EMOTIONS ON LEARNING WITH TECHNOLOGY

by

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LIST OF ABBREVIATIONS

IBL: Inquiry-Based Learning

GBL: Game-Based Learning

CSEM: Conceptual Survey of Electricity and Magnetism

BEMA: Brief Electricity and Magnetism Assessment

ABSTRACT

Previous work has identified the many difficulties that students experience in learning abstract concepts in STEM. Past studies have also identified the critical role that emotions play on students' motivation to learn. As new learning technologies are developed, they enable visualizing complex scientific concepts which can be non-visible thus assisting students' understanding of abstract ideas as well as improving their motivation as they learn. This study investigated two learning technologies and compared them to examine 1) their effectiveness on learning concepts of electricity in physics and 2) the interplay between learning with technology and emotions. Participants were randomly assigned to either Inquiry-Based Learning (IBL) with a computer simulation or Game-Based Learning (GBL) with a computer game which addressed concepts of electricity in physics. During the experiment, students in the IBL condition explored materials by using the computer simulation and posed hypotheses and questions on their own with a guiding worksheet for IBL. Students in the GBL condition played an educational computer game following the guiding worksheet while they were meeting challenges created by the game with a guiding worksheet for GBL. Students' learning gains were assessed by comparing their pretest and posttest scores. Emotions were self-reported after the posttest by responding to a survey that measured 6 emotional scales that students may perceive during the experiment. The study found that both IBL and GBL enhanced students' understanding of given concepts. However, there was no statistically significant difference between the two conditions in terms of learning gains. Students in the IBL achieved higher mean learning gains, whereas students in the GBL showed that they were more engaged. At the same time, students in the GBL perceived more confusion and frustration compared to students in the IBL.

Keywords: Inquiry-Based Learning, Game-Based Learning, STEM, Emotions, Learning with technology

CHAPTER 1. INTRODUCTION

1.1 Introduction

Emotions always live in our minds, but their roles and importance are easily underemphasized during learning. However, as many studies have suggested, emotions play significant roles in our lives, especially in learning. During learning, emotions help us accept and recollect information, guide our decisions and judgments, and influence our attention. Also, emotions have an impact on our attitudes and feelings that in consequence, affect our motivation toward education. Research by Schutz and Pekrun (2007) suggested that achievement emotions such as enjoyment of learning, hope, anger, anxiety, or hope have critical roles by influencing motivation, learning, performance, and so forth. Bower (1992) articulated that emotions serve multiple functions in learning by directing attention and promoting adaptive action. As such, emotions can be useful to help students' academic achievement and enhance memory while learning. As emotions have become a focus of attention in education research, researchers have identified ways to characterize emotion arousals and analyze their influence on learning. For instance, Pekrun, Goetz, Frenzel, Barchfeld, and Perry (2011) reported measurement instruments (i.e., The Achievement Emotions Questionnaire: AEQ) which assesses various students' achievement emotions such as hope, pride, relief, anger, etc. in education settings. Moreover, numerous studies have shown that the use of technology for learning has positive effects on enhancing academic achievement (Linnenbrink-Garcia & Pekrun 2011; Pekrun et al., 2012; D'Mello, 2013).

As diverse ways of education methods using technology have increasingly grown, a particular emphasis for studying emotions has been placed on learning with technology. Learning with technology has become an effective learning approach for students since virtual learning environments can provide more pictures, animations, and videos compared to traditional academic settings. According to the Office of Educational Technology of the U.S. Department of Education (2017), when learning with technology is designed adequately, it can inflate the impact of its effectiveness and boost students' learning. Since it makes customized learning for individuals possible and provides higher accessibility to education, students tend to feel more confident and achievement and want to be engaged more. Chen & Wang (2011) asserted that these multi-media improved students' learning performance. Furthermore, learning with technology help not only enhancing students' learning and achievement, but also contribute to developing positive emotions for students towards education (Jeong et al., 2016). As for learning with technology, two different types of computer-based tools are commonly used: one is computer simulations and the other one is computer games. Specifically, in physics learning, students often have difficulties in understanding difficult concepts such as those in electricity. Computer simulations as well as computer games have been identified as useful tools to help students learn difficult concepts in physics such as electricity (Rutten et al., 2015; Muñoz et al., 2010). To contribute further with research on the role of computer simulations and computer games in learning difficult concepts in physics and the role of emotions in this process, this study investigates if learning with technology (i.e., computer simulations and computer games) enhances students' learning performance in physics and how two different learning conditions (IBL with a computer simulation and GBL with a computer game) elicit students' emotions. In this study, we examine the effectiveness of science learning with technology and the relationship between emotions, learning, and technology.

1.2 Significance of the Study

This study articulates the importance of emotions in learning and their relationship with learning with technology. By understanding students' emotional states through learning, this study may be the guidance on how to properly select technology that can serve better learning and emotional experiences. Understanding learners' emotions and the effectiveness of learning with technology will enhance students' motivation and positive feelings towards education. Also, it can be applied in various complex science subjects and, thus, can promote and help students' science learning and achievement. Additionally, it will assist educators with teaching with technology and assist students with effective learning with positive emotions.

1.3 Statement of Purpose

In the literature, the definitions of emotions are quite different from one another (Bower, 1992; O'Regan, 2003; Pekrun, 2014; Tyng et al., 2017). Similarly, the role of emotions has been addressed differently in previous studies (O'Regan, 2003; Tyng et al., 2017). For instance, some studies only focused on negative emotions, while others mainly investigated positive emotions in students' learning (D'Mello et al., 2014; Tyng et al., 2017). Other studies have argued that particular emotions students felt during learning had similar influences on students' learning (O'Regan, 2003; Pekrun, 2014). For example, negative emotions, such as anxiety and frustration, etc. have shown negative impacts on learning. Specifically, students would show lower performance and motivation or avoid learning under negative emotions. However, while some students took frustration as a negative obstacle, yet others considered it as a positive refresher. To provide meaningful findings, this study will assess the following: Do positive emotions have positive impacts on students' learning? Do emotions considered negatively play motivational factors in learning? Do different learning environments impact emotions and learning performance differently? And is there a relationship between experienced emotions (either positive or negative) and learning gains?

This research is expected to play an important role in understanding the roles of emotions in learning with technology, particularly in the context of Inquiry-Based Learning (IBL) and Game-Based Learning (GBL). This study also concentrates on how different pedagogies embedded in technologies can elicit different emotions. To make further steps, this research will focus on various emotions including positive and negative emotions altogether. To do so, this study may provide analysis on the interaction between emotions, learning, and pedagogies enabled by different technologies. Furthermore, it may deliver improved methodology regarding how emotions can be systematically analyzed and suggest how emotions amplify their significance on learning.

1.4 Research Questions

The study aims to answer the following questions:

- RQ1: Are there differences in students' learning of concepts of electricity in physics when practiced via IBL or GBL?
- RQ2: Are there differences in students' emotions when practicing concepts of electricity in physics with IBL or GBL?
- RQ3: Is there a relationship between students' emotions and learning gains in IBL?
- RQ4: Is there a relationship between students' emotions and learning gains in GBL?

This study mainly derived hypotheses from the Control-Value Theory of Achievement Emotions by Pekrun (2000) and numerous previous studies which are discussed in greater detail in Chapter 2. According to Pekrun (2000), various academic settings, such as IBL and GBL may elicit different emotions and, therefore, impact students' learning and achievement. Furthermore, many previous studies have identified that emotions during learning have a significant influence on students' learning performance (Bower, 1992; Graesser & D'Mello, 2012; Tyng et al., 2017). Based on these studies, it is hypothesized that there would be a mean learning gains difference between students in different learning environments, such as IBL and GBL. Also, it is predicted that there would be mean emotions differences between students in IBL and students in GBL. Lastly, it is predicted there would be significant linear relationships between emotions and learning gains of students in IBL. It is also hypothesized that emotions and learning gains of students in GBL would form a correlation.

1.5 Scope of the Study

As emotions are highly complex elements, they can have multiple definitions, which has been put forth by different researchers. Moreover, sometimes, to find the interplay between emotions, cognitive loads, and learning, cognitive processes can be considered together with emotional factors. However, this study limited its scope to the role of emotions during learning with technology. It mainly focused on emotions which students experienced that they reported, while they participated in each experimental simulation. Also, this study measured learning gains based on two different learning settings. More specifically, it assessed students' understanding of electricity-related concepts. The study was performed within an undergraduate-level physics course as a part of a regular class exercise. Students were randomly assigned to one of two different experimental settings: the Inquiry-Based Learning (IBL) condition or the Game-Based Learning (GBL) condition. This study found the relationship between students' academic achievement and their emotions by comparing learning gains and students' emotions of IBL to those of GBL. Learning gains were evidenced by the pretest and posttest assessments, and students' self-reported emotions were indicated via an emotional-scale survey. Essentially, during the experiment, this study measured students' emotions and understanding and compares one another in two different kinds of simulations.

1.6 Assumptions

The following assumptions were inherent to the design of this study:

1) Students have similar prior knowledge of concepts of electricity in physics.
2) Students respond to surveys and assessments to the best of their ability.
3) The learning experience afforded by Inquiry-Based Learning is comparable to the learning experience afforded by Game-Based Learning.
4) Students will achieve higher learning gains when learning via Inquiry-Based Learning.
5) Students will experience more positive emotions when learning via Game-Based Learning.
6) Regardless of condition, students who experience more positive emotions also achieve higher learning gains.
7) The two computer-based interventions, a computer simulation for Inquiry-Based Learning and a computer game for Game-Based Learning are comparable.
8) Students' self-reported emotions via the survey will represent their experienced emotions during learning.

1.7 Limitations

The following limitations were inherent to the design of this study:

1) This study only focuses on students' emotions during two experimental settings: IBL and GBL.
2) This study only measures students' learning gains of electricity concepts in physics such as charges and fields.
3) This study was performed within during one normal class session as a replacement for the traditional laboratory in the course.
4) The computer simulations used in this study are PhET Interactive Simulations for Science and Math (open source).

1.8 Delimitations

The following delimitations were inherent to the design of this study:

1) Although this study mentioned that there have been various definitions for each emotion, a specific, clarified definition for each emotion will not be discussed in this study.
2) Even though this study performed IBL and GBL interventions, measuring the effectiveness of both interventions will not be assessed.
3) This study will focus on the experience of students' emotions only in the academic setting.

CHAPTER 2. LITERATURE REVIEW

2.1 Emotions During Learning

Students experience diverse and numerous emotions during their learning processes. Consequently, many studies have been performed with respect to the significance of emotions in learning. The need for researchers to characterize the interplay between emotions and learning has been emphasized. Also, the role of emotions in terms of learning and memory has been underscored. Various studies have found that emotions have a meaningful impact on learning (Bower, 1992; Pekrun et al., 2002; O'Regan, 2003; Craig et al., 2004; Schutz & Pekrun 2007; Pekrun et al., 2007; Hascher, 2010; Graesser & D'Mello, 2012; D'Mello et al., 2014; Tyng et al., 2017). In other words, emotional states and learning are deeply related to each other. That said, emotions have an influence on learners' attention and motivation, which is connected to enhancing learning gains and memory (Tyng et al., 2017). According to Bower (1992), emotions have important roles that promote better learning: First, emotions direct learners' attention to the preceding or accompanying events and help them to learn important items. Second, emotions assist learners in analyzing their experiences. Third, as emotions last and disappear slowly, they encourage iteration of memory in learning.

2.1.1 Methods for Measuring Emotions

While the relationship emotions and learning have been explored, methods to measure learners' emotions also have been developed. Along with the significance of students' emotional states in learning, it is also suggested that emotions as to learning can be expressed and observed (Hascher, 2010). Simply put, assessing emotions quantitatively is possible. According to Pekrun & Bühner (2014), in 1930s, the first systematic self-report measurement was devised which measured anxiety in terms of academic emotions at the University of Chicago. After this measurement, many different self-reported scales that measure divergent students' emotions besides anxiety have been designed. For example, Pekrun et al. (2004) developed Test Emotions Questionnaire (TEQ) to measure emotions related to tests (such as hope, pride, joy, relief, anger, anxiety, shame, hopelessness) other than just anxiety. Pekrun et al. (2011) also proposed

Academic Emotions Questionnaire (AEQ) to measure students' achievement emotions in the matter of learning-related, class-related, and test-related emotions in academic settings.

To measure emotional responses among various methods for measuring emotions, self-reported methods have been widely utilized. Self-report methods are based on respondents' answers to questionnaires which ask about what type of emotions participants experienced in the past or are experiencing now. "Self-reports are flexible regarding when they can be administered (e.g., before, during, or after a learning session)" as Harley (2016) stated (p. 15). Mauss & Robinson (2009) argued that "Self-reports of emotion are likely to be more valid to the extent that they relate to currently experienced emotions" (p. 3).

Emotions can be measured in ways other than the self-report method. To investigate students' emotional states, multiple emotional measurement methods can be mixed at the same time. Tracking eye movements or studying facial expressions or body behaviors can be utilized in measuring emotions. Neuroimaging techniques can also be applied to scanning people's brains. Some examples of the neuroimaging techniques that would work in this case are Electroencephalogram (EEG), Functional Magnetic Resonance Imaging (fMRI), Positron Emission Tomography (PET), and Functional Near-Infrared Spectroscopy (fNIRS) (Tyng et al., 2017). Further, to investigate emotions, the Autonomic Nervous System (ANS) can be assessed as ANS respond to emotional changes. Methods to measure ANS consists of Skin Conductance Responses (SCRs), Heart Rate (HR), Blood Pressure (BP), Total Peripheral Resistance (TPR), Cardiac Output (CO), Pre-Ejection Period (PEP), and Heard Rate Variability (HRV) (Mauss & Robinson, 2009).

2.2 Science Learning with Technology

Online education has become one of the major education channels as around 2 million students were taking online courses from higher education institutions in the United States in 2003 (O'Regan, 2003). Thus, the impact of emotions in online learning with the uses of technology has been acknowledged. The significance of students' emotions during the new type of learning, such as e-learning or digital learning with computer simulation, video games, virtual reality, etc., rather than traditional methods, has been highlighted. As the importance of emotions in education gradually has been investigated, various ways of teaching and learning methods have been developed using technology, which includes Inquiry-Based Learning (IBL), and Game-Based Learning (GBL).

2.2.1 Inquiry-Based Learning

Inquiry-Based Learning (IBL) is one way of learning that motivates learners to engage in multiple activities, explore materials and concepts, and test their assumptions to gain new knowledge (Rutten et al., 2015). As Pedaste et al. (2015) stated, IBL "aspires to engage students in an authentic scientific discovery process" (p.48). Pedaste et al. (2015) suggested five general phases of the IBL framework through a systematic literature review which consists of Orientation, Conceptualization, Investigation, Conclusion, and Discussion. In the phase of Orientation, it stimulates learners' curiosity about a problem and learning objectives are recognized. In Conceptualization, learners pose questions or hypotheses. Next, in Investigation, learners collect and analyze data while testing their questions/hypotheses via experiments or experimental learning settings. During this phase, new knowledge is produced. In Conclusion, conclusions are drawn, and inferences are compared based on collected data. Finally, in the Discussion phase, findings are presented with peer discussions, evaluations, critiques, etc.

IBL environments can be facilitated via computer simulations. With computer simulations, students can pose questions/hypotheses, collect and analyze data by participating in activities just like an in-class IBL environment (Escalada & Zollman, 1997). Essentially, providing collaborative and visualized learning environments, computer simulations can support students' scientific reasoning and conceptual understanding in physics learning (Abdullah & Shariff, 2008).

In science learning, especially in physics, where a deep understanding of scientific concepts is required and where students are required to perform experiments as real scientists, many studies demonstrated that learners would show better academic performance with IBL compared to traditional learning methods (Bransford, Brown, & Cocking, 2000; Abdullah & Shariff, 2008). In previous studies, students who received IBL treatment, during their science learning, tended to show better academic performance and more involvement than those who participated in traditional learning settings (Abdullah & Shariff, 2008; Gormally et al., 2009; Maxwell et al., 2015, Rutten et al., 2015; Abdi, 2014; Li et al., 2010). Compared to traditional methods, IBL is not only conducive to gaining significant learning, but also effective in boosting learners' emotions, such as confidence, self-efficacy, and motivation (Gormally et al., 2009).

As computer technology has advanced, various approaches to education have been utilized and implemented. Accordingly, computer technology has become an important instrument in education. And computer-based technologies hold great promise both for increasing access to knowledge and as a means of promoting learning. Computer technology can aid student-centered inquiry activities which are a main part of IBL by increasing user interaction and providing dynamic contents, simulations, and virtual environments (Kubicek, 2005). Moreover, previous studies have shown that IBL academic settings, which are accompanied by technology, promote students' learning. Specifically, Rutten et al. (2015) discussed IBL conditions along with computer simulations in physics. This study found that the IBL method with computer simulations increased students' motivation and achievement which could lead to achieving higher learning goals (Rutten et al., 2015). Vlachopoulos & Makri (2017) stated "Simulation is directly linked to the course content and students are given the opportunity to apply and better understand theoretical concepts" (p. 15).

2.2.2 Game-Based Learning

Computer technology is utilized not only for Inquiry-Based Learning (IBL) but also in Game-Based Learning (GBL). As computer technology has grown exponentially, learning settings using game elements and virtual environments have been deployed (Shaffer et al., 2005; Cheng & Annetta, 2012; Vlachopoulos & Makri, 2017). Shaffer et al. (2005) defined GBL as "a type of game play with defined learning outcomes" (as cited in Plass et al., 2015, p. 259). In GBL, students play games that are specially designed for educational purposes (Plass et al., 2015). These educational games include not only computer-based games but also non-computer-based games such as card games, puzzles, and bingo (Plass et al., 2015; Vlachopoulos & Makri, 2017). Plass et al. (2015) specified theoretical foundations of GBL: Cognitive, Motivational, Affective, and Sociocultural. In Cognitive foundations, it is "concerned with optimizing cognitive processing in the construction of mental models and with the cognitive demand of processing the meaning of the various game elements, that is the cognitive load experienced by the learning during game play" (Plass et al., 2015, p.267). Motivational foundations focus on promoting learners' motivation for playing games which enhances their learning. During playing a game in affective foundations, it concentrates on what kind of emotional states learners experienced, how GBL has an effect on them, and how emotions are connected to "cognitive, motivational, social and cultural aspects of learning" (Plass et al., 2015, p. 270). Lastly, in Sociocultural foundation, it emphasizes learners' social and cultural interactions by playing educational games that will stimulate learning.

By playing games students are required to accomplish given goals and are guided to gain learning outcomes (Shaffer et al., 2005). Especially, Shaffer et al.'s (2005) study stated the following:

> In virtual worlds, learners experience the concrete realities that words and symbols describe. Through such experiences, across multiple contexts, learners can understand complex concepts without losing the connection between abstract ideas and the real problems they can be used to solve. In other words, the virtual worlds of games are powerful because they make it possible to develop *situated understanding*. (p. 4-5)

In the context of Shaffer et al.'s (2005) suggestions, GBL enables students to learn concepts by interacting with virtual gaming learning environments. In the GBL environment, students need to repeat playing games until they carry out given goals successfully. Accordingly, this process enhances students' learning gains by increasing students' working memory and cognitive skills (Pivec, 2009).

According to Kettelhut et al., 2006; Kebritchi et al., 2008; Mayo, 2009; McClean et al., 2001; Squire et al., 2003, specifically, playing video games "can not only yield a potential increase in positive learning experiences, anywhere from seven to forty percent, over traditional classroom methods but can also work to decrease the achievement gaps between students" (as cited in Anderson & Barnett, 2010, p. 4). GBL has become a successful learning structure which magnifies students' problem-solving skills, and academic performance (Barab et al., 2007; Bradbury et al., 2017).

In addition, GBL enhances learners' engagement and provides "affective learning environments" in science learning, which contributes to "students' scientific knowledge/concept learning" (Li & Tsai, 2013, p. 877). Many studies have argued that students would have more positive emotions during GBL. With GBL, Students tend to feel motivated engaged and satisfied, which is connected to higher learning gains (Milovanović et al. 2009; Mayer et al., 2013; Dzeng et al., 2014; Hamari et al., 2016; Vlachopoulos & Makri, 2017). It has been shown that GBL develops students' motivation in learning, not only learning outcomes (Papastergiou, 2009; Erhel & Jamet, 2013; Sung & Hwang, 2013). Further, GBL is advantageous to increasing students' motivation in terms of attention, relevance, confidence, and satisfaction along with germane cognitive loads (Woo, 2014).

Moreover, GBL has shown its effectiveness over many areas in education, even in science learning, including physics. Studies have shown that GBL can enhance students' learning outcomes in science courses where a deep understanding of complex concepts is required. Anderson & Barnett (2010) found that students had increased scores from electromagnetic concepts in physics learning by playing an educational video game named *Supercharged!*. Students not only gained better learning achievement but also their motivation and self-efficacy improved positively in science courses with a collaborative game-based learning setting (Sung & Hwang, 2013).

2.3 Students' Learning Difficulties and Misconceptions in Electricity Concepts

Electricity is one of the basic concepts in physics learning (Duit & Von Rhöneck, 1997). However, according to Nguyen & Rebello (2011), students tend to have difficulties in electricity concepts (where dynamic integration between mathematics and physics is required) when solving a problem as such concepts are calculus-based (Nguyen & Rebello, 2011; Maloney et al., 2001). Additionally, some students may develop misconceptions, which is not uncommon, when understanding electricity concepts, and it obstructs students' learning (Andre & Ding, 1991; Bagno & Eylon, 1997; Dede et al., 1999; Bilal & Erol, 2009; Anderson & Barnett, 2010). Maloney et al. (2001) designed a survey scale called "Conceptual Survey of Electricity and Magnetism ("CSEM") to test students' conceptual understanding of electricity and magnetism. In this study, students were found to struggle in difficulties in learning electricity-related concepts (such as Coulomb's law, force and field superposition, force, field, & electric potential, magnetic force). Students' learning difficulties and misconceptions in electricity concepts are partly because students often fail to "interpret the physical meaning of the symbols and invoke basic mathematical equations" when solving physics problems in terms of electricity (Nguyen & Rebello, 2011, p. 10). Also, it is due to confusion between its related concepts and terms. For example, some students are not able to differentiate between electric field, force and charge (Li & Singh, 2017).

Researchers have tried to address this issue with various approaches. For example, Ronen & Eliahu (1997) suggested that qualitative computer simulation-based activities to tackle students' difficulties in electricity learning. Squire et al. (2004) found that 3D simulation computer GBL was advantageous in helping students understanding complex physics concepts, especially in electrostatics. Afra et al. (2009) and Korganci et al. (2015) indicated that students with misconceptions in electricity knowledge showed better conceptual understanding after participating in implemented IBL.

2.4 Theoretical Framework

2.4.1 Emotions and Achievement

While multiple approaches to articulate the role of emotions in learning have been suggested, Pekrun (2000) proposed the Control-Value theory of Achievement Emotions in order to provide an integrative framework to better understand emotions tied to achievement activities or achievement outcomes (achievement emotions). The theory addresses four dimensions (Environment, Appraisal, Emotion, and Learning and Achievement) that are linked to one another. First, Appraisal assesses cognitive appraisals such as Control and Values that induce achievement emotions. Control appraisals are students' subjective expectations of achievement activities and their outcomes. Value appraisals are perceived values that individuals expect over such activities and outcomes. Emotion appraises achievement emotions that include activity emotions and outcome emotions. Activity emotions are emotions that are experienced by individuals during academic achievement activities (e.g., enjoyment or boredom during a lecture). Outcome emotions are elicited by academic achievement outcomes such as when receiving a poor grade is followed by anger. Environment can be regarded as academic settings or a climate of learning that impacts learners' achievement emotions and outcomes along with appraisals. Lastly, Learning and Achievement is related to academic outcomes such as success at learning or using cognitive resources or learning strategies. Learning and achievement can be affected by emotions (either positive or negative) and vice and versa. These four dimensions influence each other and are not mutually exclusive (Pekrun et al., 2007). Figure 2.1 depicts the four dimensions of the Control-Value theory of Achievement Emotions. The figure also shows the relationship between the four dimensions.

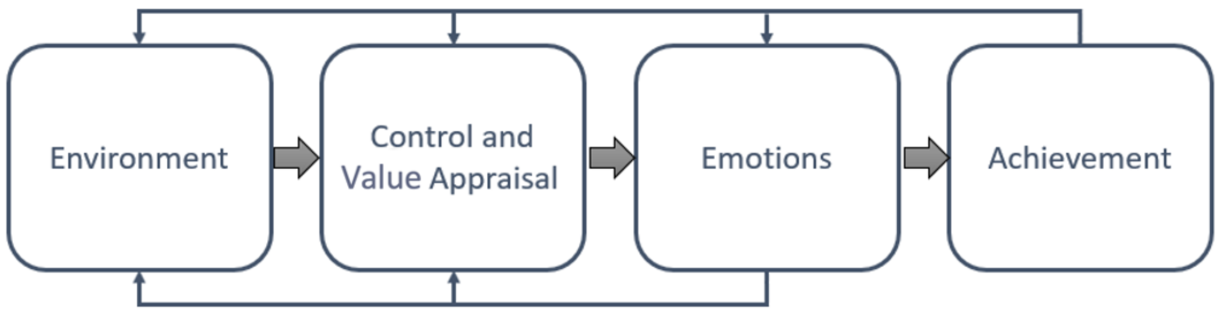


Figure 2.1 *Dimensions of the Control-Value Theory of Achievement Emotions*

Overall, the theory indicates that "students' emotions can be positively influenced by fostering their perceptions of competence and control over academic activities and outcomes, and by shaping their appraisals of the values of these activities and outcomes" (Pekrun et al., 2007, p. 334). Therefore, achievement emotions would play an important and positive role in a student's learning.

While emotions concerning learning have been studied, a great deal of studies that have investigated emotions and learning mainly focused on the effects of negative emotions (e.g., anxiety and stress) on learning. However, both positive and negative emotions are found to be essential for students' learning. Some studies have put importance on positive achievement-related emotions in learning, such as hope and pride (Pekrun et al., 2002). According to Pekrun et al. (2002), positive emotions sometimes affected students more frequently than negative emotions. Furthermore, emotions are carried differently depending on individuals in the same academic setting. Usually, negative emotions such as frustration and anxiety are considered to have a disadvantageous effect on students' learning. However, negative emotions also play a positive role in students' learning (Pekrun, 2006). For instance, when some students experience negative emotions (e.g., frustration and stress) in their learning, they consider those emotions beneficial as they help students challenge themselves, while other students take them as overwhelming (O'Regan, 2003).

2.4.2 Implications of the Theoretical Framework to the Study

This study presents an experiment that investigated the interplay between learners' emotions and learning with technology based on the Control-Value theory of Achievement Emotions by Pekrun (2000). First, in the Environment, the study set up two different academic settings (experimental conditions): one condition was Inquiry-Based Learning (IBL) setting via computer simulations, and the other condition was Game-Based Learning (GBL) design via computer games. As for the Emotion, the study will look into activity emotions (such as enjoyment and excitement) and outcome emotions which include anxiety. Lastly, in the Learning and Achievement, it assesses learning gains which are students' understanding of concepts of electricity in physics after the experiment. Figure 2.2. presents the adaptation of the Control-Value theory of Achievement Emotions. For this study, the goal was to investigate how achievements and emotions were mediated by the learning Environment, either IBL or GBL. A simplified version of the Control-Value theory of Achievement Emotions framework was adapted for this study (see Figure 2.2). In this context, students' experienced emotions during a specific task would relate to the Emotions. Similarly, under this framework, students' learning gains would relate to the Achievement.

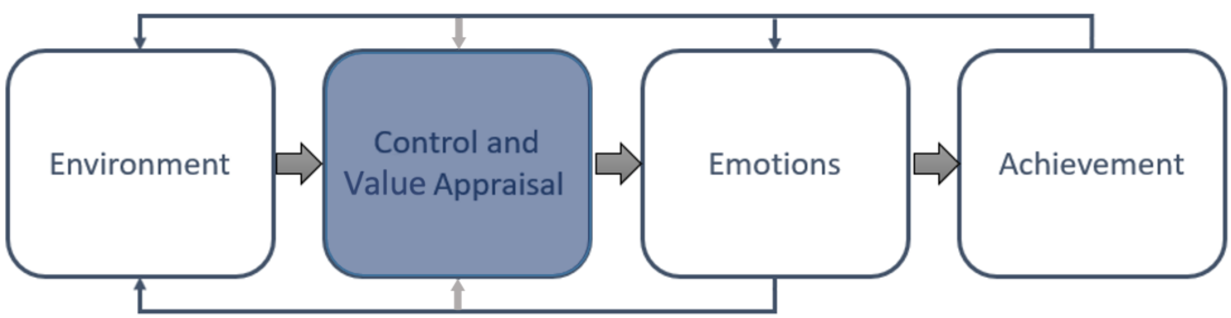


Figure 2.2. *Adaptation of the Control-Value Theory of Achievement Emotions for the study*

CHAPTER 3. METHODS

3.1 Learning Design

This study followed a true-experimental two-group pretest and posttest study design. Outcomes between two groups (IBL and GBL) were compared at the end of the experiment. Two types of experiments were conducted in both learning conditions. As for experiments, this study used programs from PhET Interactive Simulations for Science and Math programs ("PhET", n.d.) that were created at the University of Colorado Boulder. PhET provides open-source simulations and game environments which can be run online. And this study used two programs that were designed for learning concepts of electricity in physics for each condition. During both experimental conditions, students were expected to learn concepts about electricity in physics and run into diverse emotions.

3.1.1 Inquiry-Based Learning Condition

In the IBL condition, students were required to be engaged in posing hypotheses and executing the simulations to confirm or disconfirm their hypothesis on their own, while they were exploring the "Charges and Fields" computer simulation from PhET. At the same time, students were guided by designed worksheets for the IBL. Students were asked to interact with the simulation program (Charges and Fields), pose and test different scenarios, answer reflection questions that were provided through the guiding worksheet for IBL condition. When playing the simulation, students needed to place positive and negative charges in virtual space: electric field and electrostatic potential (voltage) were created accordingly (as Figure 3.1). By playing the simulation, students were expected to understand the variables that had influences on electric charges, electric fields, and electrostatic potential in IBL condition. Also, it was supposed that students would experience different emotions.

3.1.2 Game-Based Learning Condition

In GBL condition, students played a PhET computer game named "Electric Field Hockey" with the guiding worksheets. Students were required to play a hockey game and accomplish an objective by applying their knowledge about electricity (especially, electric charges and fields concepts). As similar to the Charges and Fields simulation that was used in IBL, students needed to place charges on a virtual ice hockey field. In Electric Field Hockey game, once positive and/or negative charges are placed, a puck starts to move. And when a puck gets into a goal, the objective is achieved. Students were required to play the game until they carried out given goals for each difficulty level. There were three different difficulty levels in this game, and students were asked to start with the easiest level then the hardest one. Figure 3.2 is a demonstration of the hardest level of the game. By playing Electric Field Hockey game via PhET, students were expected to learn physical electricity concepts and to feel various emotions.

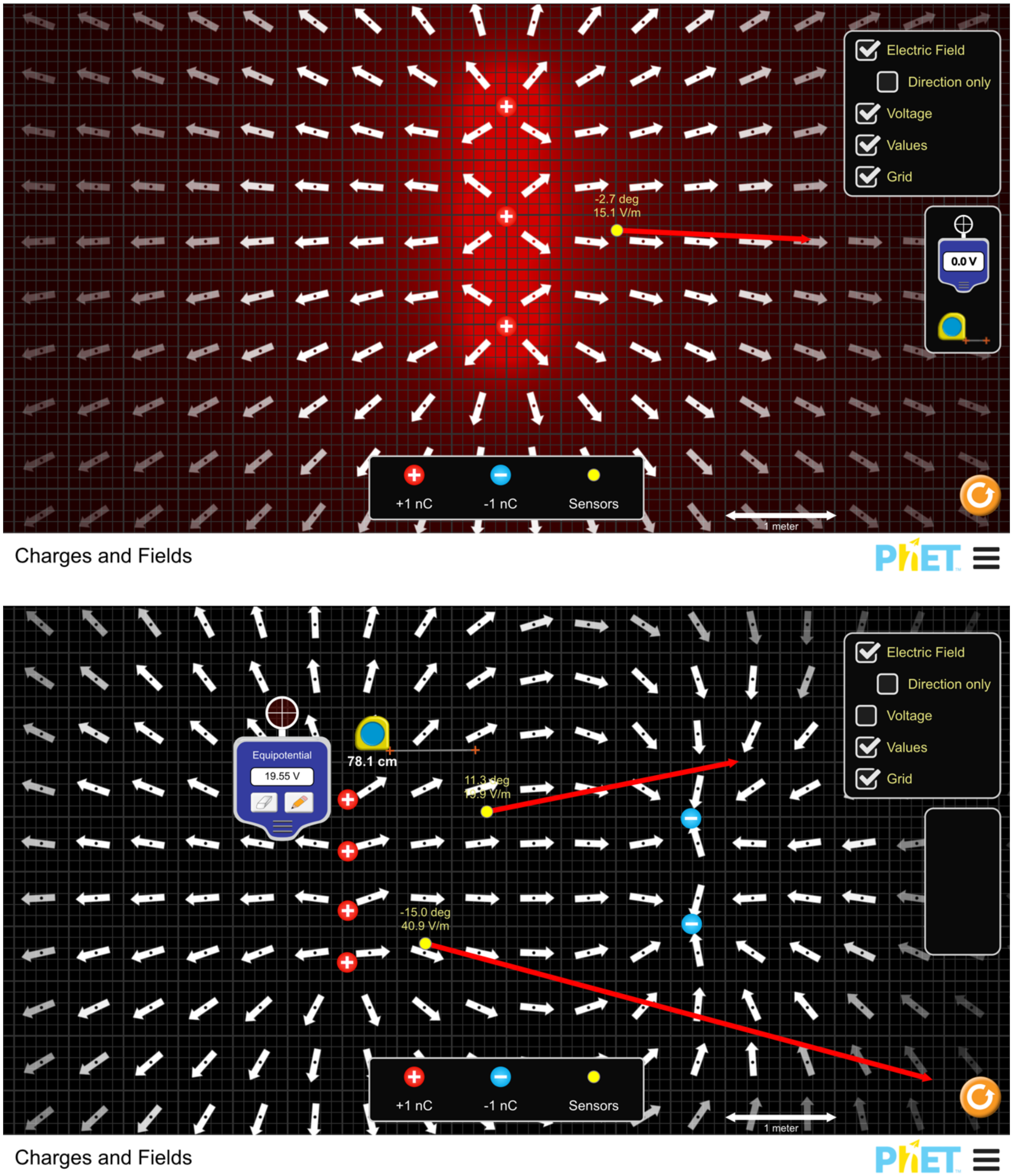


Figure 3.1 *Examples of Charges and Fields simulation from PhET, from https://phet.colorado.edu/en/simulation/charges-and-fields. Screenshot by author.*

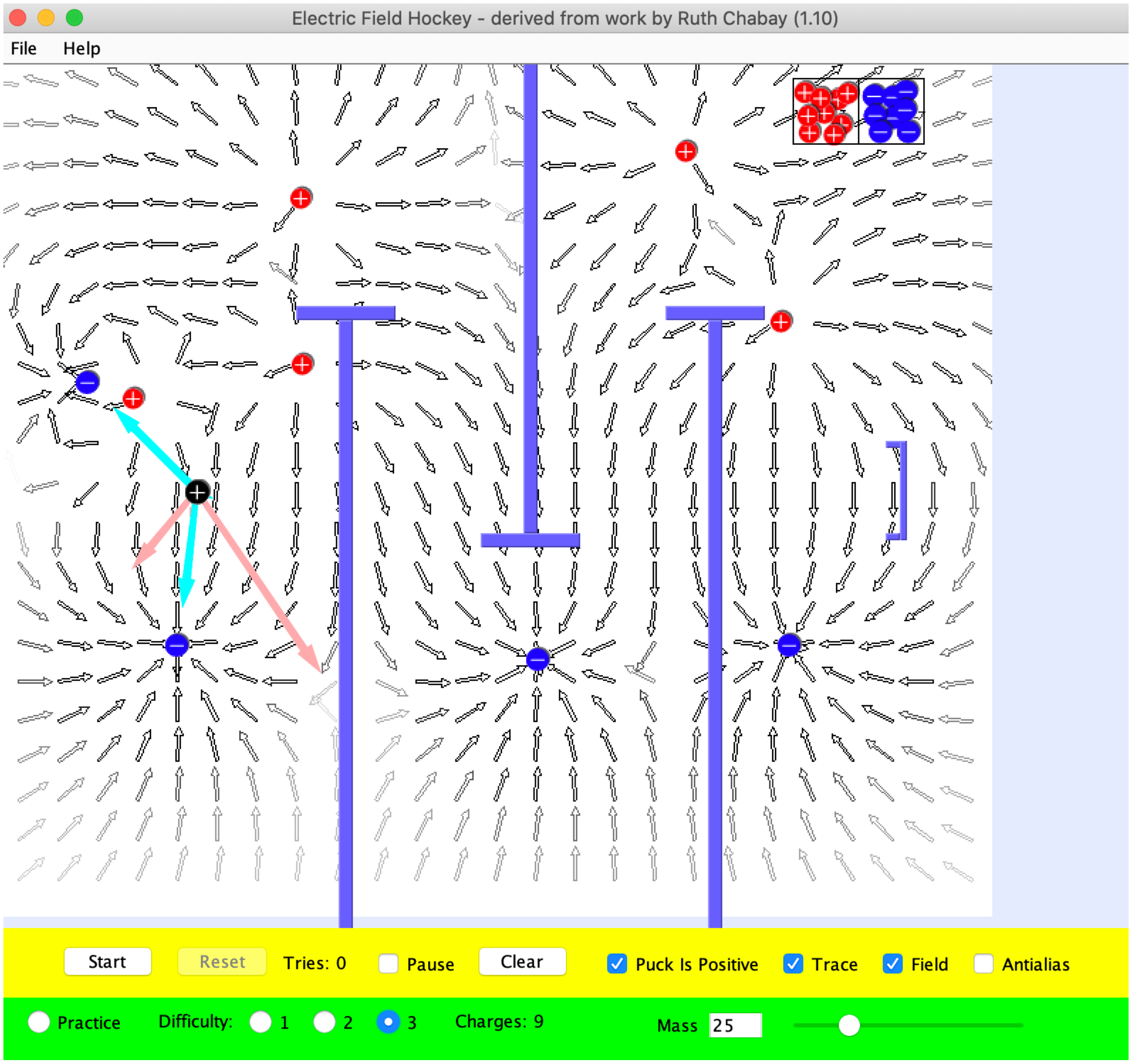


Figure 3.2. *Examples of Electric Field Hockey game from PhET, from https://phet.colorado.edu/en/simulation/legacy/electric-hockey. Screenshot by author.*

3.2 Participants and Context

The participants in this study were 46 students from a physics course for elementary education class (PHYS 21500, Physics for Elementary Education) at Purdue University. The learning objective of the course was studying physics concepts in order to teach courses in elementary school students' level (grades K-6). The study was conducted as a part of the normal class sessions during the Week 6 of the Spring 2020 semester. Data was collected on February 18th, 2020. Students were randomly assigned to one of two experimental condition groups, IBL or GBL. About 97% of the students (44 out of 45 students, one is missing) were female in this course. About 17% (8 out of 45 students, one is missing) of the students were first-generation college students. About 42% (19 out of 45 students, one is missing) of the students took physics courses in high school.

3.3 Procedures and Data Collection Method

Before the intervention starts, every participant took one pretest survey. One, same pretest survey was given to every student in both groups. During the experiment, students in both conditions (IBL and GBL) played one of the PhET programs with the guiding worksheets that were designed for each condition. After the experiment, students were asked to participate in a posttest survey. In the posttest survey, two types of questions were provided. One type included concepts of electricity in physics questions which measured students' learning gains. On the other hand, the other type of questions was to measure students' emotions during their learning. All surveys including the pretest and posttest were taken via a web-based survey software named Qualtrics.

3.3.1 Guiding Worksheets

During the experiment, students in both IBL and GBL conditions were guided to follow instructions which were provided via designed worksheets in the form of learning materials (See Figures 3.3, 3.4, and 3.5). On the PhET website, teaching materials related to each simulation are shared by instructors from different institutions, and this study adapted these materials into two different guiding worksheets, one was for IBL and the other one was for GBL. Worksheets were constructed to serve two purposes in this study. First, it provided step-by-step instructions for students so that they could get familiar and interact with each PhET program. Another goal of these worksheets was to check students' in-between conceptual understanding in the midst of the experiment by asking reflection questions. However, there was a difference between the worksheet for the IBL condition and the one for the GBL condition. Worksheet for IBL primarily provided guidance in accordance with the Inquiry-Based learning pedagogy by participation in experiments. On the other hand, the worksheet for GBL gave guidance in accordance with Game-Based learning pedagogy by asking students to achieve given goals.

➢ At the bottom click the radio button for **difficulty** set to **3**.
➢ Place various charges in different locations so that when you press start the puck reaches the goal.

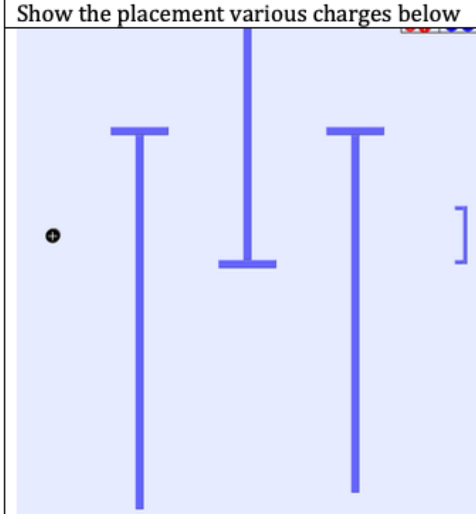
Show the placement various charges below	• Briefly explain your strategy.
	• Did you have to modify your strategy from Level 2? Were you able to use all the same charges or did you have to use different types of charges?

Figure 3.3 *A sample of guiding worksheet for GBL condition with instructions*

__Practicing__ Click on the **Practice** radio button at the bottom to be in the Practice mode.
The goal of this game is to get the black positive puck to go in the goal.

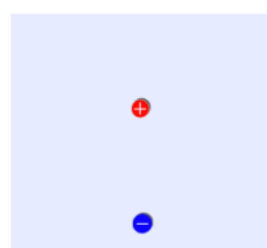
➢ To play, click and drag the blue or red charges down onto the "table". Start with a single red or blue charge and place it in the vicinity of the puck so that when you click **Start** at the bottom the puck moves.

- Suppose the puck were placed as below. Where can you put a single **positive** charge to score a goal? Show the location on the figure below.

  - What happens when you put a **positive** charge near the hockey puck?
  - Based on your experiment above, complete the following sentence: A **positive** and **positive** charge will _____________ (attract/repel/do nothing to) each other

- Suppose the puck were placed as below. Where can you put a single **negative** charge to score a goal? Show the location on the figure below.

  - What happens when you put a **negative** charge near the hockey puck?



  - Based on your experiment above, complete the following sentence: A **positive** and **negative** charge will _____________ (attract/repel/do nothing to) each other.

➢ What happens when you change the mass of the puck?

Figure 3.4 *A sample of guiding worksheet for GBL condition with reflection questions*

Electric Field box and **CLICK** the Grid box.

- PLACE one positive charge (+1 nC) from the bottom of the screen on the left side as shown below.
- **CLICK** the **Values** box on the right side of the screen.
- **SELECT** a **sensor** from the bottom and **PLACE** it onto the screen to find the strength of the electric field. For example, the figure below, the strength of the electric field is 17.2 V/m.
- Use the tape measure to find the distance between the charge and the sensor as shown below. For example, in the figure below the distance between the charge and the sensor is 73.1cm.
- **PLACE** the equipotential sensor on the center of the sensor as shown in the figure below, and it will measure the electric potential (voltage) of the place where the sensor has been placed. For example, in the figure below, the voltage is 12.55 V.
- **MOVE** the sensor around the charge (left to right of the charge, top to bottom of the charge, and closer or farther to the charge).

- As you move the sensor around the charge, how does the ***direction*** of the arrow change?

- As you move the sensor around the charge, how does the ***length*** of the arrow change?

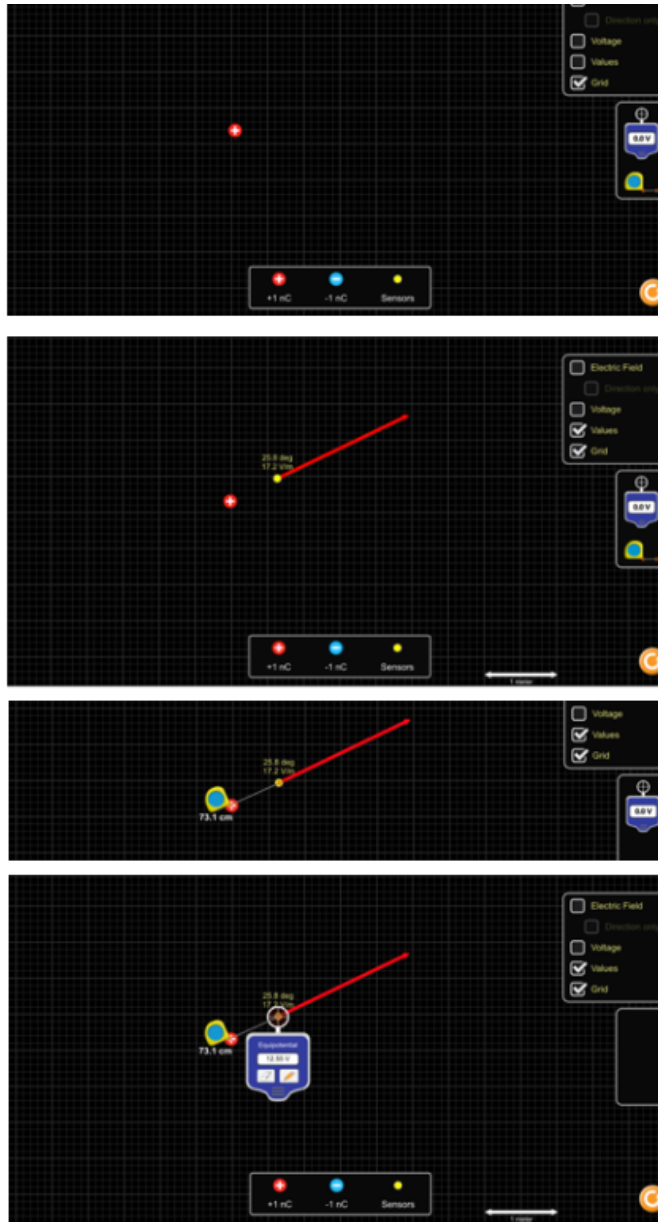


Figure 3.5 *A sample of guiding worksheet for IBL condition with reflection questions*

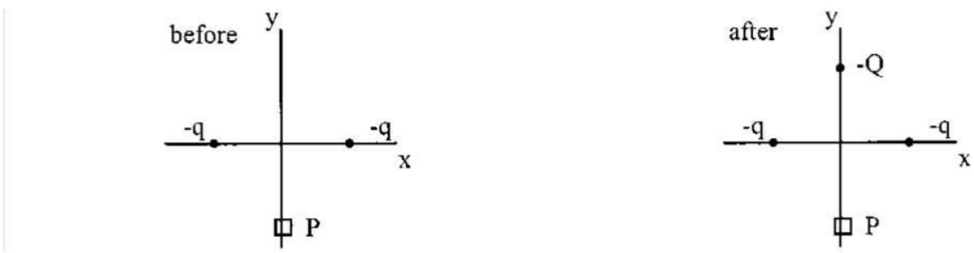
3.3.2 Pretest and Posttest

Along with guiding worksheets, this study used a pretest and posttest in the form of a survey. Before students participated in the experiment, they had to take a survey as a pretest. And after the experiment, students were required to answer the posttest questions. The pretest consisted of 13 physics question items in the context of electricity concepts. The pretest was designed to measure students' pre-knowledge and understanding of electricity concepts prior to starting the experiment (see Figure 3.6 for sample physics questions). The posttest contained the same physics question scales as the pretest had, emotions scales, and demographic questions. The purposes of the posttest were to assess students' learning gains after the experiment. Also, the posttest was designed to obtain students' emotions during the experiment and to identify their demographic information.

Physics question scales in the pretest and posttest adapted a couple of selected questionnaires from the Conceptual Survey of Electricity and Magnetism ("CSEM") developed by Maloney et al. (2001) and the Brief Electricity and Magnetism Assessment ("BEMA") presented by Ding et al. (2006). The set of physics question scales for the pretest and posttest were reviewed by experts in physics education and engineering education. To assess the internal consistency reliability of the set of physics question items, Kuder-Richardson Formula 20 was computed as those items were dichotomous. Possible scores for each item were either 0 (for incorrect answers) or 1 (for correct answers). How students' responses were calculated is further explained in section 3.4 Data Analysis Method. The computed values (alpha) were negative (pretest: -.428 and posttest: -.376) which may suggest that all question items were not interrelated. This will be further addressed in Chapter 6.

Emotional dimensions in the posttest were adapted from D'Mello (2013) and were scored using the measurement of attitudes proposed by Likert (1932). By using this scale, this study measured six emotions: *Mind-wandering, Engagement, Frustration, Confusion, Excitement*, and *Eureka* during learning (see Figure 3.7 for sample emotion questions). Flow *(Mind-wandering)/Engagement,* as D'Mello (2013) stated, "is conceptualized as a state of mild positive affect when involved with a task such that concentrations is intense, attention is focused, and focus is complete" (p. 17). *Frustration* is a negative emotional state which is related to achievement emotions and can limit students' learning. *Confusion* is also one of the achievement emotions that is related to students' cognitive status. *Confusion* is one of the important academic emotions as it may provide an opportunity for learning when it links up with a positive emotion, such as *Engagement* (D'Mello & Graesser, 2012; D'Mello et al., 2014). *Confusion* may be considered as a neutral emotional state as it may result in a positive or negative emotional state (D'Mello & Graesser, 2012; Pekrun, 2014). *Excitement* and *Eureka* moments are positive academic emotions which may boost students' interest and focus on learning. Students may experience *Excitement* when undergoing challenging and complex learning tasks or enjoying the current tasks (Pekrun,2006). Especially, students would experience *Eureka* moments when they make a good discovery in the learning process (D'Mello, 2013). These emotional scales were applied on the Emotions dimensions in the Control-Value theory of Achievement Emotions by Pekrun (2000). In accordance with the Control-Value theory of Achievement Emotions by Pekrun (2000), all these six emotions can be characterized as achievement emotions. By assessing these emotions during students' learning, it may allow us to evaluate how students' experienced emotions (achievement emotions, either positive or negative emotions) and learning are related to one another. These six emotional scales were selected by an expert in emotions and learning with technology. To understand whether scales for positive emotions and those for negative emotions were correlated to each other, Cronbach's alphas were evaluated. The alpha for positive emotions (*Engagement*, *Excitement*, and *Eureka* moments) was .625 which was an acceptable level of consistency among positive emotions scales (Mohamad et al., 2015). Another alpha for negative emotions (*Mind-wandering* and *Frustration)* was .255. This value may indicate that scales measuring negative emotions were not well-correlated. This also will be further discussed in Chapter 6. Appendix A and Appendix B provide all the questions used for the pretest and posttest assessment.

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



- ◯ Nothing since –Q is on the y-axis.
- ◯ Strength will increase because –Q is negative.
- ◯ Strength will decrease and direction may change because of the interactions between –Q and the two negative q's.
- ◯ Strength will increase and direction may change because of the interactions between –Q and the two negative q's.
- ◯ Cannot determine without knowing the forces –Q exerts on the two negative q's.

Figure 3.6 *Two samples of physics question scales used in the Pretest and Posttest*

While you were interacting with the simulation, how excited were you in conducting the experiments? Please indicate on a scale of 1 to 4 your level of excitement.

- ◯ 4. I was completely excited
- ◯ 3. I was mostly excited
- ◯ 2. I was mostly not excited in the task
- ◯ 1. I never experienced excitement in the task

Figure 3.7 *A sample of emotions scales used in the Posttest*

3.4 Data Analysis Method

Students' responses to the pretest and posttest surveys were analyzed to compare learning gains from control and treatment groups before and after the intervention. To compare outcomes from each experimental condition, descriptive statistics analysis including mean and standard deviation was performed. Students' answers for physics question scales in the pretest and posttest were scored either 0 or 1. 1 point was given to correct answers and 0 for incorrect answers. The total score that students can obtain from physics question scales was 13 points. As for six emotional measurements (*Mind-wandering, Engagement, Frustration, Confusion, Excitement*, and *Eureka* moments), a 4-point Likert scale was applied on each item, which ranged from 1 (*never experienced*) to 4 (*completely experienced*). The maximum and minimum possible scores of an emotional measurement were 4 and 1, respectively. To compare the difference of mean learning gains and mean emotional scores between two groups, independent samples *t* tests were utilized. Additionally, to determine if there was a significant mean learning gains difference between the pretest and posttest scores in IBL and that in GBL, paired samples *t* tests were performed. Leven's test was conducted to verify the equivalence of variances along with *t* tests. This study facilitated non-directional (two-tailed) hypothesis tests to find any differences and directions in mean learning gains and mean emotions between two groups. To identify if an observed difference (if any) was not only statistically significant but also meaningful, effect size may be calculated. Further, correlational analysis using Pearson R was reported to indicate the relationship between students' academic performance and emotions.

CHAPTER 4. RESULTS

In this chapter, the experimental results from the experiments outlined in Chapter 3 are presented and discussed. Descriptive statistics of learning gains and emotions are explained in 4.1 Descriptive Statistics. Next, results from hypotheses testing are reported in the 4.2 Inferential Statistic sub-section. The study tested hypotheses in order to address this study's research questions: 1) whether there is any difference in learning gains (average scores) between students from IBL and those from GBL, 2) whether there are any differences in mean emotions between students from IBL and those from GBL, 3) whether there are significant linear relationships between emotions and learning gains of students in IBL, and 4) whether there are significant linear relationships between emotions and learning gains of students in GBL, this study tested following hypotheses.

- Null Hypothesis 1: There is no mean learning gains difference between students in IBL and students in GBL ($\mu LearningGainsIBL = \mu LearningGainsGBL$).
- Alternative Hypothesis 1: There is a mean learning gains difference between students in IBL and students in GBL ($\mu LearningGainsIBL \neq \mu LearningGainsGBL$).
- Null Hypothesis 2: There are no mean emotions differences between students in IBL and students in GBL ($\mu EmotionsIBL = \mu EmotionsGBL$).
- Alternative Hypothesis 2: There are mean emotions differences between students in IBL and students in GBL ($\mu EmotionsIBL \neq \mu EmotionsGBL$).
- Null Hypothesis 3: There are no significant linear relationships (correlation) between emotions and learning gains of students in IBL.
- Alternative Hypothesis 3: There are significant linear relationships (correlation) between emotions and learning gains of students in IBL.
- Null Hypothesis 4: There are no significant linear relationships (correlation) between emotions and learning gains of students in GBL
- Alternative Hypothesis 4: There are significant linear relationships (correlation) between emotions and learning gains of students in GBL.

4.1 Descriptive Statistics

Table 1 tabulates descriptive statistics of the variables in the pretest and posttest. Before the intervention, both groups (IBL and GBL) had a similar mean of the pretest scores. After the intervention, the mean of the posttest scores increased in both conditions. Based on the skewness on each occasion, the distribution of the pretest scores in the IBL condition was close to symmetrical. However, after the intervention, its distribution is more negatively skewed. The distribution of the GBL group's pretest scores was fairly symmetrical. But after the intervention, it became highly positively skewed. Especially with the kurtosis of 6.578, the GBL condition's posttest distribution was leptokurtic which showed the distribution was greatly peaked. Figures 4.1 and 4.2 report the distribution of each score in the pretest and posttest during the experiment (IBL and GBL). Figure 4.2 also indicates that the distribution of posttest in GBL is positively skewed with a skewness of 2.191. Visualizations of these distributions are presented in Figures 4.1 and 4.2.

Table 4.1
Descriptive Statistics of Scores in the Pretest and Posttest from Each Condition

		Condition							
		IBL				GBL			
		Pretest		Posttest		Pretest		Posttest	
Pretest and Posttest Scores (Sum of Gained Scores in each test)		Statistic	Std. Error	Statistic	Std. Error	Statistic	Std. Error	Statistic	Std. Error
Mean		2.43	.234	3.65	.271	2.70	.222	3.13	.229
95% Confidence Interval for Mean	Lower Bound	1.95		3.09		2.24		2.65	
	Upper Bound	2.92		4.21		3.16		3.61	
Median		3.00		4.00		2.00		3.00	
Std. Deviation		1.121		1.301		1.063		1.100	
Minimum		0		1		1		2	
Maximum		5		6		5		7	
Interquartile Range		1		2		2		0	
Skewness		-.140	.481	-.502	.481	.429	.481	2.191	.481
Kurtosis		.426	.935	-.080	.935	-.578	.935	6.578	.935

Note. $N = 46$ (n = 23 for each condition). Total possible point for each test was 13.

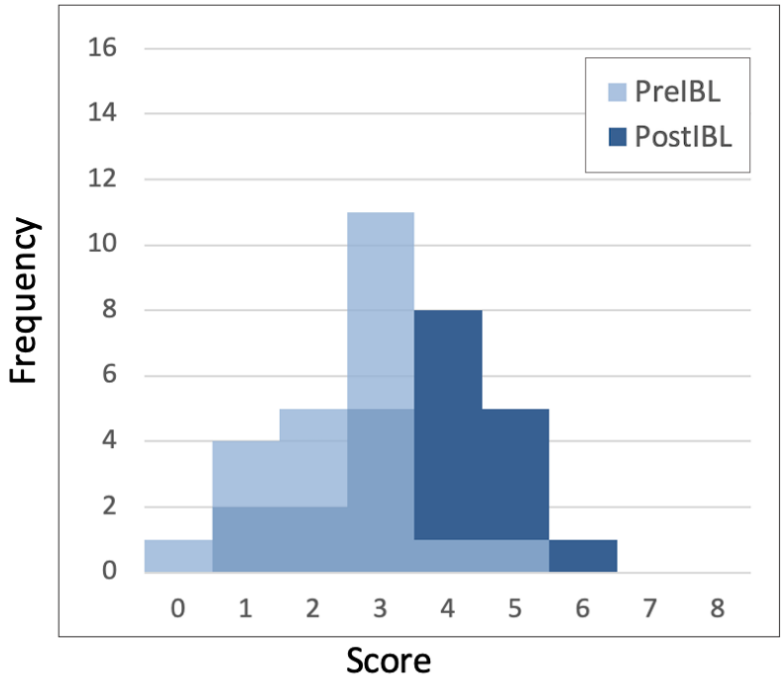


Figure 4.1 *Histogram of the IBL pretest and posttest results*

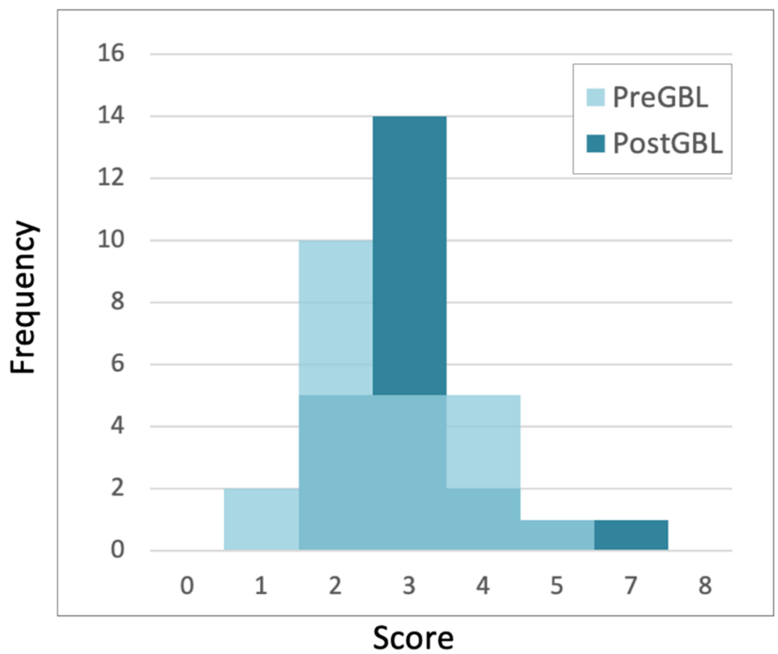
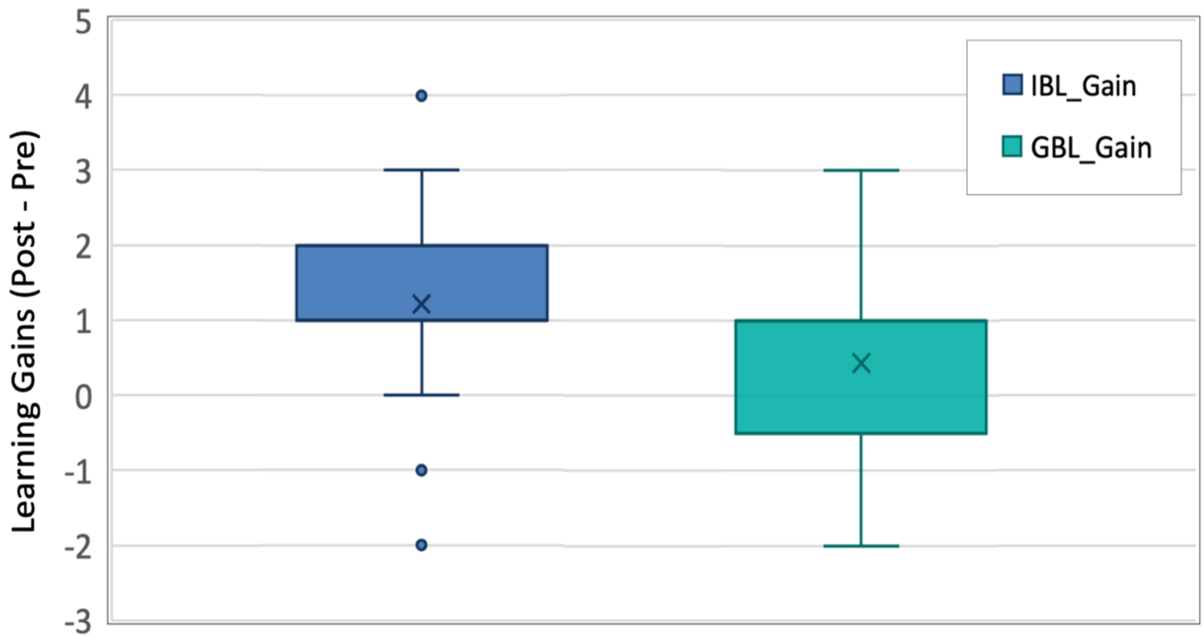


Figure 4.2 *Histogram of the GBL pretest and posttest results*

Figure 4.3 shows that the two boxes do not overlap with one another, suggesting there was a difference in the learning gain between the two groups. Further, there were outliers under the lower fence in the IBL group. There was no outlier in the GBL group, yet the GBL group had more scattered data.



Note. The Learning Gain was calculated by the difference in correct answers from the pretest and the posttest. If a participant scored one more point from the posttest compared to the pretest, the participant's learning gain would be equal to 1. If the participant gained one less point at the posttest compared to the pretest, learning gain would equal -1.

Figure 4.3 *Boxplots of Learning Gains Comparing Two Groups (IBL and GBL)*

Tables 2 and 3 outline the results of the emotion survey. Table 2 presents the frequency distribution of responses to the survey. Table 3 depicts the summary of descriptive statistics of the level of emotions in IBL and GBL. If an index is close to 4, it means the mean of the level of an emotion point is high. In contrast, if an index is close to 1, it would mean the mean of level of an emotion point is low. Figure 4.4 describes the distributions of perceived emotions means in each group. Participants in both groups experienced six types of emotions similarly, but participants in GBL group experienced all emotions more strongly except *Mind-wandering* (means of five emotions were all higher in GBL compared to IBL). For instance, participants in the IBL and the GBL experienced a very similar level of *Mind-wandering*. Particularly, participants in the GBL reported a higher level of *Frustration* than that of IBL. At the same time, participants in the GBL also perceived higher instances of *Eureka* moments.

Table 4.2

Frequency Distribution of Responses on 4-point emotion survey items (IBL and GBL)

Emotions	IBL (n = 23)								GBL (n = 22)							
	1		2		3		4		1		2		3		4	
	n	*%*	*n*	*%*	*n*	*%*	*n*	*%*	*n*	*%*	*n*	*%*	*n*	*%*	*n*	*%*
Frustration	6	26.1	14	60.9	2	8.7	1	4.3	0	0.0	8	36.4	9	40.9	5	22.7
Mind-wandering	11	47.8	11	47.8	1	4.3	0	0.0	13	59.1	8	36.4	0	0.0	1	4.5
Confusion	2	8.7	15	65.2	5	21.7	1	4.3	1	6.7	14	64.4	6	24.4	1	4.4
Engagement	2	8.7	3	13.0	14	60.9	4	17.4	0	0.0	0	0.0	14	63.6	8	36.4
Excitement	3	13.0	11	47.8	8	34.8	1	4.3	1	4.5	10	45.5	9	40.9	2	9.1
Eureka	9	39.1	8	34.8	4	17.4	2	8.7	1	4.5	6	27.3	12	54.5	3	13.6

Note. One participant in GBL did not respond emotional scales (one missing data).

Table 4.3

Descriptive Statistics of Types of Learning Gains, Emotions, Interventions (IBL and GBL)

	IBL			GBL		
	M	SD	Std. Error	M	SD	Std. Error
Learning Gains	1.22	1.506	.314	.43	1.121	.234
Frustration	1.91	.733	.153	2.86	.774	.165
Mind-wandering	1.57	.590	.123	1.50	.740	.158
Confusion	2.22	.671	.140	2.32	.646	.138
Engagement	2.87	.815	.170	3.36	.492	.105
Excitement	2.30	.765	.159	2.55	.739	.157
Eureka	1.96	.976	.204	2.77	.752	.160

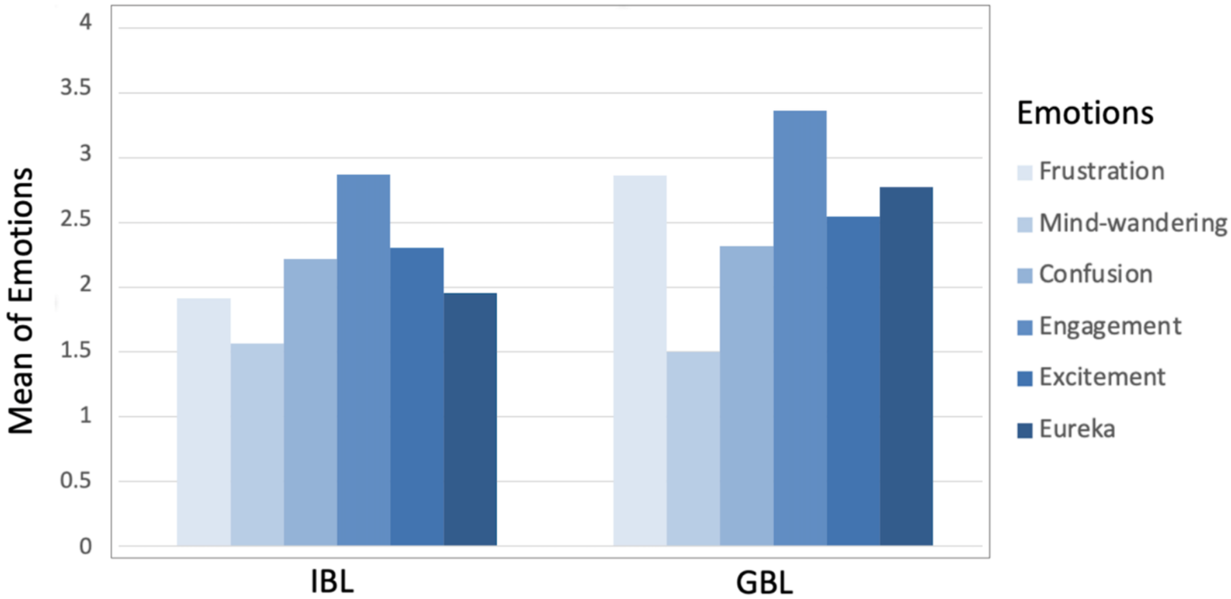


Figure 4.4 *A bar graph of Distributions of Emotions (Mean) in IBL and GBL*

4.2 Inferential Statistics

At the beginning of this study, it was assumed that two groups had similar prior knowledge of concepts of electricity in physics. To ensure the equivalence prior to the experiment between the IBL and the GBL group, an independent samples *t* test (two-tailed) with the level of significance is .05 (alpha = 0.05) was performed. The result indicated that there was no significant difference between mean pretest scores of IBL students (M=2.43, SD =1.121, n=23) and that of GBL students (M=2.70, SD =1.063, n=23), $t(44)$=-.810, p= .422, 95% CI for mean difference -.910 to .388. Therefore, may infer that the level of pre-knowledge (in concepts of electricity in physics) of both groups may be comparable before the experiment. On the other hand, the difference between mean posttest scores of IBL (M=3.65, SD =1.301, n=23) and that of GBL (M=3.13, SD =1.100, n=23) was not also statistically significant, $t(44)$=1.469, p= .149, 95% CI for mean difference -.194 to 1.238.

4.2.1 Learning Gains: Hypothesis Test 1.

In order to test hypothesis 1, an independent samples *t* test (two-tailed) was performed to compare the difference of mean learning gains between two groups with the level of significance is .05 (alpha = 0.05). Table 4 presents the result of the test. From the independent samples *t* test, there was no significant difference between mean learning gains of IBL group (*M*=1.22, *SD* =1.506, *n*=23) and that of GBL group (*M*=.43, *SD*=1.121, *n*=23), *t*(44)=1.999, *p*= .052, 95% CI for mean difference -.006 to 1.572. Since the *p* value is greater than .05, it failed to reject the null hypothesis 1 that there is no mean learning gains difference between students in IBL and students in GBL. As it failed to reject the null hypothesis 1, the effect size was not computed. On the other hand[1], from the paired samples *t* test, the means of learning gains between the pretest and posttest in the IBL group were significantly different (*M*=1.217, *SD*=1.506, *n*=23), *t*(22)=3.876, *p*< .001, 95% CI for mean difference .566 to 1.869. From the same test, however, there was no significant mean learning gains difference between the pretest and posttest scores in the GBL (*M*=.435, *SD*=1.121, *n*=23), *t*(22)=1.860, *p*= .076, 95% CI for mean difference -.050 to .920.

The study assumed there would be a significant mean difference in learning gains between two groups (i.e., average learning gains in IBL will be significantly higher than average learning gains in GBL). Even though students in IBL showed a significant mean learning gains difference between the pretest and posttest (from the paired samples *t* test), yet there was no mean learning gains difference between two groups from the independent samples *t* test. And this did not support the assumption of the study. Thus, the answer to the first research question is that there is no significant difference in mean learning gains between IBL and GBL.

Table 4.4
Independent Samples t Test Results Comparing Mean Learning Gains between IBL and GBL

		Levene's Test for Equality of Variances		*t* test for Equality of Means						
									95% Confidence Interval	
		F	Sig.	t	df	p	Mean Difference	SE Difference	Lower	Upper
Mean Learning Gains	Equal variances assumed	.706	.405	1.999	44	.052	.783	.392	-.006	1.572
	Equal variances not assumed			1.999	40.652	.052	.783	.392	-.008	1.574

[1] Note: the study only compares the difference of mean learning gains between two groups. It does not examine the statistical difference between the pretest and posttest scores within the same group.

4.2.2 Experienced Emotions: Hypothesis Test 2.

Next, the null hypothesis 2 was tested to determine if there are no mean emotions differences between IBL and GBL. The results of the independent samples t test (two-tailed) are presented in Table 5. Concerning *Frustration*, the mean *Frustration* significantly differed between IBL (M=1.91, SD = .733, n=23) and GBL (M=2.86, SD= .774, n=22), $t(43)=-4.230$, $p < .001$, 95% CI for mean difference -1.404 to -.497. In addition, according to *Mind-wandering (MW),* there was no statistically significant mean difference between IBL group (M=1.57, SD = .590, n=23) and GBL group (M=1.50, SD= .740, n=22), $t(43)= .328$, $p= .745$, 95% CI for mean difference -.336 to .467. On the other hand, in terms of *Confusion*, the mean difference was not significantly different between students in IBL (M=2.22, SD = .671, n=23) and students in GBL (M=2.32, SD= .646, n=22) at the .05 level of significance, $t(43)=-.513$, $p= .611$, 95% CI for mean difference -.497 to .296. However, as for *Engagement*, the results suggested that there was a statistically significant mean difference between IBL group (M=2.87, SD = .815, n=23) and GBL group (M=3.36, SD= .492, n=22), $t(43)=-2.448$, $p= .019$, 95% CI for mean difference -.901 to -.087. On average students in the GBL group strongly experienced *Engagement* as well as *Frustration* than those in the IBL. Also, for *Excitement*, there was no significant difference between mean *Excitement* scores for IBL group (M=2.30, SD = .765, n=23) and for GBL group (M=2.55, SD= .739, n=22), $t(43)=-1.075$, $p= .288$, 95% CI for mean difference -.693 to .211. Lastly, findings from the independent samples t test revealed a statistically significant difference in the mean responses for *Eureka* between IBL students (M=1.96, SD = .976, n=23) and GBL students (M=2.77, SD= .752, n=22), $t(43)=-3.133$, $p= .003$, 95% CI for mean difference -1.342 to -.291. With these findings, as regards *Frustration*, *Engagement*, and *Eureka*, we can reject the null hypothesis 2, and conclude that the mean differences were significant between the two groups. However, with respect to *MW*, *Confusion*, and *Excitement*, since the p values were greater than .05, we retain the null hypothesis 2 and infer that the mean differences in such emotions were not significantly different. Accordingly, we can answer the second research question that, between IBL and GBL, there were no statistically significant differences in mean emotions (*MW*, *Confusion*, and *Excitement)* and that there were statistically significant differences in mean emotions (*Engagement*, *Frustration*, and *Eureka)*.

Table 4.5
Independent Samples t Test Results Comparing Mean Emotions Scores between IBL and GBL

Variable		Levene's Test for Equality of Variances		*t* test for Equality of Means					95% Confidence Interval	
		F	Sig.	t	df	p	Mean Difference	SE Difference	Lower	Upper
Frustration	**1**[2]	**1.058**	**.309**	**-4.230**	**43**	**<.001**	**-.951**	**.225**	**-1.404**	**-.497**
	2			**-4.225**	**42.575**	**<.001**	**-.951**	**.225**	**-1.404**	**-.497**
MW	1	.257	.615	.328	43	.745	.065	.199	-.336	.467
	2			.326	40.129	.746	.065	.200	-.339	.469
Confusion	1	.060	.807	-.513	43	.611	-.101	.197	-.497	.296
	2			-.513	42.997	.610	-.101	.196	-.497	.295
Engagement	**1**	**.482**	**.491**	**-2.448**	**43**	**.019**	**-.494**	**.202**	**-.901**	**-.087**
	2			**-2.474**	**36.438**	**.018**	**-.494**	**.200**	**-.899**	**-.089**
Excitement	1	.002	.965	-1.075	43	.288	-.241	.224	-.693	.211
	2			-1.076	42.995	.288	-.241	.224	-.693	.211
Eureka	**1**	**1.068**	**.307**	**-3.133**	**43**	**.033**	**-.816**	**.261**	**-1.342**	**-.291**
	2			**-3.151**	**41.161**	**.003**	**-.816**	**.259**	**-1.339**	**-.293**

4.2.3 Relationship between Learning and Emotions: Hypothesis Test 3 and 4.

Finally, a hypothesis test of the significance of the correlation coefficient (Pearson product-moment correlation coefficient) was performed in order to determine whether there were linear relationships between emotions and learning gains of students in IBL and students in GBL. Appendix C depicts the relationships between learning gains and emotions in IBL and GBL, respectively. Table 6 summarizes the results of calculated Pearson product-moment correlation coefficients.

[2] 1 and 2 mean Equal variances assumed, Equal variances not assumed, respectively.

There was a moderate negative correlation between *Frustration* and *learning gains* in the IBL group, r=- .435, n=23, p= .038. Increases in *Frustration* were correlated with decreases in *learning gains* in the IBL group. The correlations between other emotions and learning gains were weak and statistically not significant. Therefore, as for the Hypothesis Test 3, concerning *MW*, *Confusion*, *Engagement, Excitement,* and *Eureka,* we retain the null hypothesis 3 and infer that there was insufficient evidence to conclude that there were significant linear relationships between such emotions and learning gains of students in IBL group. However, with regard to *Frustration*, we reject the null hypothesis 3 in favor of the alternative and conclude there is a linear relationship between *Frustration* and *learning gains* of students in IBL. As for the Hypothesis Test 4, we retain null hypothesis 4 and infer that there was insufficient evidence to conclude that there were significant linear relationships between all emotions and learning gains of students in the GBL group.

Table 4.6
Correlations between Emotions and Learning Gains in IBL and GBL

	Learning Gains	
Emotions	IBL	GBL
Frustration	**-.435***	.120
Mind-wandering	.060	-.028
Confusion	-.049	.138
Engagement	.172	-.108
Excitement	.137	-.221
Eureka	.069	.058

Note. *. Correlation is significant at the 0.05 level (2-tailed): ***p*= .038**

CHAPTER 5. DISCUSSION AND IMPLICATIONS

The relationship between learning with technologies (IBL and GBL) and emotions in science education has been discussed in numerous past studies. For instance, Rutten et al. (2015) investigated the learning effect of IBL with PhET computer simulations in physics learning and examined students' positive attitudes (e.g., motivation and engagement) throughout the process. Clark et al. (2009) argued that computer simulations and games as learning interventions can bring about more positive learning outcomes than traditional learning approaches in science learning.

The difference between previous studies and the present one (i.e., in this thesis) is that this study compared the effectiveness of IBL with that of GBL whereas many previous studies focused on either the effectiveness of IBL or that of GBL only. Also, this study contrasted the self-reported emotions of students in IBL with those in GBL. The purpose of this study was to identify the differences between two learning interventions, IBL and GBL, in terms of learning gains and emotions. Although students in IBL showed a statistically significant mean difference in learning gains between the pretest and posttest whereas students in GBL did not, the statistical analysis did not result in a significant mean learning gains difference between the two groups. Therefore, we can conclude that the effectiveness of IBL and that of GBL were comparable, with no statistically significant difference.

This finding was expected as many previous studies have demonstrated the effectiveness of both IBL and GBL in STEM learning. According to Abdullah and Shariff (2008), students who participated in Inquiry-Based Learning with computer simulations showed significant outperformance in understanding physics Gas Laws concepts. On the other hand, as discussed by Squire et al. (2004), Game-Based Learning with digital simulation games could be also effective in developing students' understanding of physics electromagnetism concepts. In addition, Anderson and Barnett (2011) identified the GBL as a powerful tool in order to support students' science learning. In their study, students who played an educational video game to study electromagnetism concepts showed a significant learning gains difference between the pretest and posttest. In this study, the mean learning gains of students in both IBL and GBL groups increased after the experiment. These results may suggest that both IBL and GBL learning environments hold promise in enhancing students' learning of complex science concepts.

Furthermore, from the experimental test results, the study was able to assess that IBL and GBL related students' emotions in classrooms in line with the theoretical framework, the Control-Value theory of Achievement Emotions (Pekrun, 2006) of this study. This study identified how students perceived achievement emotions - *Frustration*, *Mind-wandering*, *Engagement*, *Confusion*, *Excitement*, and *Eureka* moments - differently during their learning activities. As many past studies have suggested that emotions play an important role in academic environments (Bower, 1992; Pekrun, 2006; Pekrun et al., 2007; Graesser & D'Mello, 2012; Tyng et al., 2017), the study was able to address that various educational settings, such as IBL and GBL, may bring about different emotions and have an effect on students' learning achievement.

Specifically, findings in this study suggest that GBL significantly elicited learners' positive emotions such as *Engagement* and *Eureka* moments compared to IBL. This result was also predictable as many past studies have shown that GBL evokes positive emotions. Especially, Sabourin and Lester (2013) highlighted the interplay between positive emotions and learning in GBL. In Sabourin and Lester's study, it was shown that GBL can promote students' positive emotions (including *Engagement* during learning) which are essential to increase students' attention in learning activities. It was presented that students in GBL reported more positive emotions than negative emotions. At the same time, interestingly, students in the GBL condition experienced more *Frustration* which is one of the negative emotions, and the mean difference was statistically significant. This result can be also related to the study by Sabourin and Lester (2013). In Sabourin and Lester's study, students who participated in GBL reported frustration (16%) as the next most frequent self-reported emotion after a positive emotional state, focused (24%), which was the most frequent self-reported emotion. As Sabourin and Lester (2013) also stated, negative emotions (e.g., *Frustration*) were expected due to the nature of GBL where students are not told exactly what to do.

On the other hand, the mean difference in *Confusion* was not significantly different between students in IBL and students in GBL in this study. Yet the study considered *Confusion* important as it may play a positive role in promoting learning when it transitions to a positive emotion, *Engagement* (D'Mello & Graesser, 2012; D'Mello et al., 2014), in which the difference in means was statistically significant between IBL and GBL in this study. During *Confusion* states, students may still pay attention to what they are doing (e.g., discovering, reasoning, thinking, etc.) during the learning process. However, they may not fully understand at the moment. When appropriately managed by students, *Confusion* may become an opportunity to learn, help students deeply understand later on, lead to *Engagement*, and, ultimately, to *Eureka* moments (D'Mello & Graesser, 2012; D'Mello et al., 2014). Further, *Confusion* can increase motivation while remaining interested in overcoming learning challenges (Pekrun, 2014).

Finally, the study was able to find that there was a linear relationship between *Frustration* and learning gains of students in the IBL group. The more *Frustration* students experienced, the fewer learning gains they showed in the IBL condition. This finding supports existing literature concerning the effects of negative emotions (e.g., frustration) on learning that negative emotions, such as *Frustration*, can hinder students from paying attention to learning material and obstruct their learning (Pekrun, 2014; Tyng et al., 2017).

From the findings of this research, this study was able to test how different environments have an impact on students learning and achievement emotions and how they are related to one another. It seems that both IBL and GBL can be utilized to support students’ learning of scientific concepts. As suggested by Pekrun (2014), emotions in classrooms can be addressed to enhance students’ learning. The findings of the study may call the attention of educators to the development of teaching strategies which nourish learners’ motivation and foster learning while cultivating a welcoming environment (Schutz et al., 2006; Dirkx, 2008). Also, by understanding learner’s emotions in a classroom (in the process of learning), teaching methods can be designed to turn negative emotions (e.g., *Frustration* and *Confusion*) into positive results (e.g., overcoming learning obstacles) as some students manage such emotions and achieve their learning goals while enjoying challenges (D'Mello & Graesser, 2012; D'Mello et al., 2014; Richey et al., 2019). When numerous learning technologies, including IBL and GBL, adequately address emotions in learning, would be beneficial for both students and teachers as emotions enrich learning and teaching processes. Thus, learning technologies may be embedded in the classroom considering students' various emotions during learning in order to assist their deep understanding of complex concepts (such as STEM topics) and increase academic motivation (Graesser et al., 2014).

CHAPTER 6. CONCLUSION, LIMITATIONS, AND FUTURE WORK

Overall, the experimental results of the study revealed that (a) both IBL and GBL could contribute to the students' scientific conceptual learning, and (b) IBL and GBL can elicit different levels of emotions during learning. Furthermore, students' experienced emotions may form a linear relationship with learning gains depending on different learning environments.

However, this study has a couple of potential limitations that need to be addressed in future research. One limitation is that the sample size of this study might not have been sufficient to obtain precise results to represent the population at large. As stated in Chapter 4, the p value from the independent samples t test (two-tailed) comparing the difference of mean learning gains between two groups (IBL and GBL) was very close to the threshold (alpha = 0.05). Therefore, having a different sample size may yield a different result when the same experiment is performed. This may limit the statistical results of this study from being generalized to a larger population.

The second limitation concerns the lower internal consistency of the measurements. The reliability of the original tests, the CSEM (by Maloney et al., 2001) and BEMA (by Ding et al., 2006) were different from the values computed for this study. The reliability of the CSEM was around 0.75 (computed using Kuder-Richardson Formula 20). And that of BEMA was 0.85 which was calculated using Kuder-Richardson Formula 21. However, in this study, the reliability indexes (computed with Kuder-Richardson Formula 20) for the pretest and posttest were negative. This may indicate that physics question items used in this study were not significantly correlated. The Cronbach's alpha of negative emotions (*Frustration* and *Mind-wandering*) scales was also very low. Yet, in the study of D'Mello (2013), the Cronbach's alpha of those emotions was not computed. Nonetheless, according to Ritter (2010), it cannot simply be interpreted as if the measurements lacked reliability. One of the reasons for a negative alpha is due to students' very weak scores. Also, as Tavakol and Dennick (2011) suggested, the small number of question items can result in a low alpha value. There are a couple of differences to consider between the CSEM, BEMA, and this study. First, the numbers of participants were remarkably different. Between 600 and 2000 students[3] participated in the CSEM. Participants in BEMA were 434 students. Contrarily, 46 students took part in this study. Second, the numbers of physics questions used in each study were different. The CSEM assessed 30 multiple-choice questions. BEMA contained 30 multiple-choice questions. This study was a 13-item multiple-choice test which adopted 10 questions from the CSEM and 3 questions from BEMA. Lastly, the characteristics of participants in each study were different which may result in different students' performances. For instance, the CSEM was completed with students who were mostly majoring in science and engineering. Also, BEMA was administered with algebra and calculus-based students. On the other hand, participants in this study who were studying physics concepts to teach courses in elementary school were more education-based. Therefore, students' scores were dissimilar. For example, students in the CSEM had about 28% and 45% of the questions correct on the pretest and posttest, respectively. In BEMA, the average scores of the pretest and posttest were 23% and 42% respectively. Especially, the average score of students who were in senior physics majors at Carnegie Mellon University was 80% in BEMA (Ding et al., 2006). On the contrary, participants in this study showed a poor performance. The mean score of the pretest was 19.73%[4] and that of the posttest was 26.08%[5]. For some questions in the pretest and posttest, only one person answered correctly. In the posttest, there was a question that none of the students answered correctly. These differences may indicate that participants from dissimilar groups can induce contrasting outcomes.

The third limitation is that the study may have a lack of validity of a self-report measure of emotions. Students may under-report their negative emotions during learning or exaggerate positive emotions to avoid any penalty for their responses.

Another limitation is that the study did not assess individual differences in emotions during learning. As previous research suggested (D'Mello & Graesser, 2012; D'Mello et al., 2014; Pekrun 2014), numerous students can experience various emotions in the same circumstance. For example, some students may have better learning performance under negative emotions such as frustration and anxiety (Richey et al., 2019). A systematic analysis of these

[3] Note. The numbers of students who answered each physics question were different in each pretest and posttest.
[4] The average scores of the pretest were 18.69% (IBL) and 20.76% (GBL).
[5] The average scores of the posttest were 28.07% (IBL) and 24.07% (GBL).

individual differences in emotions and learning may yield a better understanding of the relationship between them.

The last limitation is the study did not consider measuring students' learning gains in the traditional lecture-based approach. By measuring this variable, the study may have better assessed the impact of learning with technology and emotions (i.e., IBL and GBL).

This study suggests the following extensions for future research. To address the generalizability limitation, this study can be performed with larger sample sizes. Increasing the sample size may help determine what caused the low internal consistency reliability of measurements in this study. One way toward future research would be to consider using a power analysis. By performing a power analysis, future research may be able to determine the necessary number of participants with sufficient power to justify carrying out the research (Cohen, 2013). Also, to address the internal consistency reliability of the study appropriately, future research may increase the number of question items for both physics questions and emotions scales. Having different types of participants such as students with strong science and math backgrounds may result in good internal consistency reliability in the future study. In order to enhance the accuracy of the self-report measures, future research can utilize multiple emotional measurement methods such as neuroimaging techniques (e.g., EEG and fMRI) which can be mixed with self-report methods simultaneously. To better assess the effectiveness of two learning technologies (IBL and GBL), future work can consider measuring students' learning gains and emotions during a traditional academic setting. Lastly, a future study may investigate the impact of individual differences in emotions on learning gain differences. In this study, for instance, even though some students in GBL experienced negative emotions (e.g., frustration), they had a good performance. However, such negative emotions might have yielded lower learning gains for other students. It may be fruitful to find how such individual differences influence learners’ motivation, self-esteem, academic goals, and performance in academic contexts.

APPENDIX A. PRETEST SURVEY

Default Question Block

Please enter your LAST name :

Please enter your FIRST name (as it appears in Blackboard) :

We kindly ask you to answering all questions INDIVIDUALLY, without the use of external resources.
There is NO PENALTY for incorrect answers. Please do the best you can

For questions 1 and 2, please use the following diagram:

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

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

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

- 16F
- 4F
- F
- F/4
- Other

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

- 16F
- 4F
- F
- F/4
- Other

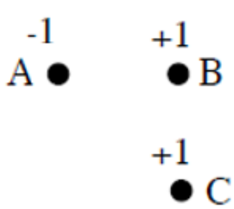
For question 3, please use the following diagram.

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

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

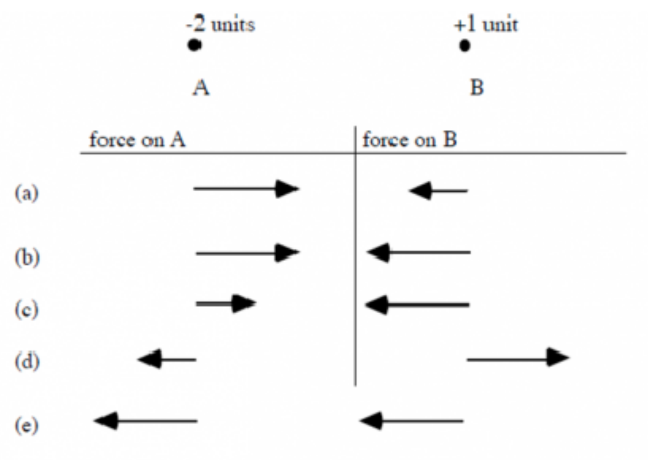
- F/9
- F/3
- 4F/9
- 4F/3
- Other

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



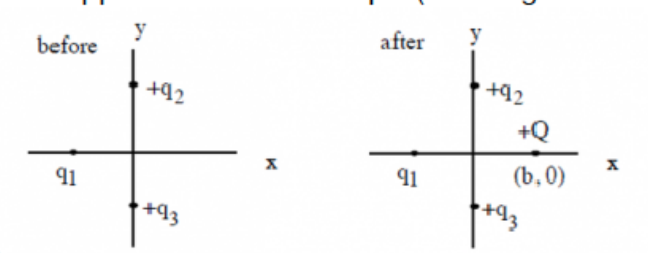
None of the above

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



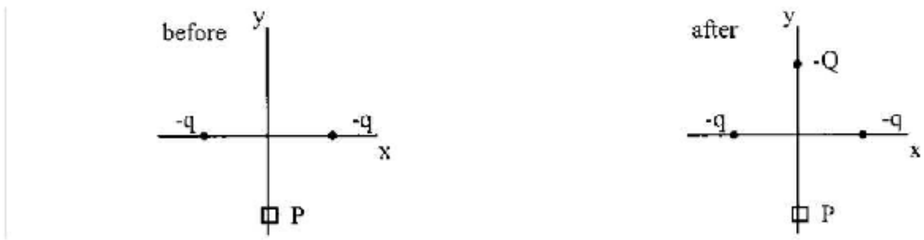
- (a)
- (b)
- (c)
- (d)
- (e)

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



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

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

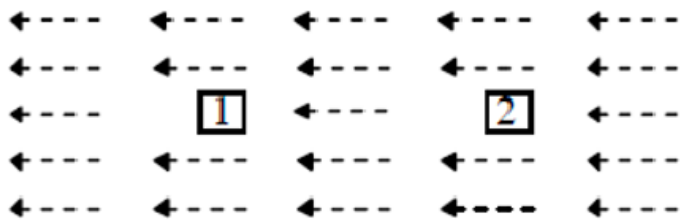


- Nothing since –Q is on the y-axis.
- Strength will increase because –Q is negative.
- Strength will decrease and direction may change because of the interactions between –Q and the two negative q's.
- Strength will increase and direction may change because of the interactions between –Q and the two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

8. A positive charge is placed at rest the center of a region of space in which there is a uniform, three-dimensional electric field. (A uniform field is one whose strength and direction are the same at all points within the *reigion*). When the positive charge is released from the rest of the uniform electric field, what will its subsequent motion be?

- It will move at a constant speed.
- It will move at a constant velocity.
- It will move at a constant acceleration.
- It will move with a linearly changing acceleration.
- It will remain at rest in its initial position.

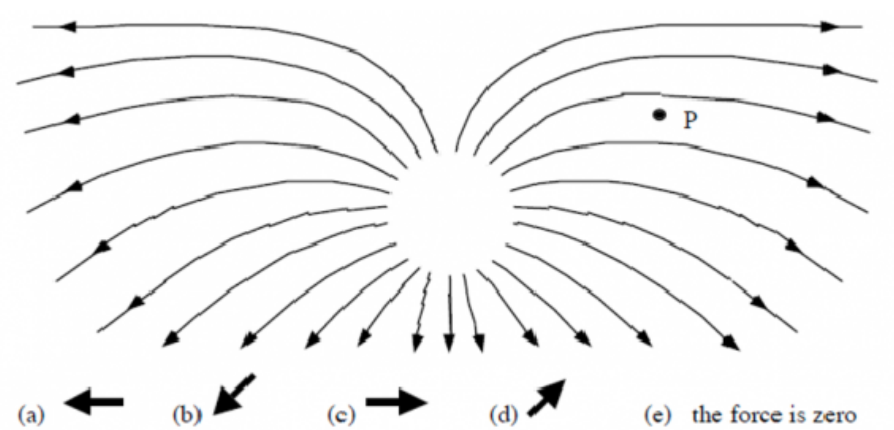
9. A positive charge might be placed at one of two differet locations in a region where there is a uniform electric field, as shown below:



How do the electric forces on the charge at positions 1 and 2 compare?

- Force on the charge is greater than 1.
- Force on the charge is greater than 2.
- Force at both positions is zero.
- Force at both positions is the same but not zero.
- Force at both positions has the same magnitude but is in opposite directions.

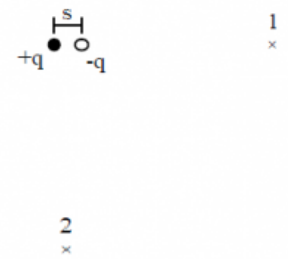
10. What is the direction of the electric force on a negative charge at point P in the diagram below?



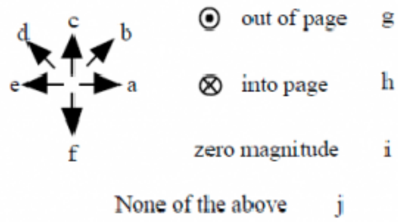
- (a)
- (b)
- (c)
- (d)
- (e)

For questions 11-12:

Here are two charges of equal magnitude but opposite sign, separated by a distance s:



Choose from the following possible directions to answer the questions below:



11. What is the direction (*a* - *j*) of the electric field at location 1 (marked with an x)?

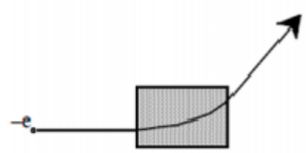
a ○ b ○ c ○ d ○ e ○ f ○ g ○ h ○ i ○ j ○

12. What is the direction (*a* - *j*) of the electric field at location 2 (marked with an x)?

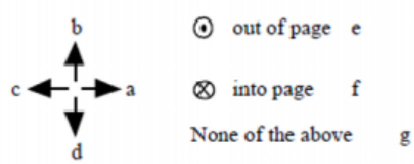
a ○ b ○ c ○ d ○ e ○ f ○ g ○ h ○ i ○ j ○

For question 13:

A moving electron with charge -e travels along the path shown, and passes through a region of electric field. There are no other charges present. The electric field is zero everywhere except in the gray region.



Choose from the following possible directions to answer the question below:



13. What is a possible direction (*a* - *g*) of the electric field in the region where the field is non-zero?

a ○ b ○ c ○ d ○ e ○ f ○ g ○

APPENDIX B. POSTTEST SURVEY

NAME

Please enter your LAST name :

Please enter your FIRST name (as it appears in Blackboard) :

We kindly ask you to answering all questions INDIVIDUALLY, without the use of external resources.

There is NO PENALTY for incorrect answers. Please do the best you can.

For questions 1 and 2, please use the following diagram:

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

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

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

- ○ 16F
- ○ 4F
- ○ F
- ○ F/4
- ○ Other

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

- ○ 16F
- ○ 4F
- ○ F
- ○ F/4
- ○ Other

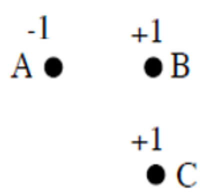
For question 3, please use the following diagram.

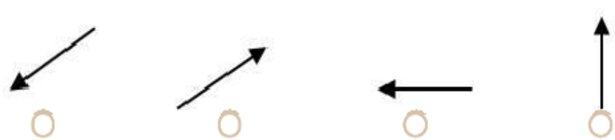
Next we move the +Q and +4Q charges to be 3 times as far apart as they were:

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

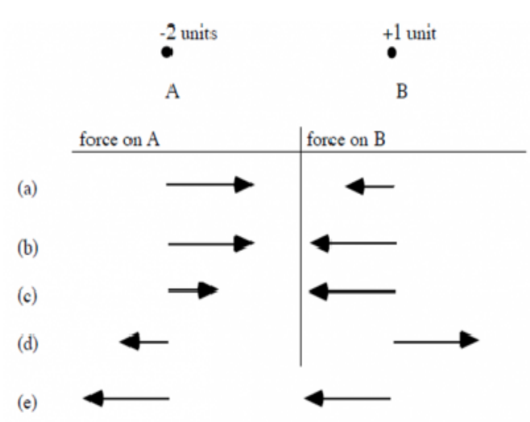
- F/9
- F/3
- 4F/9
- 4F/3
- Other

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



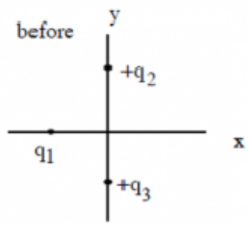


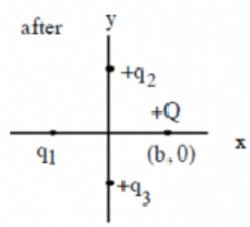
5. The picture below shows a particle (labeled B) which has a net electric charge of +1 unit. Several centimeters to the left is another particle (labeled A) which has a net charge of -2 units. Choose the pair of force vectors (the arrows) that correctly compare the electric force on A (caused by B)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



- (a)
- (b)
- (c)
- (d)
- (e)

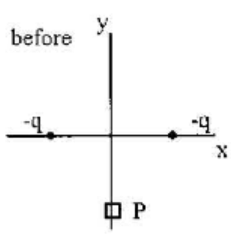
6. In the figure below, positive charges q2 and q3 exert on charge q1 a net electric force that points along the +x axis. If a positive charge Q is added at (b,0), what now will happen to the force on q1? (All charges are fixed at their locations.)

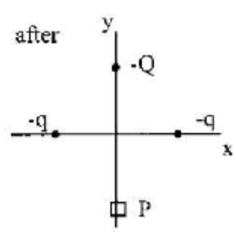




- No change in the size of the net force since Q is on the x-axis.
- The size of the net force will change but not the direction.
- The net force will decrease and the direction may change because of the interaction between Q and the positive charges q2 and q3.
- The net force will increase and the direction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

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





- Nothing since –Q is on the y-axis.
- Strength will increase because –Q is negative.
- Strength will decrease and direction may change because of the interactions between –Q and the two negative q's.

◯ Strength will increase and direction may change because of the interactions between –Q and the two negative q's.

◯ Cannot determine without knowing the forces –Q exerts on the two negative q's.

8. A positive charge is placed at rest the center of a region of space in which there is a uniform, three-dimensional electric field. (A uniform field is one whose strength and direction are the same at all points within the *reigion*). When the positive charge is released from the rest of the uniform electric field, what will its subsequent motion be?

◯ It will move at a constant speed.

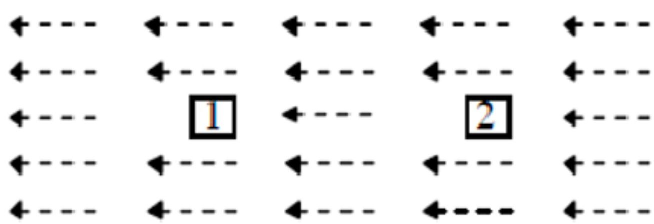
◯ It will move at a constant velocity.

◯ It will move at a constant acceleration.

◯ It will move with a linearly changing acceleration.

◯ It will remain at rest in its initial position.

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



<u>How do the electric forces on the charge at positions 1 and 2 compare?</u>

◯ Force on the charge is greater than 1.

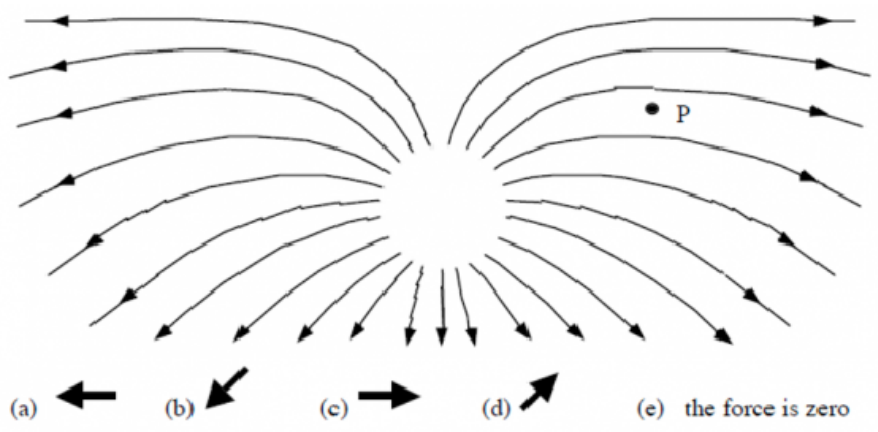
◯ Force on the charge is greater than 2.

◯ Force at both positions is zero.

◯ Force at both positions is the same but not zero.

◯ Force at both positions has the same magnitude but is in opposite directions.

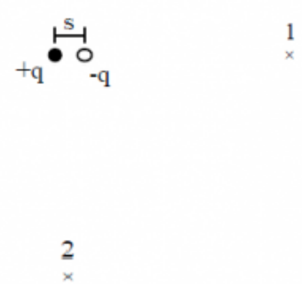
10. What is the direction of the electric force on a negative charge at point P in the diagram below?



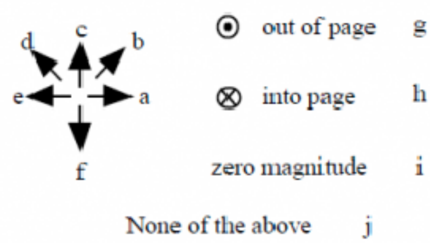
- (a)
- (b)
- (c)
- (d)
- (e)

<u>For questions 11-12:</u>

Here are two charges of equal magnitude but opposite sign, separated by a distance s:



Choose from the following possible directions to answer the questions below:



11. What is the direction (*a* - *j*) of the electric field at location 1 (marked with an x)?

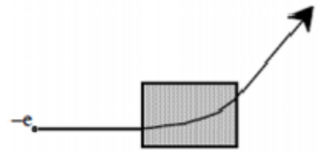
a b c d e f g h i j

12. What is the direction (*a* - *j*) of the electric field at location 2 (marked with an x)?

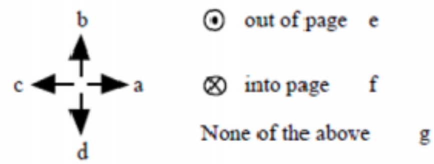
a b c d e f g h i j

<u>For question 13:</u>

A moving electron with charge -e travels along the path shown, and passes through a region of electric field. There are no other charges present. The electric field is zero everywhere except in the gray region.



Choose from the following possible directions to answer the question below:



13. What is a possible direction (*a* - *g*) of the electric field in the region where the field is non-zero?

a b c d e f g

The following questions will provide us information about your attitudes toward the learning experience:

While you were interacting with the simulation, was your attention focused on the task of conducting the experiments? Please indicate on a scale of 1 to 4 whether you largely stayed on task or if you were thinking about task unrelated concerns while completing the assignment.

- 4. I stayed completely on task
- 3. I stayed mostly on task
- 2. I was somewhat distracted by task unrelated concerns
- 1. I focused completely on task unrelated concerns

While you were interacting with the simulation, how engaged in conducting the experiments were you? Please indicate on a scale of 1 to 4 your level of boredom/engagement.

- 1. I was completely bored
- 2. I was mostly bored
- 3. I was mostly engaged in the task
- 4. I was completely engaged in the task

While you were interacting with the simulation, how frustrated were you in conducting the experiments? Please indicate on a scale of 1 to 4 your level of frustration.

- 4. I was completely frustrated
- 3. I was mostly frustrated
- 2. I mostly did not experience frustration in the task
- 1. I was never frustrated in the task

While you were interacting with the simulation, how confused were you while conducting the experiments? Please indicate on a scale of 1 to 4 your level of confusion.

- 4. I was completely confused
- 3. I was mostly confused
- 2. I mostly did not experience confusion in the task
- 1. I was never confused in the task

While you were interacting with the simulation, how excited were you in conducting the experiments? Please indicate on a scale of 1 to 4 your level of excitement.

- 4. I was completely excited
- 3. I was mostly excited
- 2. I was mostly not excited in the task
- 1. I never experienced excitement in the task

While you were interacting with the simulation, did you ever experience a moment of "eureka!"? Please indicate on a scale of 1 to 4 your level of experiencing an "eureka!" moment.

- 4. I had eureka moments throughout the task
- 3. I had some eureka moments
- 2. I mostly did not experience any eureka moments in the task
- 1. I never had eureka moments in the task

The following questions are for demographic purposes:

Preferred gender pronouns:

- ○ he/him
- ○ she/her
- ○ they/them

Race (Choose all that apply)

- ☐ American Indian or Alaskan Native
- ☐ Asian
- ☐ Native Hawaiian or another Pacific Islander
- ☐ Black or African American
- ☐ White

Ethnicity:

- ○ Hispanic or Latino or Spanish origin
- ○ not Hispanic or Latino or Spanish origin

First-generation status:

- ○ I am a first-generation college student
- ○ I am NOT a first-generation college student

Native language:

- ○ English native language
- ○ Non-English native language

I would rate my overall academic science performance as:

- ○ Excellent
- ○ Good
- ○ Fair
- ○ Poor
- ○ Very poor

Did you take physics in high school?

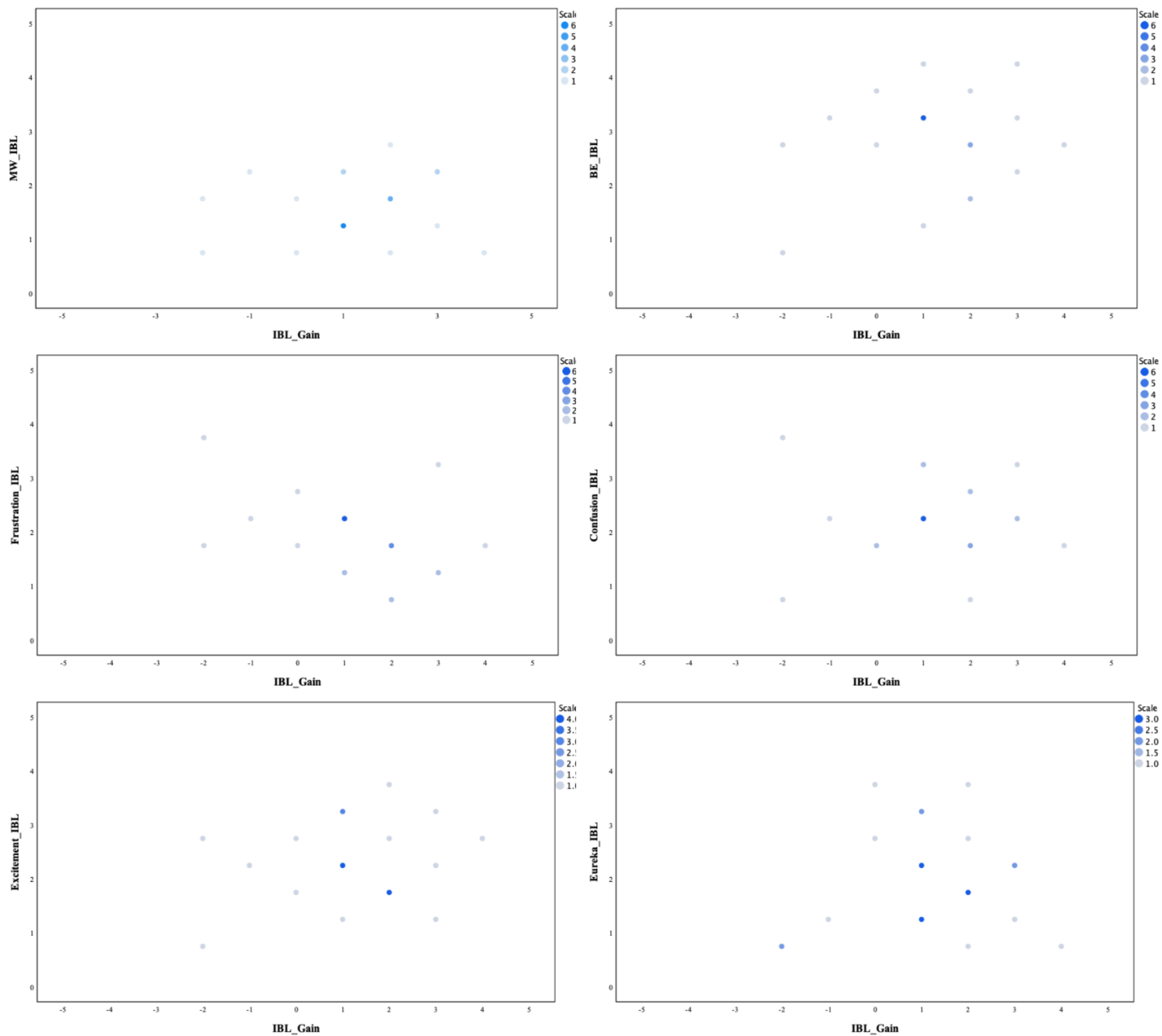
- ○ YES
- ○ NO
- ○ Not Sure

If you answered YES to the question above, which physics class(es) did you take in high school?

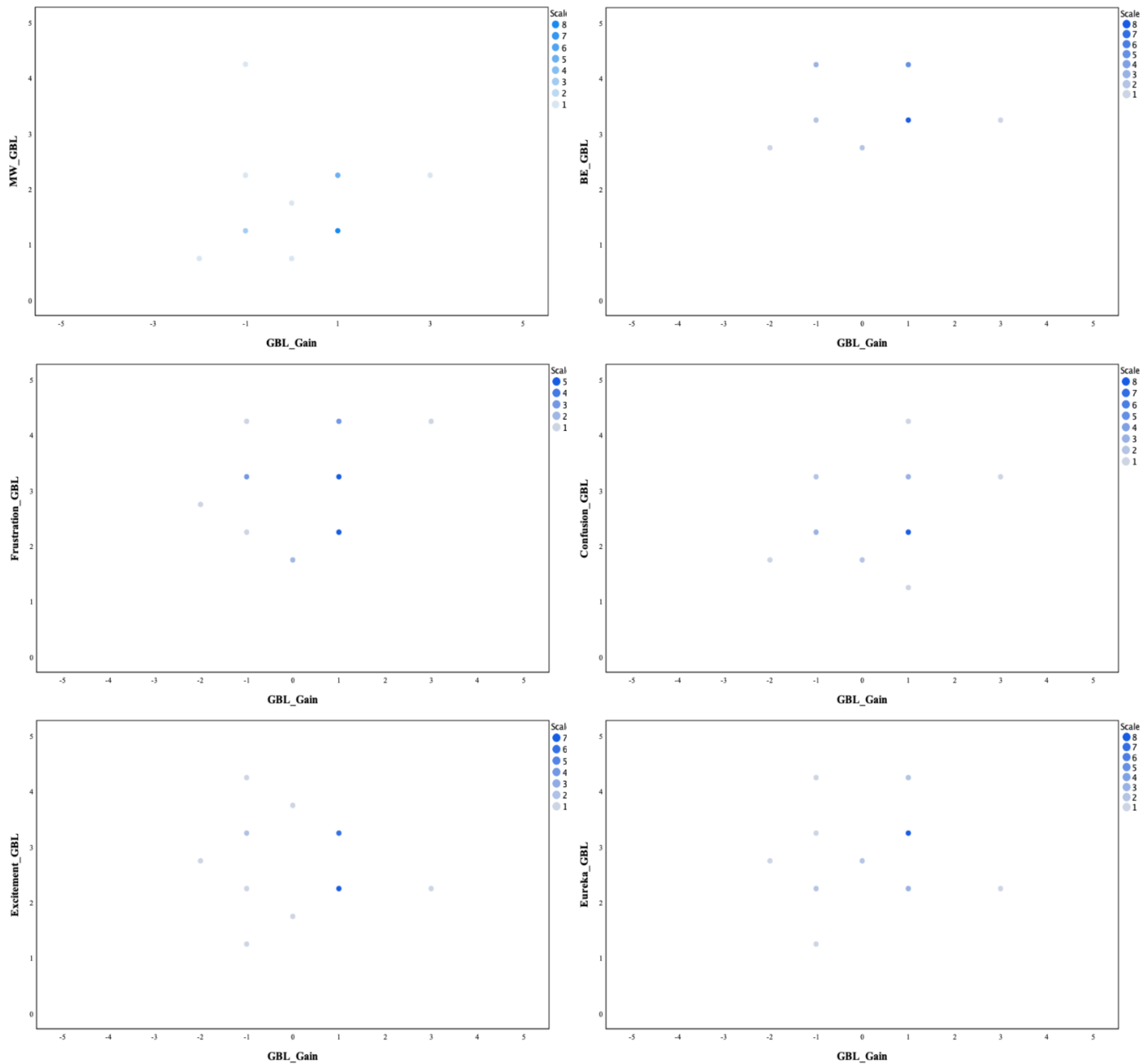
[ ]

APPENDIX C. SCATTER PLOTS

Scatter Plots of Relationships between Emotions and Learning Gains in IBL



Scatter Plots of Relationships between Emotions and Learning Gains in GBL



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