________ pole.

   a. What is the direction of the magnetic field in the interior of the bar magnet? And how did you find out?

PICKUP COIL TAB

Click the **Pickup Coil** tab. You should see a bar magnet, a compass needle grid, and a coil attached to a light bulb.

1. Describe the most effective way of using the magnet and the coil to light the bulb if the coil cannot be moved.

2. Describe the most effective way of using the magnet and the coil to light the bulb if the magnet cannot be moved.

3. Rank the arrangements and motions shown below (**Figure 4**) from most effective to least effective in terms of lighting the bulb. **Try each of the motions shown with the simulation.**

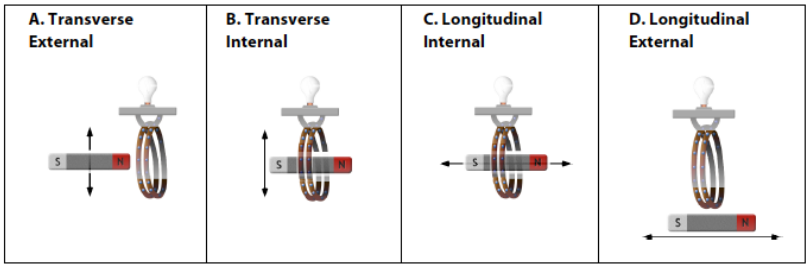


Figure 4

4. Move the bar magnet through the coil and observe the motion of the electrons in the forward arc of the coil loops.

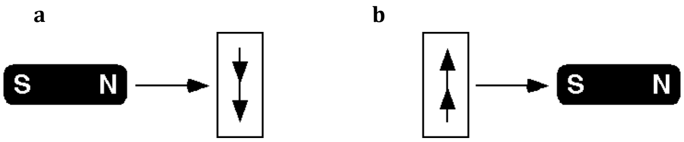


Figure 5

   a. Magnet approaches from the left, north pole first; electrons **move downward (Figure 5a).**

   b. Magnet departs to the right, south end last; electrons **move upward (Figure 5b).**

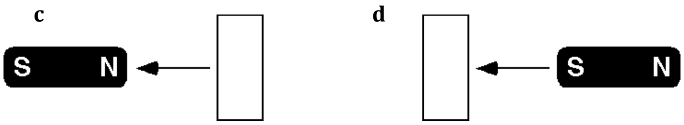


Figure 6

   c. Magnet approaches from the right, south pole first; electrons move ________________. Draw the direction on the image above (**Figure 6c**).

   d. Magnet departs to the left, north end last; electrons move ________________. Draw the direction on the image above (**Figure 6d**).

Figure 7

   e. Magnet approaches from the left, south pole first; electrons move ________________. Draw the direction on the image above (**Figure 7e**).

   f. Magnet departs to the right, north end last; electrons move ________________. Draw the direction on the image above (**Figure 7f**).

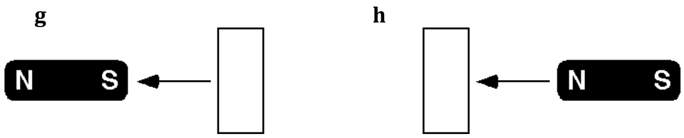


Figure 8

g. Magnet approaches from the right, north pole first; electrons move _______________. Draw the direction on the image above (**Figure 8g**).

h. Magnet departs to the left, south end last; electrons move _______________. Draw the direction on the image above (**Figure 8h**).

ELECTROMAGNET TAB

Click on the **Electromagnet** tab.

1. Arrange the on-screen elements so that the top of the battery is along the second or third row of the compass grid. Notice that the magnetic field around the coil is very similar to the magnetic field around the bar magnet.

2. There is no “Strength %” slider on the control panel. How can you change the strength of the electromagnet?

3. There is no “Flip Polarity” button on the control panel. How can you reverse the polarity of the electromagnet?

4. In the control panel, switch the **Current Source** from the battery (**DC: direct current**) to an oscillator (**AC: alternating current**). If necessary, move the electromagnet so that you can see the entire oscillator.
   a. What does the vertical slider on the AC source do?

   b. What does the horizontal slider on the AC source do?

TRANSFORMER TAB

Click on the **Transformer** tab. You should see an electromagnet and a pickup coil.

1. Experiment with the various control panel settings and the positions of the electromagnet and the pickup coil to determine a method for getting the most light out of the bulb. Describe the settings and locations.

GENERATOR TAB

Click on the **Generator** tab. You should see a faucet, paddlewheel with bar magnet, compass, and a pickup coil.

1. Experiment with the various settings to determine a method for getting the most light out of the bulb. Describe the settings.

2. What is the story of light production here? Organize and connect the given “plot elements” and add any key elements that were omitted from the list to construct the complete story.

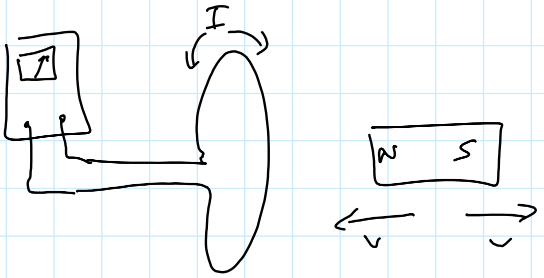
• light radiated from the bulb	**• changing magnetic field**
• induced electric current	**• motion of the bar magnet**
• kinetic energy of the water	**• heat the filament**

APPENDIX F

Overview Presentation Notes From Instructor.

Monday, June 15, 2015 3:18 PM

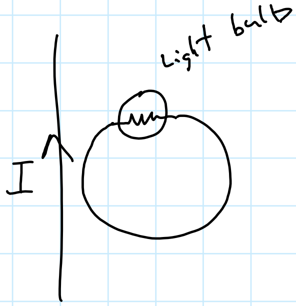
Induction Review:

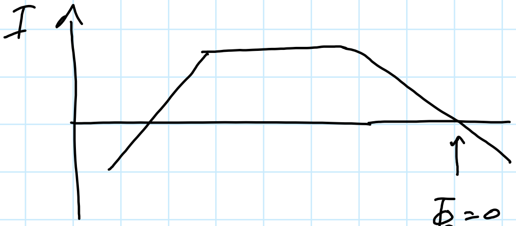


motion induced current

No motion → No current

$$\mathcal{E} = -N \frac{d\Phi_B}{dt}$$





$\Phi_B = 0$
at this
instant

In Loop: $\mathcal{E} \neq 0$

bulb is on

$$\Phi_B = \int B \cdot dA$$

B can change

A can change

orientation can change

Faraday's Law $|\mathcal{E}| = \frac{d\Phi_B}{dt} = \frac{d}{dt}\left(\int \vec{B} \cdot d\vec{A}\right)$

if B is constant over A_n (and Normal):

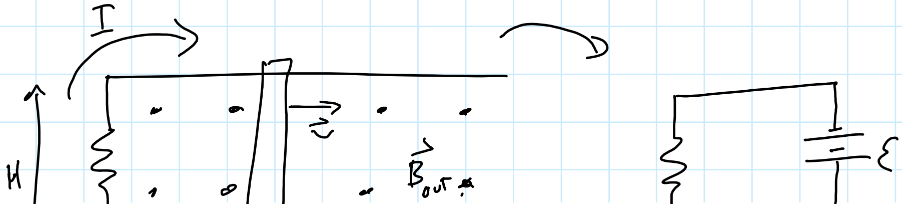
$$\Phi = BA$$

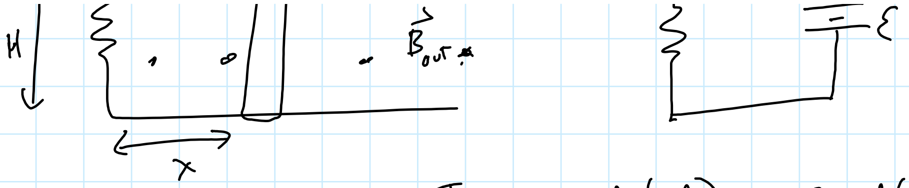
$$= \frac{d}{dt}(BA)$$

Lenz's Law:

direction

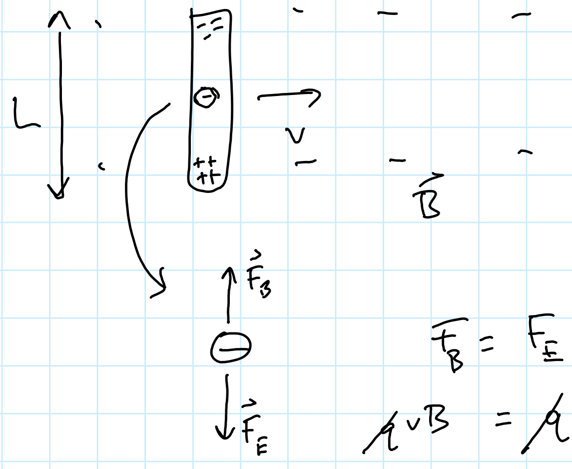
Induced current creates B field that opposes the change that created the current





$$|\mathcal{E}| = \frac{d\Phi_B}{dt} = \frac{d}{dt}(BA) = B\,\frac{d(xH)}{dt}$$

$$= BH\frac{dx}{dt} = BHv$$

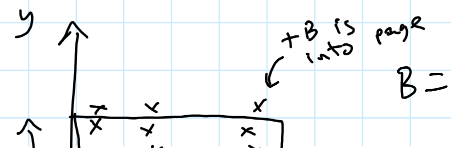


$$F_B = F_E$$

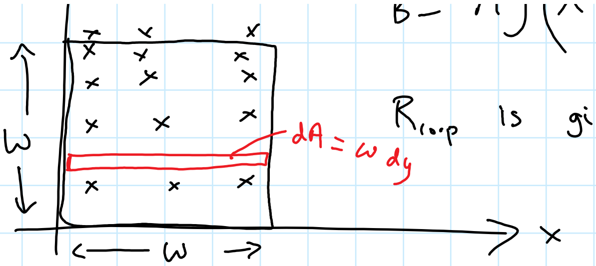
$$\cancel{q}vB = \cancel{q}E$$

$$vB = \frac{\mathcal{E}}{L}$$

$$\mathcal{E} = BLv$$



$$B = Ay(t - z)$$



R_{loop} is given

Find I at $t = 2$ sec.

$$|\mathcal{E}| = \frac{d\Phi}{dt} = \frac{d}{dt}\left(\int \vec{B}\cdot d\vec{A}\right)$$

$$= \frac{d}{dt}\left[\int_0^w A\,y\,(t-2)\,w\,dy\right]$$

$$= \frac{d}{dt}\left[A\,w\,(t-2)\,\frac{y^2}{2}\Big|_0^w\right]$$

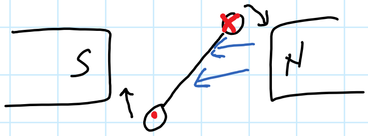
$$= \frac{d}{dt}\left[\frac{A w^3}{2}(t-2)\right]$$

$$= \frac{A w^3}{2}\underbrace{\frac{d}{dt}(t-2)}_{1}$$

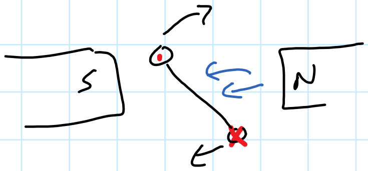
$$= \frac{A w^3}{2}$$

$$I = \frac{\mathcal{E}}{R} = \frac{A w^3}{2 R_{loop}}$$

Top view



Now



APPENDIX G

Description of Induction Hands-on Lab From the Instructor's Website.

Induced Voltage from a Dropped Magnet

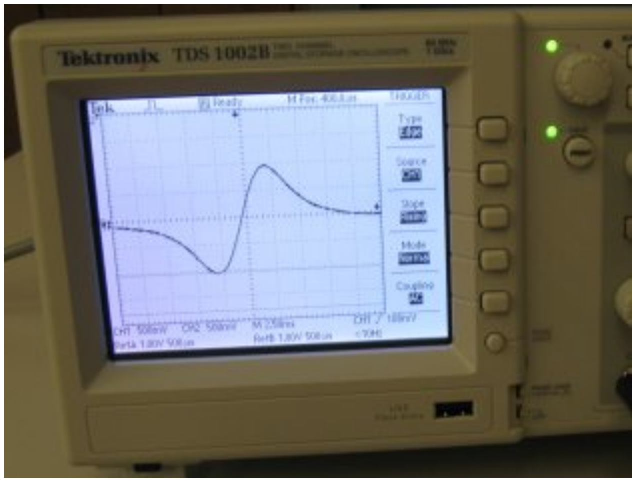
We know from lecture that a changing magnetic field will create a voltage. In this week's lab we will drop a magnet through a coil and use an oscilloscope to measure the signal.

Build your measurement rig. An arm on the top should support a string. This string goes through a strong magnet, a detecting coil, and is held in tension by a weight. This arrangement allows you to drop the magnet through the coil. It is also handy to mount a ruler so you know the height of each drop.

We'll use an oscilloscope to collect our data. Up to this point we haven't worried about triggering when we've used our oscilloscope, we've just let the machine automatically decide how to best operate. In this case we will be trying to capture single events, so we'll have to be a bit more careful with how the oscilloscope captures the signal.

Press the trigger button to bring up the proper menu. We'll want to set our options as follows:
Type - Edge
Source - CH1
Slope - Rising
Mode - Normal
Coupling - AC

Make sure you set the trigger level close to zero. If you do not do this you will have trouble capturing the induced voltage on your oscilloscope. Drop a magnet through your coil from a decent distance, you should get a signal that looks like this:



In your lab notebook, explain why the signal is shaped the way it is.

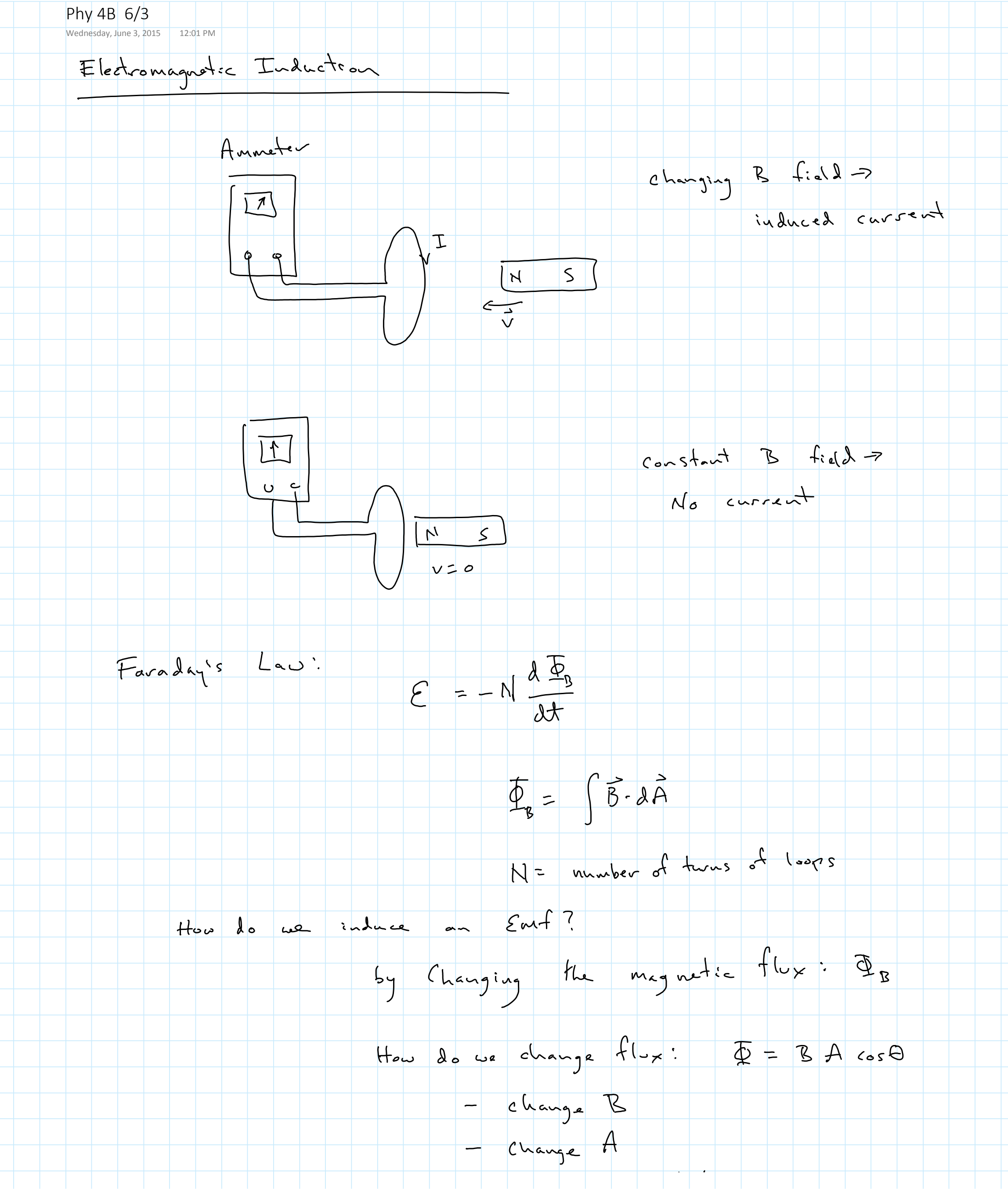
Drop your magnet from six or seven different heights, exporting your data to a memory stick as you go. Import the data into Excel, and compare the peak-to-peak voltages to the calculated velocities (remembering your kinematics might be helpful here). What do you expect? What do you see?

Once you've made sense of the height of the voltages, concentrate on the total area under the curves. If you are think about Riemann Sums, you are going down the right track. Actually, you want to sum the absolute values. This is hard to do in Excel, but you can use the command =SUMIF(B6:B2505,">0")-SUMIF(B6:B2505,"<0")
This will add up all the positive values, and then subtract off the negative values (of course, subtracting a negative is the same as adding a positive). Again, what do you expect to find? What do you actually find?

APPENDIX H

Instructor Lecture Notes From Regularly Scheduled Lectures

Students received the lectures before the experiment took place.



Phy 4B 6/3
Wednesday, June 3, 2015 12:01 PM

Electromagnetic Induction

changing B field → induced current

constant B field → No current

Faraday's Law: $\mathcal{E} = -N \frac{d\Phi_B}{dt}$

$\Phi_B = \int \vec{B} \cdot d\vec{A}$

N = number of turns of loops

How do we induce an Emf?

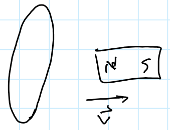
by Changing the magnetic flux: Φ_B

How do we change flux: $\Phi = B A \cos\theta$

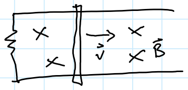
- change B
- change A

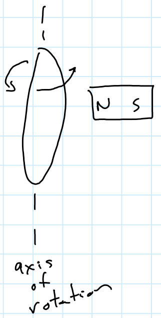
– change orientation

Change B



Change A





Workbook p.136

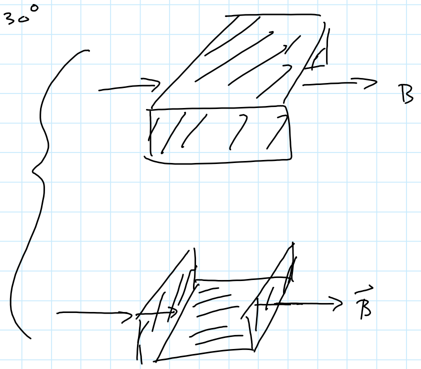
a) $\Phi = BA \cos 90^\circ = 0$

b) $\Phi = BA \cos 30^\circ = Bab \cos 30^\circ$

c) $\Phi = BA \cos 0^\circ = B \pi r^2$

d) $\Phi = 0$

either way



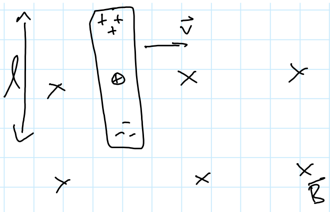
e) $\Phi = B c a$

f) like d

$\Phi = 0$

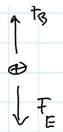
Motional EMF

× × ×



$V = E\ell$

↑ potential



$F_B = F_E$

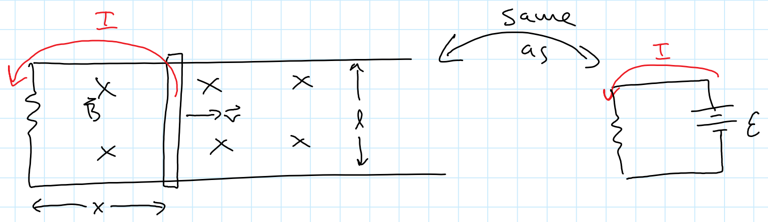
velocity

$qE = qvB$

$\frac{V}{\ell} = vB$

$V = v\ell B$

↑ potential ↑ velocity



$\underline{\mathcal{E} = v\ell B}$

OR,

Faraday's Law:

$$|\mathcal{E}| = \left|\frac{d\Phi_B}{dt}\right|$$

$$= \frac{d}{dt}\left[BA(\cos 0°)\right]$$

$$= \frac{d}{dt}(BA)$$

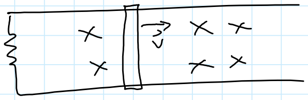
$$= B\frac{d}{dt}A$$

$$= B\frac{d}{dt}(\ell x)$$

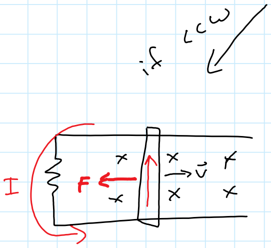
$$= B\ell\frac{dx}{dt}$$

$$= B\ell v$$

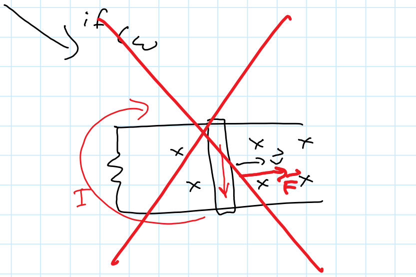
velocity



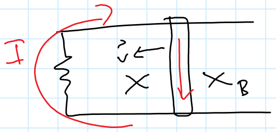
Which way does the current flow?



This is what happens



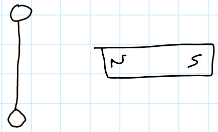
Cannot be the case due to conservation of energy



Lenz's Law: Induced current always creates a magnetic field that opposes the change in flux that created the current

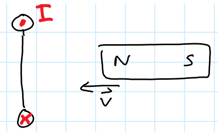
---

p.134 a)

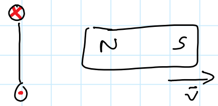


No current

b)



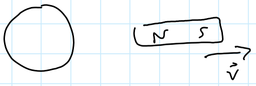
c)



d)

No current

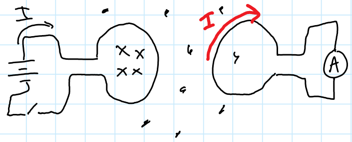
e)



No current

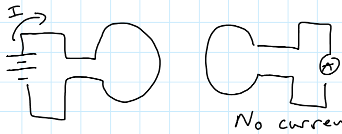
---

p.135 a)



switch is just closed

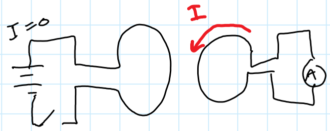
extra



switch closed for a long time

No current (if some Resistance in wires)

b)

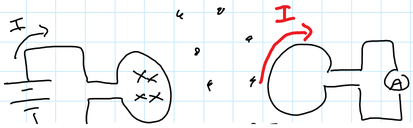


switch just opened

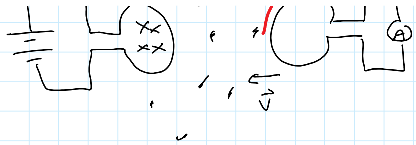
c) No induced current

d) No induced current

e)



e)



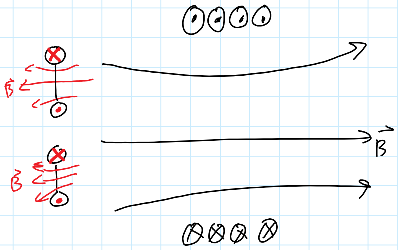
workbook p. 139

A) 1) before: No

just after: yes

long time: No

2)



3)

$$\frac{I_1}{I_2} = \frac{R_2}{R_1}$$

so, $V_1 = V_2$

B) Emf : yes

current : No

c) yes

No

p.140

D) 1) Loop 2: $\mathcal{E}_2 = 2\mathcal{E}_1$

loop 3: $\mathcal{E}_3 = \frac{1}{4}\mathcal{E}_1$

2) $R_2 = 2R_1$

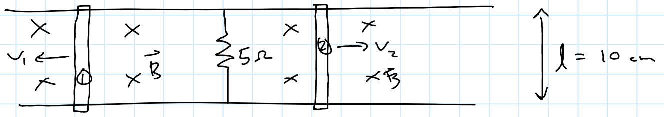
$$R_3 = \frac{1}{2} R_1$$

3) $$I_1 = \frac{\mathcal{E}_1}{R_1}$$

$$I_2 = \frac{\mathcal{E}_2}{R_2} = \frac{2\mathcal{E}_1}{2R_1} = I_1$$

$$I_3 = \frac{\mathcal{E}_3}{R_3} = \frac{\frac{1}{4}\mathcal{E}_1}{\frac{1}{2}R_1} = \frac{1}{2} I_1$$

Problem conducting rails (zero resistance)



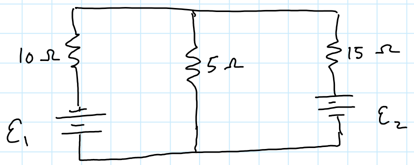
$R_1 = 10\ \Omega$ $R_2 = 15\ \Omega$

$v_1 = 4\ \frac{m}{s}$ $v_2 = 2\ \frac{m}{s}$

$B = 0.01\ T$

Find I in the 5 Ω Resister

Like this



$$|\mathcal{E}_1| = \left|\frac{d\Phi}{dt}\right|$$
$$= \frac{d}{dt}(BA)$$
$$= B\frac{d}{dt}A$$

$$\mathcal{E}_2 = Blv$$
$$= 2 \times 10^{-3}\ V$$
$$= 2\ mV$$

$= Bl v$

$= 4 \times 10^{-3}$ V

$= 4$ mV

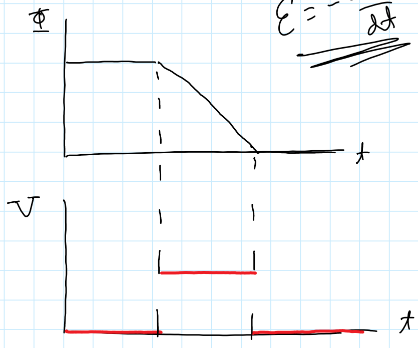
use Kirchhoffs Rules

⋮

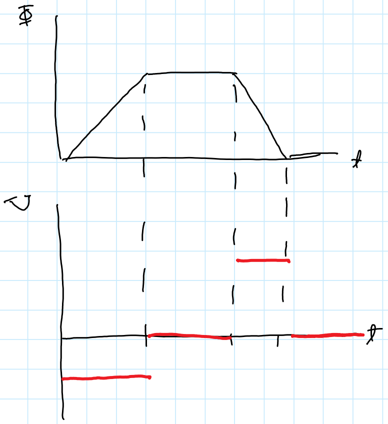
---

p. 137 a)

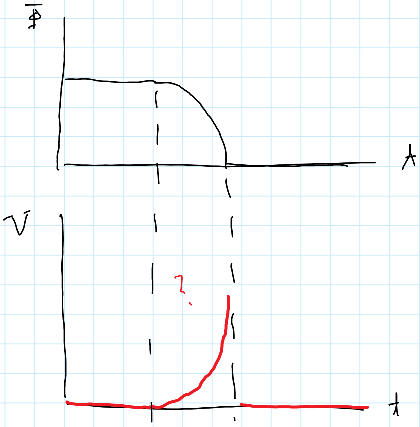
$$\mathcal{E} = -\frac{d\Phi_B}{dt}$$



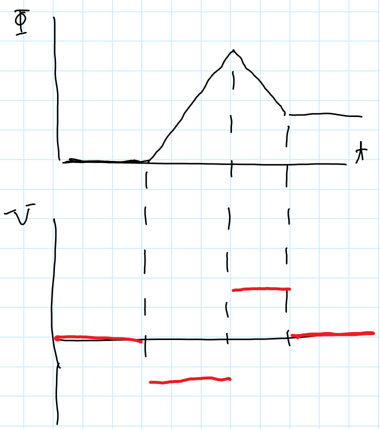
b)



c)

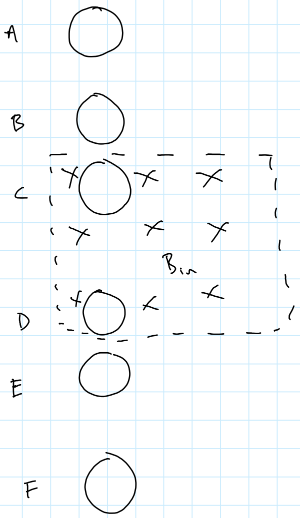


d)



Phy 4B 6/10

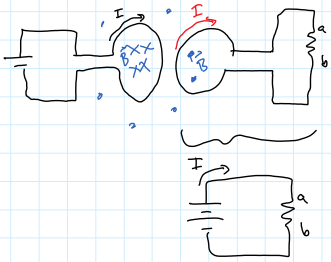
Wednesday, June 10, 2015 11:56 AM



As the loop moves From	current Induced
A → B	None
B → C	CCW ↶
C → D	None
D → E	CW ↷
E → F	None

workbook p. 138

a)

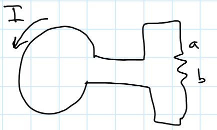


$V_a > V_b$

b) Nothing is changing

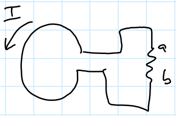
$\Delta V_{ab} = 0$ No current in circuit on Right

c)

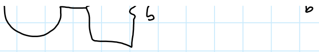


$V_b > V_a$

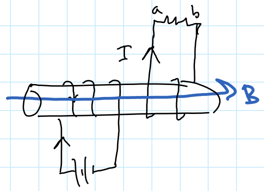
d)



$V_b > V_a$



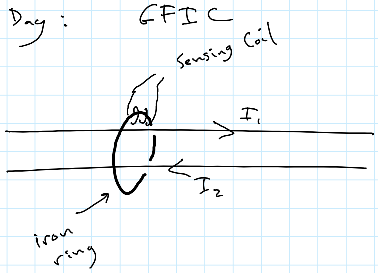
e)



$V_a > V_b$

f) No change, No current induced, $V_a = V_b$

Application of the Day: GFIC



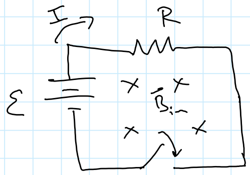
if all is well: $I_1 = I_2$

if current finds another path to ground

$I_1 > I_2$

Net Flux in Sensing coil is No longer zero

Inductance (ch 32)

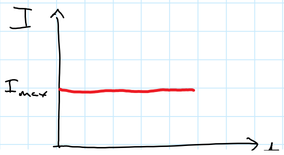


1) Close switch →
Current begins to flow

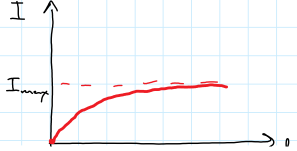
2) Current creates B field
Magnetic flux increases into page

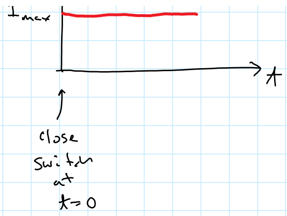
3) Increasing flux creates an Emf or current in the opposite direction
(back Emf)

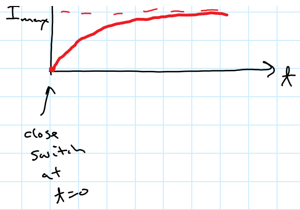
our view until now:



what actually happens:







Self-induction : same circuit causes change in flux and experiences the induced emf

$$\mathcal{E}_L = -N\frac{d\Phi_B}{dt}$$

self induction

For a solenoid:

$$\mathcal{E}_L = -N\frac{d\Phi}{dt}$$

$B = \mu_0 n I$ ideal solenoid

$\Phi_B = BA = \mu_0 n I A$

$$= -N\mu_0 n A\frac{dI}{dt}$$

$$= -N\mu_0 n A\frac{I}{I}\frac{dI}{dt}$$

$$= \underbrace{-\frac{N\Phi_B}{I}}_{L}\frac{dI}{dt}$$

inductance

$$\mathcal{E}_L = -L\frac{dI}{dt}$$

L = inductance
(depends on geometry, etc. of inductor)

units: Henry

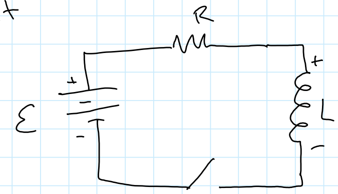
$$1\ H = 1\ \frac{Vs}{A}$$

for ideal solenoid: $L = \frac{N \Phi_B}{I}$

symbol:

inductor

RL Circuit



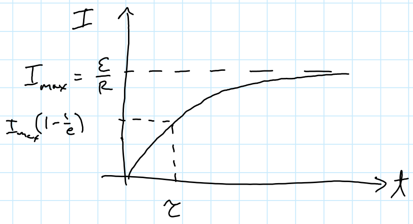
Kirchoff's Loop Rule:

$$\mathcal{E} - IR - L\frac{dI}{dt} = 0$$

$$\vdots$$

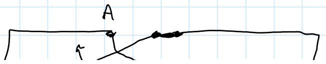
$$I = \frac{\mathcal{E}}{R}\left(1 - e^{-\frac{t}{\tau}}\right)$$

τ = time constant = $\frac{L}{R}$



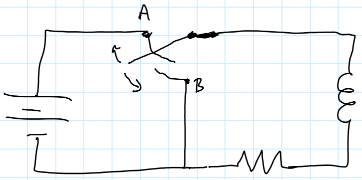
Voltage across inductor
drops to zero as
I goes to steady state

Open switch



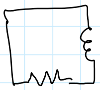
with switch at "a" :
$I \rightarrow$

open sw

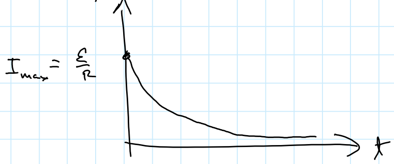


with switch at "a":

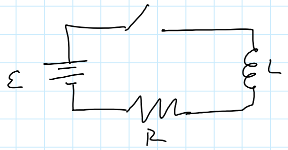
with switch at "b":



$$I = \frac{\mathcal{E}}{R} e^{-\frac{t}{\tau}}$$



Energy in the magnetic field:



Loop Rule:

$$\mathcal{E} = IR + L \frac{dI}{dt}$$

multiply by I:

$$I\mathcal{E} = I^2R + \underbrace{LI \frac{dI}{dt}}$$

Power supplied by battery

Power delivered to Resistor

Power stored in inductor

U = energy stored

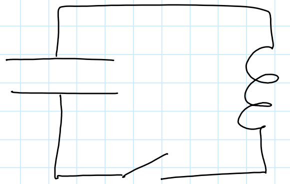
$$\frac{dU}{dt} = P = LI \frac{dI}{dt}$$

⋮

$U = \frac{1}{2} L I^2$ energy stored in inductor (in magnetic field)

$U = \frac{1}{2} C V^2$ energy stored in Capacitor (in electric field)

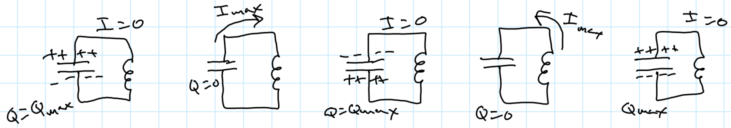
LC circuit

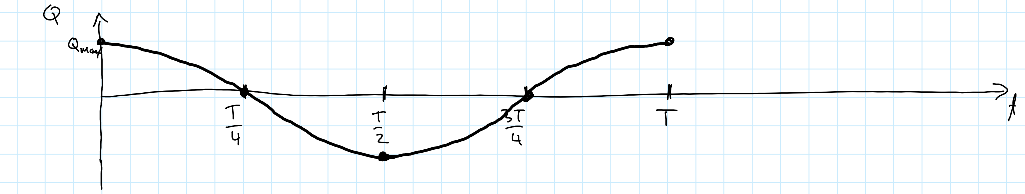


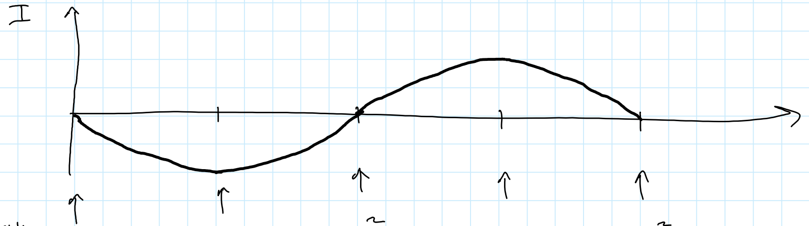
Cap. is initially charged

close switch

wires are perfect conductors (no Resistance)







Energy in Cap.:	$\frac{Q_{max}^2}{2C}$	0	$\frac{Q_{max}^2}{2C}$	0	$\frac{Q_{max}^2}{2C}$
Energy in Inductor:	0	$\frac{1}{2} L I_{max}^2$	0	$\frac{1}{2} L I_{max}^2$	0

Total energy:

$$U = U_C + U_L$$

$$= \frac{Q^2}{2C} + \frac{1}{2} L I^2$$

if No resistance

$$\frac{dU}{dt} = 0$$

$$\frac{d}{dt}\left(\frac{Q^2}{2C} + \frac{1}{2} L I^2\right) = 0$$

$$\vdots$$

$$\frac{d^2Q}{dt^2} = -\frac{1}{LC} Q$$

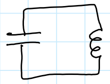
$$Q = Q_{max} \cos(\omega t + \phi)$$

$$I = \frac{dQ}{dt} = -\omega Q_{max} \sin(\omega t + \phi)$$

$$\omega = \frac{1}{\sqrt{LC}}$$ angular freq of oscillation

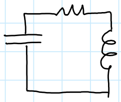
Circuit

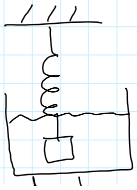
Analogy

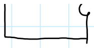


LC circuit

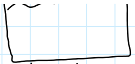
frictionless harmonic Oscillator



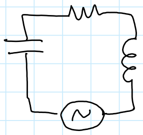




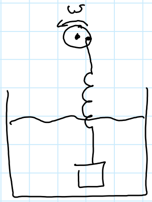
RLC circuit



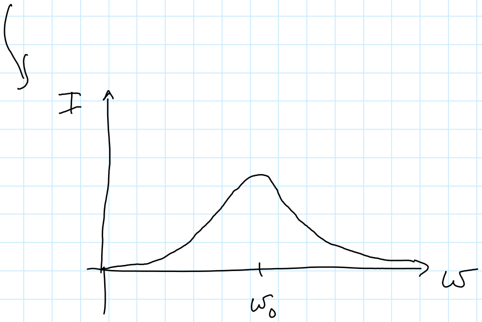
damped harmonic oscillator



Driven RLC circuit



damped, driven harmonic oscillator

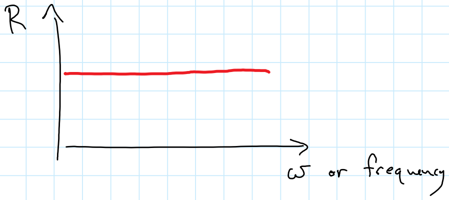


$$\omega_0 = \frac{1}{\sqrt{LC}}$$

AC circuits

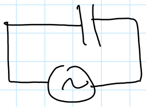
Resistors:

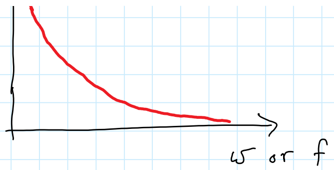
$\Delta V = V_{max} \sin \omega t$



$\omega = 2\pi f$

Capacitors:

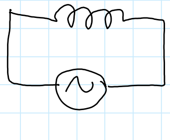


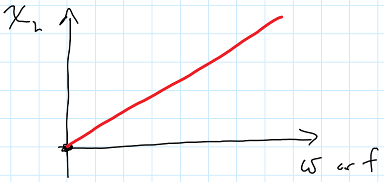


Reactance X_C (Like resistance for a cap.)

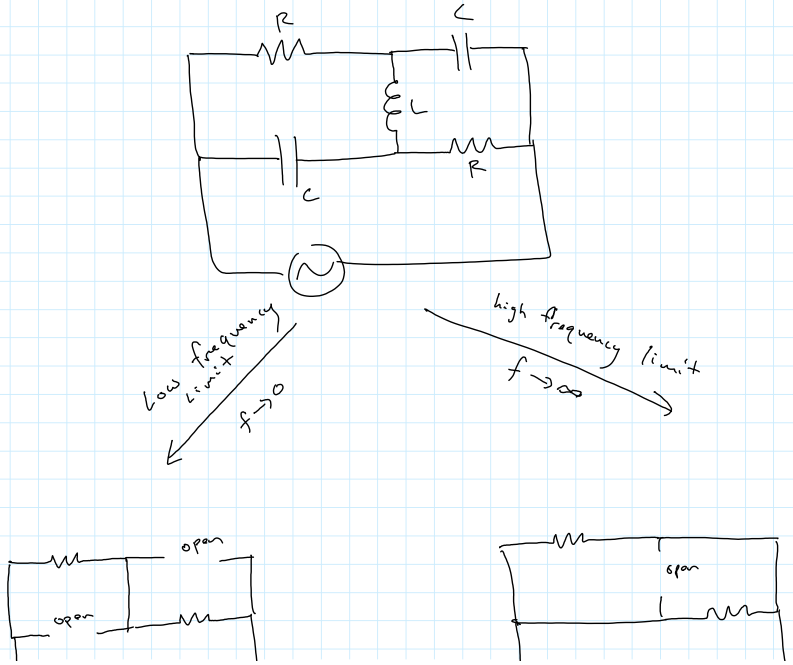
$$X_C = \frac{1}{\omega C}$$

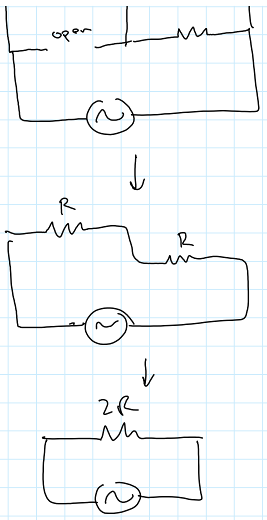
Inductor:

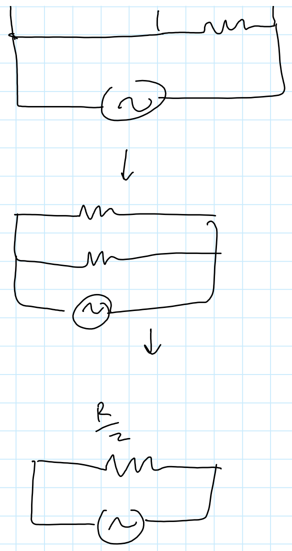




Reactance $X_L = \omega L$



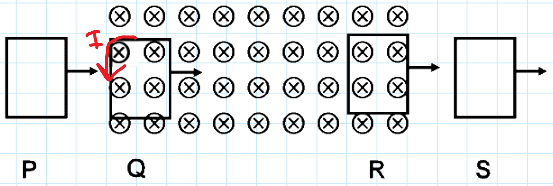

open
R
R
2R


R/2

Phy 4B 6/12

Friday, June 12, 2015 11:29 AM

Consider coil positions P, Q, R and S. A uniform magnetic field is confined to the region shown, and a loop moves to the right with a uniform speed. What happens to the magnitude of the current in the loop between positions P and Q?

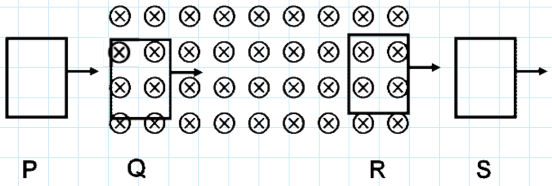


[✓ 1.] Increases
2. Stays the same
3. decreases
4. Can not say for sure

What direction?

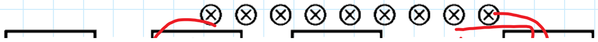
ccw ↶

Consider coil positions P, Q, R and S. A uniform magnetic field is confined to the region shown, and the loop moves to the right. What happens to the magnitude of the flux through the loop between positions Q and R?

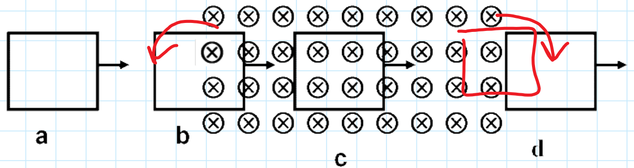


1. Increases
[✓ 2.] Stays the same
3. decreases
4. Can not say for sure

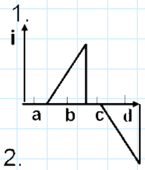
Which of the following graphs best represents the current in the loop as it moves at constant speed from position a to position d?



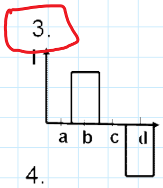
loop as it moves at constant speed from position a to position d?



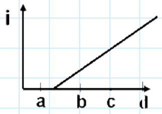
1.



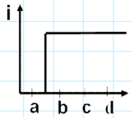
[✓ 3.]



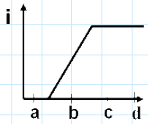
2.



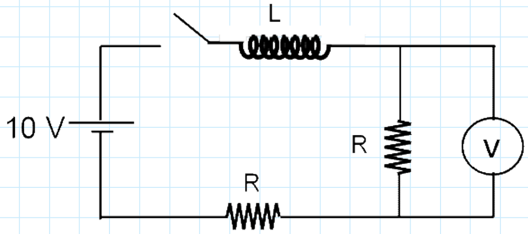
4.



5.

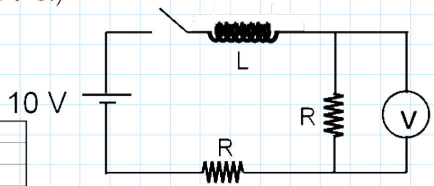


What is the value of the voltmeter ***just after*** the switch is closed? Both resistors have the same value.



[✓ 1.] 0 V
2. 3.33 V
3. 5 V
4. 10V
5. None of the above

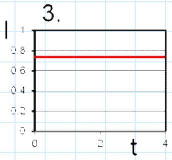
Which of the following graphs correctly shows the current passing through the resistance as a function of time? (The time when the switch is closed is defined as t=0.)



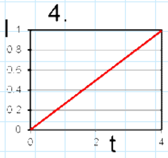
[✓ 1.]

2.

3.

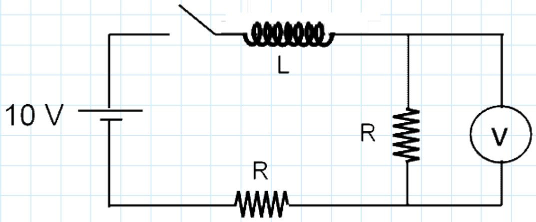


4.



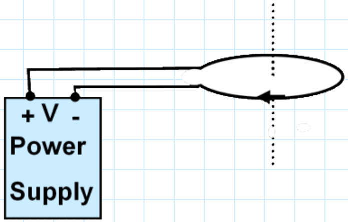
5. None of the above

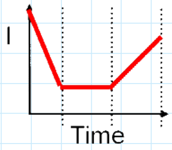
What is the value of the voltmeter reading ***a long time after*** the switch has been closed? Remember that there are ***two*** resistors with the same value.



1. 0 V
2. 3.33 V
[✓ 3.] 5 V
4. 10V
5. None of the above

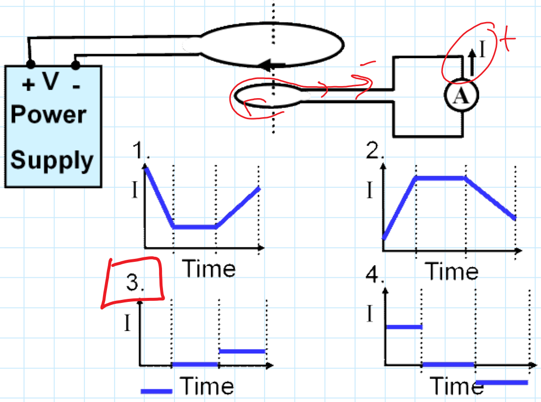
The current through the top coil varies with time as shown on the right. Which description corresponds to the graph shown?

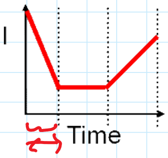




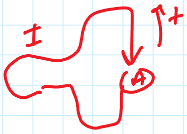
[✓ 1.] The current first decreases at a constant rate, then it stays constant, and finally increases at a constant rate.
2. The current first increases at a constant rate, then it stays constant, and finally decreases at a constant rate.
3. The current first stays constant, then it increases, and finally increases more.
4. The current first decreases, then it increases, and finally increases more.
5. None of the above.

The current through the top coil varies with time as shown on the right. Which of the following curves gives the correct current versus time in the secondary circuit on the right? Arrows show the direction of positive current in both coils.

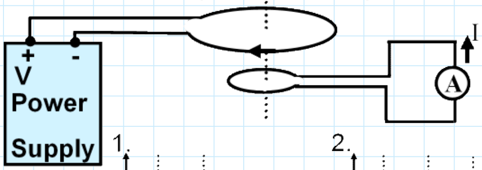


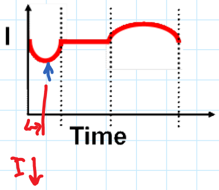


I ↓
Φ_B ↓
I

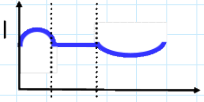


Another pattern for current versus time is shown on the right. Which of the following qualitatively shows the ***ammeter reading current*** in the secondary. It is hooked up so that it reads ***positive current*** when its top side is more positive than its bottom side.

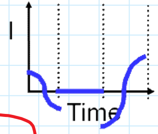




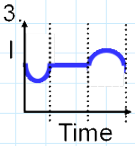
1.



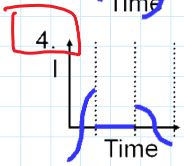
2.



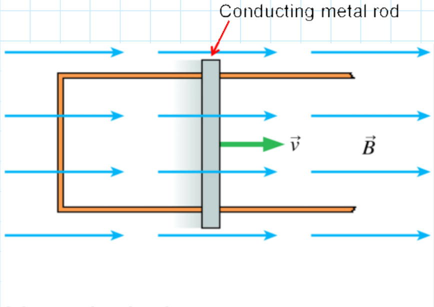
3.



4.



Is there an induced current in this circuit? If so, what is its direction?

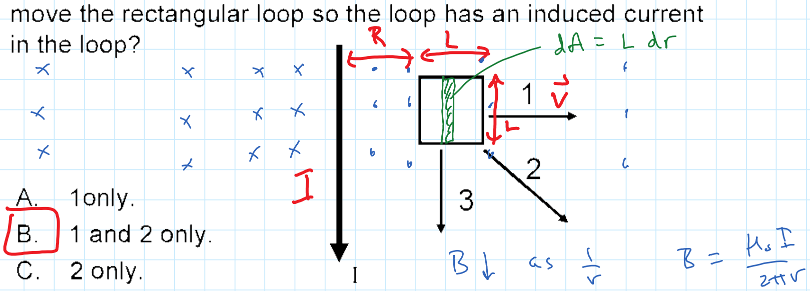


0% 1. Yes, clockwise.

0% 2. Yes, counterclockwise.

0% [✓ 3. No.]

A rectangular loop could move in three directions near a straight long wire with current I. In which direction can you move the rectangular loop so the loop has an induced current in the loop?



B ↓ as $\frac{1}{r}$

$B = \frac{\mu_0 I}{2\pi r}$

A. 1only.

[✓ B. 1 and 2 only.]

C. 2 only.

D. 1 and 3 only.

E. 2 and 3 only.

F. 1, 2, and 3.

G. None of the above.

Find ε induced in the loop in terms of I, R, L, v :

G. None of the above.

Find ℰ induced in the loop in terms of I, R, L, v :

$$|\mathcal{E}| = \left|-\frac{d\Phi_B}{dt}\right| = \frac{d}{dt}\left(\int \vec{B}\cdot d\vec{A}\right) = \frac{d}{dt}\left[\int_R^{R+L}\left(\frac{\mu_0 I}{2\pi r}\right) L\,dr\right]$$

$$\cancel{\frac{d\Phi}{dt} = \frac{d(BA)}{dA}}$$

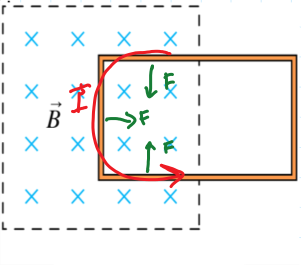
$$= \frac{d}{dt}\left[\frac{\mu_0 I L}{2\pi} \ln r \Big|_R^{R+L}\right]$$

$$= \frac{d}{dt}\left[\frac{\mu_0 I L}{2\pi}\left(\ln(R+L) - \ln R\right)\right]$$

$$= \frac{\mu_0 I L}{2\pi}\left(\frac{1}{R+L} - \frac{1}{R}\right)\frac{dR}{dt}$$

$$= \frac{\mu_0 I L}{2\pi}\left(\frac{1}{R+L} - \frac{1}{R}\right) v$$

A conducting loop is halfway into a magnetic field. Suppose the magnitude of the magnetic field begins to increase rapidly in strength. What happens to the loop?



1. The loop is pushed upward, toward the top of the page.
2. The loop is pushed downward, toward the bottom of the page.
3. The loop is pulled to the left, into the magnetic field.

[✓ 4.] The loop is pushed to the right, out of the magnetic field.

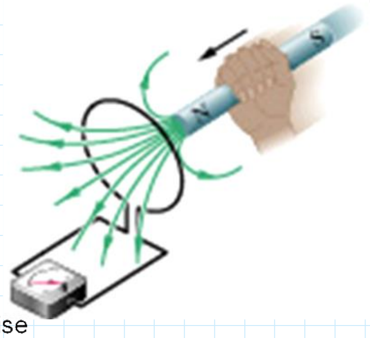
5. The tension in the wires increases, but the loop doesn't move.

Φ ↑ into page

I ↺

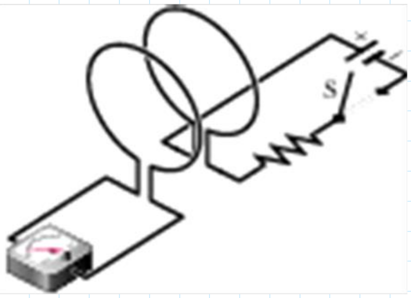
I in a B field feels a force

You move the north end of a magnet toward a loop as shown. What will be the direction of the induced current viewed from the meter side?



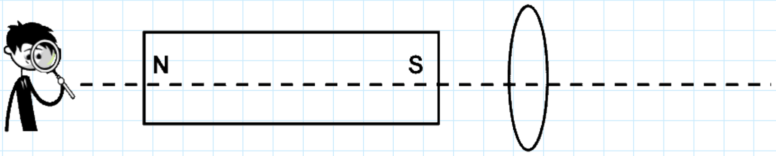
1. Clockwise
2. Counter Clockwise
3. No current

Immediately after you close the switch, what will be the direction of the induced current, again viewed from the meter side?



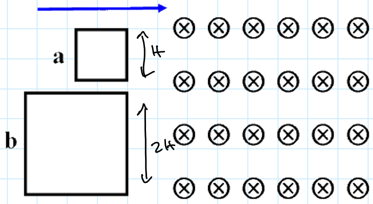
1. Clockwise
2. Counter Clockwise
3. No current

Initially, the magnet and the loop are not moving. Then, the loop starts to rotate around its center (denoted by the dotted line). The rotation is clockwise when viewed from the magnet side. What will be the direction of the induced current in the loop when viewed from the magnet side?

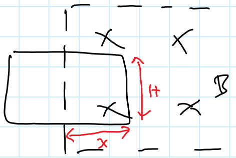


1. Clockwise
2. Counter Clockwise
3. No current

The figure shows two wire loops, with edge lengths of L and 2L, respectively. Both loops will move through a region of uniform magnetic field B at the *same constant velocity*. Rank them according to the EMF induced ***just as their front edges enter the B field region***.



1. a>b
2. a=b
[✓ 3.] a<b
4. Depends on the magnitude of their common velocity
5. Depends on the magnitude of the B field.



$$|\mathcal{E}| = \frac{d\Phi_B}{dt} = \frac{d}{dt}\int B \cdot dA$$

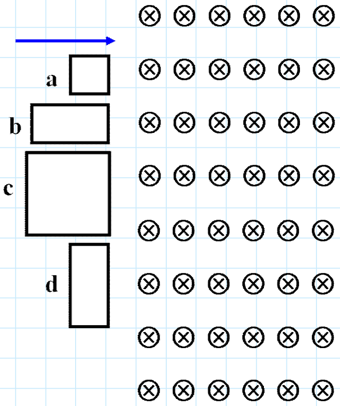
$$= \frac{d}{dt}(BA) = B\frac{dA}{dt}$$

$$= B\frac{d}{dt}(Hx)$$

$$= BH\frac{dx}{dt}$$

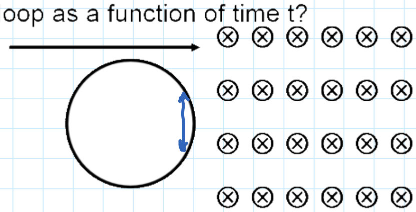
$$= BHv$$

The figure shows four wire loops, with edge lengths of either L or 2L. All four loops will move through a region of uniform magnetic field B at the same constant velocity. Rank them according to the EMF induced ***just as they enter the B field region***.

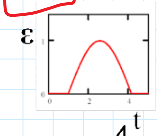


1. a<b<d<c
2. a<b=d<c
3. a<b<c<d
4. [✓ 4.] a=b<c=d
5. a=b<d<c

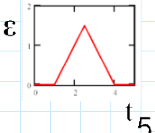
A circular wire loop moving at constant velocity enters a long region of uniform magnetic field B. Which one of the graphs describes the emf ε in the loop as a function of time t?



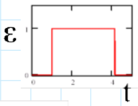
[✓ 1.]



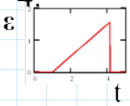
2.



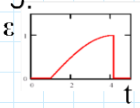
3.



4.



5.



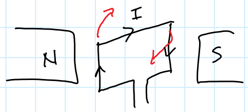
Phy 4B 6/15

Monday, June 15, 2015 12:04 PM

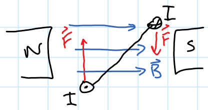
Motors + Generators
Transformers

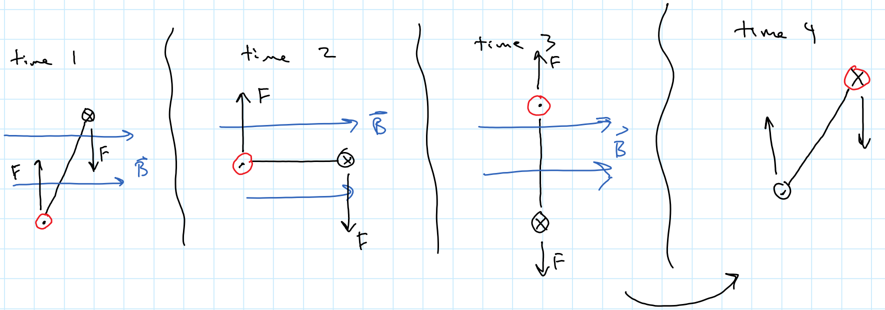
Motor

Side view



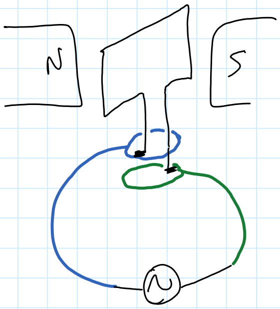
Top View



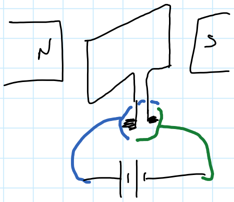


flip the current direction
to keep loop rotating in same direction

AC motor

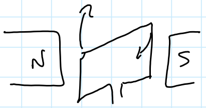


DC motor

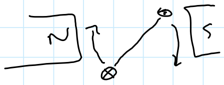


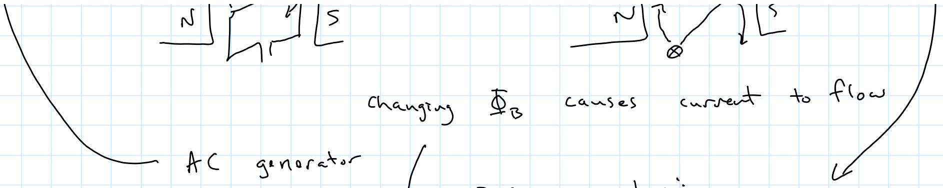
Generator:

Side view



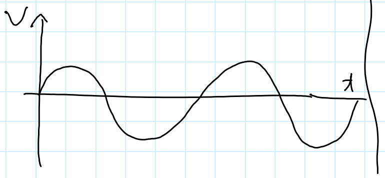
Top view



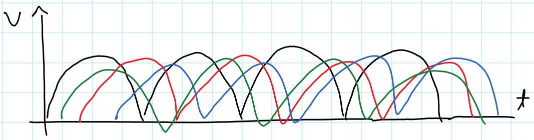


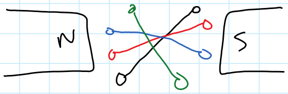
Changing Φ_B causes current to flow

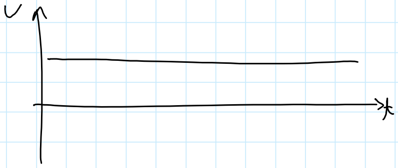
AC generator



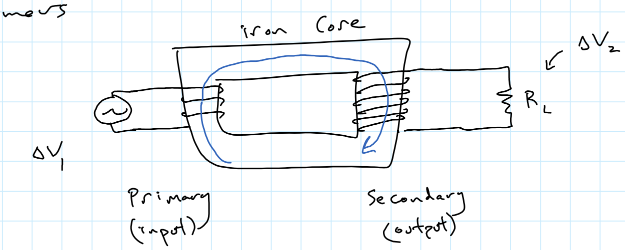
DC generator:







Transformers



N_1 = # of turns in primary

N_2 = # of " " secondary

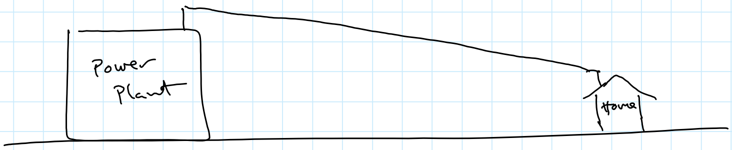
$$V_2 = \frac{N_2}{N_1} V_1$$

$P_1 = P_2$ ideal transformer

so,

$$I_2 = \frac{N_1}{N_2} I_1$$

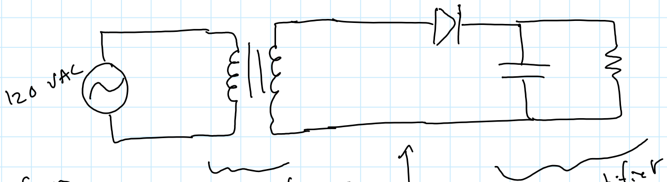
Transmission of Power



Power loss

$$P = \begin{cases} I V \\ I^2 R \\ \frac{V^2}{R} \end{cases}$$

Transmit at high voltage and low current



from wall outlet

transformer

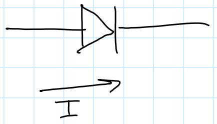
step down voltage to the battery voltage (maybe 9v) but still AC

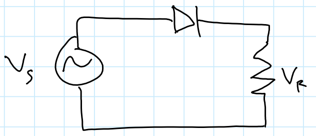
Rectifier

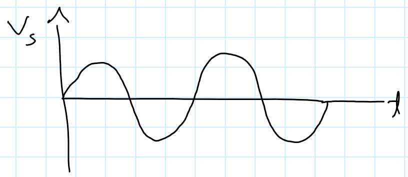
Approx. DC out at the desired voltage

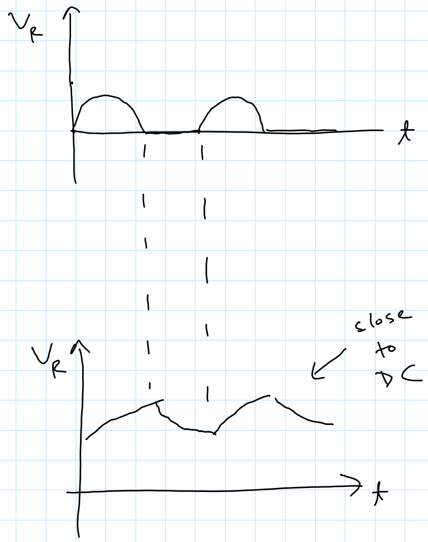
Rectifier → changes AC to DC

Diode → one way value for current flow

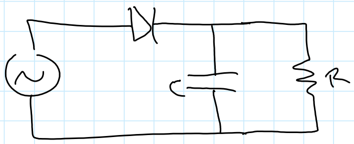


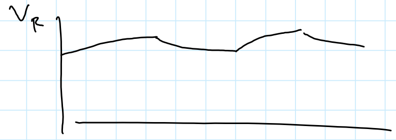


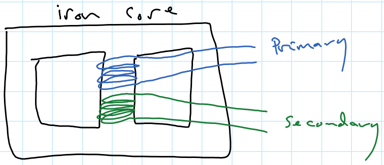


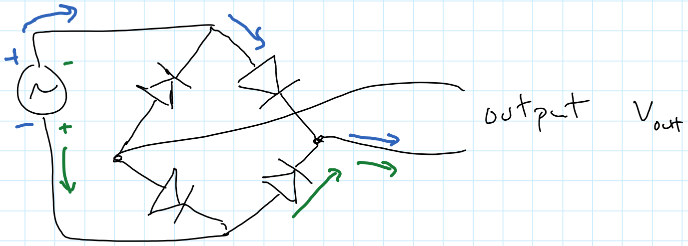


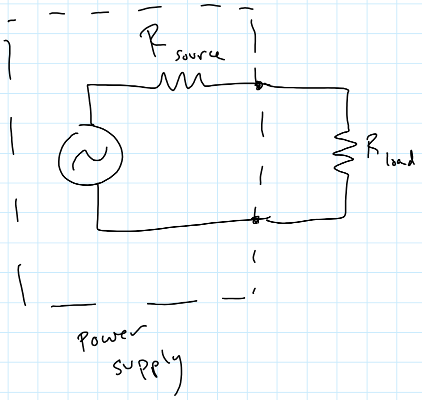
add a capacitor:









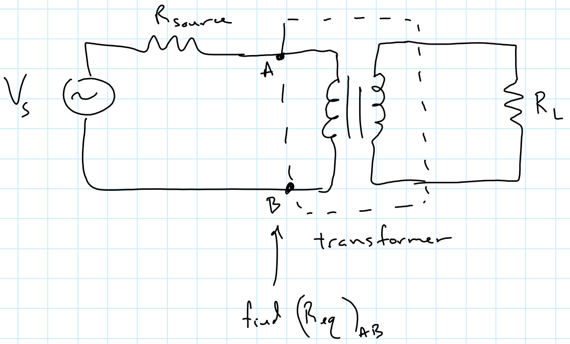


get best power delivered to R_{load} when

$$R_{load} = R_{source}$$

Called: Impedance matching

Impedance



Workbook
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t_1	B is brighter, both are on
t_2	A is brighter, B is off
t_3	Both same, both on
t_4	Both same, both on
t_5	Both off

Look at slope

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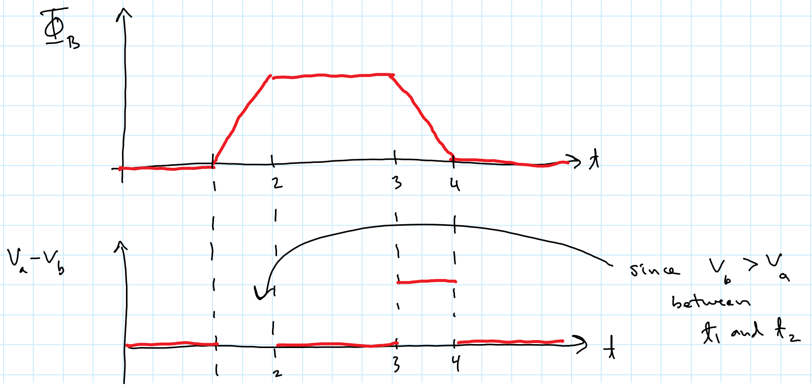

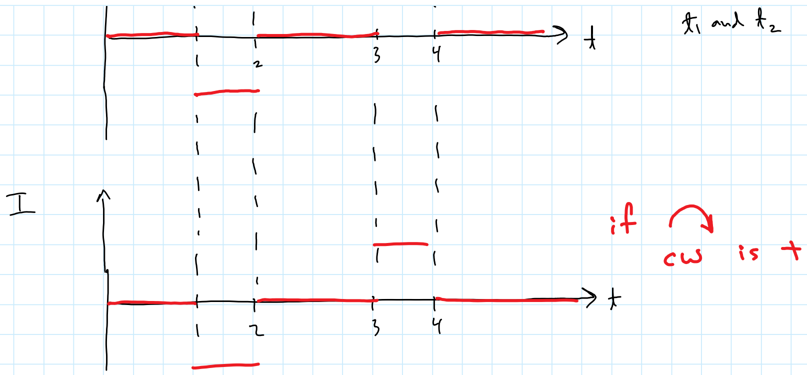
t_1 and t_2
I
t
1
2
3
4
t
1
2
3
4
if ↷ cw is +

Phy 4B 6/17

Wednesday, June 17, 2015 12:02 PM

Semiconductor Talk
and "Show and Tell"

Phy 4B summary

EM waves

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workbook
p. 144

Time interval A : a, b, c

B : d, g

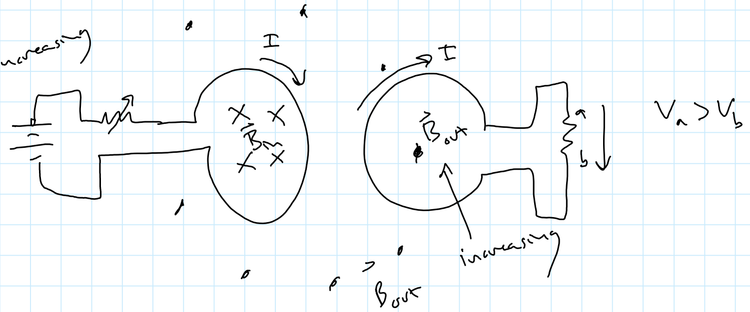
C : a, b, c

D : e, f

E : e, f

F : a, b, c

d) I increasing



Maxwell's Equations:

$$\oint \vec{E} \cdot d\vec{A} = \frac{q}{\epsilon_0}$$ Gauss's Law
→ charged particles create an electric field

$$\oint \vec{B} \cdot d\vec{A} = 0$$ Gauss's Law for magnetism

$$\oint \vec{B} \cdot d\vec{A} = 0$$

Gauss's Law for magnetism
→ there are No magnetic monopoles

$$\oint \vec{E} \cdot d\vec{s} = -\frac{d\Phi_B}{dt}$$

Faraday's Law
→ a changing magnetic field creates an electric field

$$\oint \vec{B} \cdot d\vec{s} = \mu_0 I + \mu_0 \epsilon_0 \frac{d\Phi_E}{dt}$$

Ampere - Maxwell Law
1st half → currents create magnetic fields
2nd half → changing E fields create B fields

Need one more:

$$\vec{F} = q\left(\vec{E} + \vec{v} \times \vec{B}\right)$$

Lorentz force Law
1st part: a force is exerted on a charged particle in an electric field

2nd part: a force is exerted on a moving charge in a mag. field

Classical Physics:

Phy 4A {
Newton's 1st law
" 2nd law
" 3rd law
" Law of gravitation

Phy 4B {
Gauss's law
Gauss's law for magnetism
Faraday's law
Ampere - Maxwell law
Lorentz Force law

4C { 1st law of thermodynamics

Phy 4C { 1st law of thermodynamics
2nd " " "

Maxwell & the speed of light:

$$\oint \vec{E}\cdot d\vec{s} = -\frac{d\Phi_B}{dt}$$

⋮

$$E_{max} = \underset{\substack{\uparrow \\ \text{velocity of wave}}}{v}\, B_{max}$$

$$v = \underset{\substack{\uparrow \\ \text{wavelength}}}{\lambda}\, \underset{\substack{\nwarrow \\ \text{frequency}}}{f}$$

⋮

$$E_{max} = \frac{B_{max}}{\epsilon_0 \mu_0 v}$$

so, 2 equations

$$\underbrace{E = vB \quad \text{and} \quad E = \frac{B}{\epsilon_0 \mu_0 v}}_{\text{only if}}$$

$$v = \frac{1}{\sqrt{\epsilon_0 \mu_0}} = 3\times10^8 \frac{m}{s} = c \quad \text{speed of light}$$

APPENDIX I

Cognitive Theory of Multimedia Learning (CTML) and Principles of Multimedia Learning Instructor Handout

Cognitive Theory of Multimedia Learning (CTML) and Principles of Multimedia Learning Instructor Handout

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This handout can serve as a guide for you when choosing or designing multimedia-based instructional environments or when creating your own lectures and presentations.

Table of Contents

Note. The information on this handout was adapted from the list of references at the end of this handout. For a PDF version of this handout, contact Blanca Pineda at bspineda@usfca.edu.

Cognitive Theory of Multimedia Learning (CTML)

Mayer’s Cognitive Theory of Multimedia Learning (CTML) is based on three assumptions (Mayer, 2010a; Mayer & Moreno, 2002; Mayer & Moreno, 2010b):

1. Humans process information through different channels (verbal and auditory).
2. Humans can only actively process information a few items at the time for each channel.
3. Learners must engage in cognitive processing to achieve meaningful learning.

There are three kinds of cognitive processes (Mayer & Moreno, 2010a, p. 153; 2010b, p. 133):

1. *Extraneous processing* is the type of cognitive processing that is not required in order to make sense of new information and makes no contribution to someone’s learning.
2. *Essential processing* is the type of cognitive processing that is needed to be able to select new information and is “imposed” by how difficult the learning materials are.
3. *Generative processing* is the type of cognitive processing that helps a learner organize new information in a clear structure in order to be able to integrate it to new knowledge, making a contribution to learning

Achieving meaningful learning is a complex effort given the limited capacity that learners have for cognitive processes (Mayer & Moreno, 2003). The goal of the CTML is to reduce extraneous processing, manage essential processing, and to promote generative processing (Mayer & Moreno, 2010b).

There are several principles of multimedia learning that can help meet these goals. In addition, there are several other principles specific to using computer animations and other more advanced principles. These principles can be used as a guide to help you when choosing or developing multimedia-based learning environments or lectures and presentations.

Principles of multimedia learning that can help reduce extraneous cognitive processing

These principles of multimedia learning can be used as a guide to help you develop multimedia-based instructional environments or lectures and presentations that could help learners reduce their extraneous cognitive processing.

Reference	**Principle**	**Description**
Mayer and Moreno (2002); Mayer and Moreno (2003); Mayer (2008); Mayer and Moreno (2010b); Mayer (2010c)	Coherence	Eliminate extraneous words, sounds, and pictures. Although some extraneous materials may be interesting, avoid them in order to reduce cognitive processing.
	Redundancy	Present words as narration and graphics rather than narration, on-screen text, and graphics. It is better to present just the narration of words, versus having words printed on the screen in addition to narrating the information.
	Signaling	Give cues that highlight the organization of essential material to promote better transfer of information. Providing a signal to process materials helps reduce processing of extraneous information.
	Temporal Contiguity	Present narration simultaneously with corresponding animation or words and pictures rather than successively.
	Spatial Contiguity	Place on-screen text near rather than far from corresponding pictures on pages or screens. It is important to reduce the need to scan for relevant information, placing words near graphics reduces unnecessary scanning

Principles of multimedia learning that can help manage essential cognitive processing

These principles of multimedia learning can be used as a guide to help you develop multimedia-based instructional environments or lectures and presentations that could help learners manage their essential cognitive processing.

Reference	Principle	Description
Mayer and Moreno (2003); Mayer (2008); Mayer and Moreno (2010b); Mayer (2010b); Mayer (2010c)	Segmenting	It is better to present information to allow learners control what they are learning rather than having a continuous unit. It is better to allow time between sections of information that is being presented to the learner.
	Pre-training	It is better when students have knowledge of names and characteristics of the main concepts before the formal instruction begins.
Low and Sweller (2010); Mayer and Moreno (2002); Mayer and Moreno (2003); Mayer (2008); Mayer and Moreno (2010b); Mayer (2010b); Mayer (2010c)	Modality	It is better to present information with images and narration rather than images and on-screen text. Instead of providing too much text, use an audio narration format.

Note. The same references apply to the segmenting and pre-training principles.

Principles of multimedia learning that can help promote generative cognitive processing

These principles of multimedia learning can be used as a guide to help you develop multimedia-based instructional environments or lectures and presentations that could help learners promote their generative cognitive processing.

Reference	**Principle**	**Description**
Mayer and Moreno (2002); Mayer (2008); Mayer and Moreno (2010a)	Multimedia	Use both spoken text and pictures as animations or a series of still frames. Mental connections can be better built when both words and pictures are presented rather than words or pictures alone.
Mayer and Moreno (2002); Mayer (2008); Mayer and Moreno (2010a); Mayer (2010d)	Personalization	Use words in a conversational style rather than a formal style. Increasing learner interest encourages active cognitive processing and deeper learning.
Moreno and Mayer (2007); Mayer and Moreno (2010b)	Guided activity	Students learn better when they receive guidance and interact with an instructional agent that can help them guide their cognitive processes.
Moreno and Mayer (2007); Mayer and Moreno (2010b)	Feedback	Students learn better with positive feedback.
Moreno and Mayer (2007); Mayer and Moreno (2010b)	Reflection	Students learn better when they reflect upon correct answers while they are processing meaning.

Principles of multimedia learning specific to designing computer animations

These principles of multimedia learning are specific to animations and can be used as a guide when you are designing or creating multimedia-based instructional environments or lectures and presentations that include animations.

Reference	Principle	Description
Betrancourt (2010)	Apprehension	External characteristics of the animation should be easily understood by students, features in the animation that are “cosmetic” in nature should be avoided for these do not add anything directly to student understanding. This principle is similar to the coherence principle from table 1.
Betrancourt (2010)	Congruence	Depending on the phenomenon under study, events in an animation should be presented successively in order to allow students to form efficient mental models of what they are learning. This principle is similar to the segmenting principle from table 2.
Betrancourt (2010)	Interactivity	Learners will have a better understanding of the information presented through an animation when they are given control over how fast or how slow they view the animation. This principle is similar to the segmenting principle from table 2.
Betrancourt (2010)	Attention-guiding	Because animations are dynamic in nature and change rapidly, it is important to incorporate guidance to direct students to relevant parts of the animation through signals in verbal and graphic forms.
Betrancourt (2010)	Flexibility	Takes into account that not all students have the same level of knowledge. It is important to design animations that provide clear instructions with different options on how to start the animation

Additional principles of multimedia learning

These principles of multimedia learning can be used as a guide when you are designing or creating multimedia-based instructional environments or lectures and presentations. The voice and image principles are related to social cues, which is an aspect of multimedia learning that encourages learners/instructors to be social partners and interact with a conversational and human voice style (Mayer, 2010e).

Reference	Principle	Description
Ayres and Sweller (2010)	Split-attention	Information that comes from different sources must be integrated in order for the information to be mentally understood by learners.
Mayer (2010e)	Voice	Use a friendly human voice rather than machine voice.
Mayer (2010e)	Image	Avoid putting speaker's image on screen because the speaker's image hinders learning.

Advanced principles of multimedia learning

These are eight additional advanced principles of multimedia learning that can also be used as a guide when you are creating or developing multimedia-based instructional environments or lectures and presentations.

Reference	Principle	Description
de Jong (2010)	Guided discovery	Multimedia learning environments that are discovery-based should incorporate guidance into their learning environment.
Renkl (2010)	Worked-out examples	Learners gain a deeper understanding of the materials they are learning when worked-out examples are provided at the beginning of their learning.
Jonassenm, Lee, Yang and Laffey (2010)	Collaboration	Learners perform better when online learning activities are provided.
Roy and Chi (2010)	Self-explanation	Learners engage in deeper learning when they are encouraged to provide explanations while they are learning.
Rouet and Potelle (2010)	Navigational	Learners perform better when navigation guidance is provided in "hypertext" learning environments. Hypertext is an electronic document made of multiple pages connected through links.
Shapiro (2010)	Site-map	Learners perform better when a map that shows where they are in the lesson and a map that supports their goals is provided in an online learning environment. A site map is "a graphical or linguistic representation of the organization of a hypertext" (p. 322).
Kalyuga (2010)	Prior knowledge	Principles of multimedia learning depend on the learner's prior knowledge. The same principles that may help novice learners may not help expert learners.
Paas, Van Gerven and Tabbers (2010)	Cognitive aging	Using more than one modality of instruction may be more efficient in helping older adults expand their working memory.

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