THE EFFECTS OF MANIPULATION OF VIRTUAL OBJECTS IN A GAME-LIKE ENVIRONMENT AS A SUPPLEMENT TO A TEACHING LESSON IN THE CONTEXT OF PHYSICS CONCEPTS

by

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Date February 14, 2018

Submitted in partial fulfillment of the Requirements for the Degree of Doctor of Education in Teachers College, Columbia University

2018
ABSTRACT

THE EFFECTS OF MANIPULATION OF VIRTUAL OBJECTS IN A GAME-LIKE ENVIRONMENT AS A SUPPLEMENT TO A TEACHING LESSON IN THE CONTEXT OF PHYSICS CONCEPTS

Pantiphar Chantes

Many scientific domains deal with abstract and multidimensional phenomena, and students often struggle to comprehend theoretical and complex abstractions and apply scientific concepts to real life contexts (Anderson & Barnett, 2013). One of these scientific domains that impose theoretical and complex abstractions is physics. The way that physics has traditionally been taught in school is through learning mathematical formulas and equations (Price, 2008). Many researchers proposed several ways to teach physics effectively. There are several virtual reality applications and computer games that were designed and utilized in the area of science education. In the case of physics
education, many studies yielded positive results when using computer games to teach abstract concepts to students (Maxmen, 2010; Price, 2008; Squire et al., 2004).
Furthermore, both physical and virtual manipulative tools were shown to be effective and essential in physics learning.

This study examined the effects of manipulation of virtual objects in a game-like environment when supplemented with a descriptive or a narrative lesson in the context of physics concepts related to force, distance, and conservation of energy. In particular, the study examined learners' performance on a test of physics knowledge related to the study when encountered with two factors that influence learning: lesson type and type of manipulation. The study drew on the research done on using virtual manipulatives in education and theoretical support from constructivist theories of learning implying that learners form their own knowledge through meaningful interactions with the world, and that prior knowledge greatly influences the construction of new knowledge in individual learners (Barbour et al., 2009; Bruner, 1966).

From the study's results, it seems that providing a textual pre-lesson is important for low-prior knowledge learners when it comes to learning physics concepts. Moreover, having engaged in a manipulation task also contributed to participants' learning gain (in both low-prior knowledge and high-prior knowledge groups) as measured by the post-assessments used in this study. Moreover, the results from this study help inform educational game designers who incorporate manipulatives about the role of providing pre-lessons that tie to concepts targeted by the manipulation activity, and how different kinds of manipulation in a game-like environment affect learning outcomes. The findings suggest that the role of these two factors combined requires further research.
ACKNOWLEDGEMENTS

Writing a dissertation is surely like running a marathon. Without the help of the many, I would not be one of the few who made it to the finish line. Therefore, I would like to express my gratitude to all those who helped me through this recent chapter of my life.

To my parents, Dr. Songpon Chantes and Tipp Chantes. None of this would be possible without your unconditional love and never ending support. Thank you for always believing in me.

To Professor Charles Kinzer, my advisor and mentor, for your great patience and support you have given me over the years. This dissertation would not have been possible without your continuous guidance and encouragement. I know I’ve procrastinated a lot, but I’m grateful that you still haven’t lost faith in me.

To my committee members, Dr. Joey Lee, Dr. Sandra Okita, and Dr. Andrew Gordon, for your support, feedback, and insightful commentary.

To Aj. Pearl Phaovisaid from GSSE at Thammasat University, who helped me tremendously during my data collection in Thailand.

To Dr. Maria Hwang, my dear friend and occasional partner in crime, who has gone above and beyond to support and encourage me during my doctoral study. I am grateful to have gotten to know you and shared this journey with you.

To Kwanchanok Intathong, Bank Apichai Chaiwinij, Kate Panada Vijayakul and Non Sitawach Nila Siri, for many types of assistance you have provided. I feel very fortunate to have worked with amazing people.
To Dr. Jin Kuwata, Dr. Katherine Williams, Dr. Sorachai Kornkasem, Dr. Selen Turkay, Ahram Choi, Mark Santolucito, Bebee Thavornchak for your moral support and advice.

To the Gildersleeve family, for your continued support and caring. Thank you for occasionally participating in my research studies. I am truly grateful.

To my friends and colleagues, who helped me in numerous ways each day. You know who you are. Thank you from the bottom of my heart.

Lastly, I would like to dedicate this dissertation to my grandparents, Teera Kannikar and Somjit Kannikar. I am who I am today because of you.

“If you only do what you can do, you’ll never be more than you are now.” – Master Shifu

P.C.
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LIST OF DEFINITIONS

**Building condition:** The Building condition required participants to virtually put mechanical parts (blocks) together to create a trebuchet corresponding to various specifications. The total arm length was given and the number of blocks needed for each arm was specified.

**Constructivist theory:** A learning theory that implies that learners form their own knowledge through meaningful interactions with the world, and that prior knowledge greatly influences the construction of new knowledge in individual learners (Barbour et al., 2009; Bruner, 1996).

**Computer games:** Interactive multimodal environments (that sometimes create a somewhat realistic depiction of abstract concepts e.g., physics concepts) where users can virtually manipulate and interact with objects to meet a challenge. They provide a sandbox environment for learners to explore and strengthen the understanding of concepts they are learning.

**Descriptive lesson:** The concepts of force, distance, and conservation of energy were explained descriptively in a chronological order starting with the different types of lever, mechanical advantage/disadvantage, lever in a context of medieval engineering e.g., learning about different types of catapult and the physics behind the launching/throwing mechanisms, physics of a trebuchet (the type of catapult that is the main focus of a given lesson and subsequently in the interactive learning task), and conservation of energy.
**High-prior knowledge:** Participants whose pre-invention test score is 50% or higher of the possible test score.

**Low-prior knowledge:** Participants whose pre-invention test score is lower than 50% of the possible test score.

**Manipulation task:** A type of interactivity in a learning context of this study. Learners are allowed to directly control virtual objects on the screen.

**Narrative lesson:** The lesson in the context of medieval engineering that began with a depiction of the historical siege engine from 1210 that was first used to conquer Minerve, a town in southern France that was deemed to be impregnable. The content in the narrative format did not give readers background (i.e., starting with different types of levers and the principle of mechanical advantage) or explicitly explain the physics concepts behind the mechanism of the trebuchet.

**Physical manipulatives:** Important tools in teaching because they are concrete, hands-on models that appeal to the senses particularly because they can be touched and manipulated by students (Schweyer, 2000). Physical manipulatives also relate to students' real experiences, since they are used in daily lives. Examples of these manipulatives include marbles, rubber bands, thermometers, inclined plane models, gears, wood, and aluminum.

**Physics concepts:** The concepts used in this study pertained to the topic of force, distance, and conservation of energy.

**Selecting Experimental condition:** The Selecting condition did not require participants to put mechanical parts together to create a trebuchet, but rather, focus on manipulating pre-
made trebuchets with different arm-length variations. Participants in this version were asked to count the number of blocks on each arm instead of putting them together.

**Text-based pre-lesson:** A lesson provided to participants. Depending on the experimental condition they were in, participants were asked to either read a descriptive lesson or a narrative lesson.

**Type of manipulation:** Different ways that participants interact with virtual objects in a game-like environment.

**Virtual manipulatives:** Dynamic visual representations on a computer that can be manipulated in the same way as physical manipulatives (Moyer, Bolyard, & Spikell, 2002). Virtual manipulatives simply involve the use of corresponding real-life instruments, objects, and materials in digital form.

**Virtual mechanical blocks:** Block-based virtual objects in the game that allows players to add, delete, or manipulate one block at a time. There are different kinds of blocks provided in the game and these blocks are categorized into eight groups (basic blocks, locomotion, mechanical, weaponry, flight, armor, hybrid, and uncategorized).
I – INTRODUCTION

Many scientific domains deal with abstract and multidimensional phenomena, and students often struggle to comprehend theoretical and complex abstractions and apply scientific concepts to real life contexts (Anderson & Barnett, 2013). One of these scientific domains that impose theoretical and complex abstractions is physics. The way that physics has traditionally been taught in school is through learning mathematical formulas and equations (Price, 2008). According to some research (e.g., Barnett, Keating, Barab, & Hay, 2000; Redish, 1994), students are required to be able to construct mental models that are testable and flexible in order to master the concepts in scientific domains. Understanding physics concepts is difficult and challenging for many students, but it is considered necessary as the Physics First curricular movement has emphasized that a deep understanding of physics provides a fundamental basis for future science learning (Squire, Barnett, Grant, & Higginbotham, 2004).

Many researchers proposed several ways to teach physics effectively. For example, a use of interactive-engagement methods was proven to have enhanced problem-solving ability of students (diverse populations in high schools, colleges, and universities) enrolled in an introductory physics course (Hake, 1998). Another example is when McDermott and Shaffer (2000) developed a teacher preparation program called Physics by Inquiry in which they drew on research findings and teaching experience when designing this laboratory-based curriculum program for K-12 teachers to teach physics and physical science. They summarized the instructional approach as follows:
Science instruction for young students is known to be more effective when concrete experience establishes the basis for the construction of scientific concepts. We and others have found that the same is true for adults, especially when they encounter a new topic or a different treatment of a familiar topic. Therefore, instruction for prospective and practicing teachers should be laboratory-based. However, “hands-on” is not enough. Unstructured activities do not help students construct a coherent conceptual framework. Carefully sequenced questions are needed to help them think critically about what they observe and what they can infer. (p. 75).

Moreover, many authors have claimed there are positive benefits gained out of using technology in both teaching and learning (Davies & Merchant, 2009, p. 7; Dickey, 2005; Gee, 2008; Habgood & Ainsworth 2011; Kirriemuir & McFarlane, 2004; Krussmaul, Dunn, Bagley, & Watnik, 1996; Willis & Raines, 2002). For example, many school teachers have noted the usefulness of computer applications as effective instructional support tools (Hannon, 2000, p. 8) and Fletcher (1991) showed that technology contributed to more efficient teaching by reducing time needed for instruction. Similarly, others view the use of computer and other forms of technologies in teaching as integral to making learning more fun, exciting and motivating, which can positively adjust the learners' preferences (Dickey, 2005, p. 70; Kirriemuir & McFarlane, 2004). This is especially true in the case of computer games, which are used in some schools to enhance or improve learners’ thinking and problem-solving skills (Dickey, 2005; Papastergiou, 2009; Hwang, Yang, & Wang, 2013). Fundamentally, as cited in Sadiq (2010), some difficult concepts can be understood more easily when using games as teaching and learning tools in educational environments (Squire, 2003).

There are several virtual reality applications and computer games that were designed and utilized in the area of science education. In the case of physics education, many studies yielded positive results when using computer games to teach abstract
concepts to students (Maxmen, 2010; Price, 2008; Squire et al., 2004). Furthermore, both physical and virtual manipulative tools were shown to be effective and essential in physics learning in a study conducted by Zacharia and Olympiou (2011), who investigated the effects of these two approaches. Compared to a controlled condition where the manipulation of both physical and virtual materials was absent, the results of the study showed that interacting with objects that had manipulative features was capable of promoting students’ understanding of concepts in the domain of heat and temperature (Zacharia & Olympiou, 2011).

**Using Computer Games in Learning and Teaching Physics**

For the purposes of this study, computer games are defined as interactive multimodal learning environments where learners can virtually manipulate and interact with objects to meet a challenge. Whatever occurs in games depends on the actions of each player during gameplay (Moreno & Mayer, 2007). In a study that aimed to assess the impact of a physics-based simulation game in a first year engineering design course, Ranalli and Ritzko (2013) considered the effectiveness of this type of simulation game as a place where students could practice their understanding of concepts through design process and production. They also posited that the game created a somewhat realistic depiction of physics concepts and could provide students with an environment to explore these concepts as they played (Ranalli & Ritzko, 2013). There is something unique about the way games shape our learning experiences. Not only can games promote and foster an understanding of knowledge in a discipline, they can also provide learners a playground where the understanding of knowledge can be strengthened through a series of play activities. From these notions, however, we know that the interactions one has
with computer games can be vastly different. There are many types of games (e.g., sandbox, puzzle) that allow players to not only interact with virtual objects, but to manipulate those objects, for example to assemble and combine small components to create a new one. This type of game provides a sandbox environment that has become increasingly attractive for education.

Nonetheless, little is known about whether it is the manipulation component or the game platform that support creativity or problem solving. Does manipulative ability in a game contribute to a positive learning experience? How much or little should one be able to manipulate virtual objects to make learning effective? Moreover, providing a lesson before a gaming activity is something that has been done in a normal classroom setting, but is providing a lesson prior to a gaming activity necessary when learning within game-based interactive media?

**Statement of Problem**

Games have received significant attention over the years by educators, researchers, practitioners, and parents by providing authentic experiences for learners (Gee, 2007). Some researchers suggest that games contain the best theories of learning from a cognitive science perspective (Foreman et al., 2003; Gee, 2003, as cited in Foster, 2011). There are several attributes of games that make them unique and appealing for use in educational contexts. One of the important attributes is the learner’s ability to manipulate and interact with virtual objects in simulated environments. The interactions that learners have in those environments are what make the learning experience unique to each learner. Although there is a growing body of research indicating the positive effects of using manipulatives in physics education, whether it be in virtual or physical forms
(e.g., Brelsford, 1993; Gire et al., 2010; Zacharia & Olympiou, 2011), research on how teaching lessons can be supplemented by virtual manipulatives in a game-like environment and how different interaction and manipulation one has in such environments is limited.

The complexity of physics concepts presents challenges for educators to deliver a meaningful learning experience through traditional methods, and conventional methods of instruction for physics are often insufficient to overcome the difficulties associated with learning physics concepts (Borrego, 2007). Therefore, it is important to explore alternative and potentially effective instructional methods, which can be used to facilitate the learning of these concepts.

**Purpose of the Study**

The purpose of this study is to examine the effects of manipulation of virtual objects in a game-like environment as a supplement to a teaching lesson in the context of physics concepts. Manipulation, which is a type of interactivity in a learning context, has long been regarded as playing an important role in instructional design (Mayer & Moreno, 2003). Bruner (1973) posited that active learning, which includes prolonged engagement and construction of meaning, could result in a deep and long-term understanding of a given knowledge domain. This study aims to examine how manipulation of virtual objects can influence learning as well as the effects of reading a lesson prior to a manipulation task (in a game-like environment) in the domain of physics education. Practically, the study was started in the hope of providing some insights for educational game designers, especially when designing a game in sandbox environment,
which has implications for how to properly leverage this kind of environment for better learning.

**Research Questions and Hypotheses**

The research problem addressed by this study is summarized in the following overarching question: How do different types of manipulation of virtual objects, and provision of descriptive or narrative text-based pre-lessons, affect learners’ learning outcomes when used in a game-like environment?

To address this overarching question, three research questions guided the study's design and data analysis (see Table 1.1).

Table 1.1

<table>
<thead>
<tr>
<th>Study Design</th>
<th>Type of Manipulation</th>
<th>Building (B)</th>
<th>Selecting (S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lesson type on physics concepts</td>
<td>Descriptive (D)</td>
<td>DB</td>
<td>DS</td>
</tr>
<tr>
<td></td>
<td>Narrative (N)</td>
<td>NB</td>
<td>NS</td>
</tr>
</tbody>
</table>

**Research Question 1. How does receiving a lesson on physics concepts before a manipulation task affect the participants’ learning outcomes as measured by post-tests?**

Research Question 1.1 Is there a difference in learning outcomes before and after reading a lesson?

Research Question 1.2 Is there a difference in learning outcomes between the descriptive lesson group (DB and DS) and the narrative lesson group (NB and NS) after reading a lesson?
Hypothesis 1. The text-based pre-lesson will positively affect participants’ learning outcomes as measured by the post-tests. Moreover, the narrative type of lesson was expected to have a more positive effect on participants’ learning outcome than the descriptive lesson.

**Research Question 2.** How do different types of manipulation (building or selecting) of virtual objects in a game-like environment affect participants’ learning outcomes as measured by post-tests?

- Research Question 2.1 Is there a difference in learning outcomes after engaging in a manipulation task in across groups?
- Research Question 2.2 Is there a difference in learning outcomes between the building condition lesson group (DB and NB) and the selecting condition lesson group (DS and NS) after engaging in a manipulation task?

Hypothesis 2. Being able to interact with and manipulate virtual objects in a game-like environment will positively affect participants’ learning outcomes as measured by the post-tests. Moreover, the building condition was expected to have a more positive effect on participants’ learning outcome than the selecting condition.

**Research Question 3.** How does reading a lesson followed by engaging in a manipulation task affect participants’ learning outcomes as measured by post-tests?

- Research Question 3.1 Is there a difference in learning outcomes between the groups that read a descriptive lesson on physics concepts followed by a manipulation task (either building or selecting conditions) in a game-like environment (i.e., DB vs. DS)?
Research Question 3.2 Is there a difference in learning outcomes between the groups that read a narrative lesson on physics concepts followed by a manipulation task (either building or selecting conditions) in a game-like environment (i.e., NB vs. NS)?

Research Question 3.3 Is there a difference in learning outcomes between the groups that read a lesson (in either version) on physics concepts followed by a building manipulation task in a game-like environment (i.e., DB vs. NB)?

Research Question 3.4 Is there a difference in learning outcomes between the groups that read a lesson (in either version) followed by a manipulation task with selecting of virtual objects in a game-like environment (i.e., DS vs. NS)?

Research Question 3.5 Is there a difference in learning outcomes between the four groups after reading a lesson and engaging in a manipulation task?

Hypothesis 3. There is an interaction between providing a lesson prior to a gaming activity and types of manipulation. That is, the effect of types of manipulation is different for participants who read a lesson and participants who do not read a lesson.

Manipulation of the graphical representations of objects is considered to be one of the predominant modes of interaction with computer systems (Sedig, Klawe, & Westrom, 2001). It allows users to directly manipulate and control virtual objects on the screen. In this study, the building condition refers to a task that allows users to assemble and deconstruct the virtual mechanical blocks to build trebuchets in the gaming environment whereas the selecting condition only allows users to interact with the given/pre-existing virtual objects. The selecting group’s interactions consisted of choosing pre-assembled trebuchet, counting the number of blocks (i.e., the length of an arm that would throw a projectile), examining a projectile’s range on each trebuchet, and observing what
happens. The current study is focused on examining the effects of manipulation of virtual objects and supplemental lesson types in a game-like environment.

**Overview of the Dissertation**

This dissertation is organized into five chapters. In this chapter, the rationale and purpose of the study are presented, followed by the research questions and hypotheses.

Chapter II provides a review of literature relevant to the study. The chapter reviews the literature on how technologies such as manipulatives have been used to assist in learning science in classrooms, the theoretical perspective of using manipulatives in science education. Since a computer game was used as a tool to study user’s ability to manipulate virtual objects on learning, there is a review of the literature on game-based learning as well as its affordances for the purpose of education.

Chapter III describes the research methodology, participants and study design, research instrument, materials developed for assessment, detailed procedures of how the study was conducted, and the data analysis procedures corresponding to the research questions.

Chapter IV reports the results of the study. The chapter begins with a preliminary analysis demonstrating experimental equivalency among different experimental conditions. The chapter ends with primary analyses that present the findings in detail.

Chapter V discusses the results corresponding to the research questions, interprets the findings, and presents the study's implications. Limitations of the study are discussed and future directions for further study are explored.
The domain of the instrument was first defined by the Motivation – Technology Training in the Workplace framework, but has evolved through the four phases of research to broadly be defined by five aspects of motivation: Manager Influence, Patient Care, Organization and Recommended Education, Individual Learning, and Peer and Social Observations (Figure 7).
II - LITERATURE REVIEW

How Physics is Learned in School

The emphasis in physics education has been on a central role of experiments, which ties to knowledge formation and conceptualization (Koponen & Mäntylä, 2006). Duit and Confrey (1996) argued that physics education could be improved through finding ways in which experiments are conducted in the classroom, and that suitable study materials and experimental models of teaching should be developed. Experiments conducted by physics students play a crucial role in their knowledge building and in understanding of how the world and universe work. This is why educators have historically placed high value on laboratory experiences in science classrooms (Gire et al., 2010).

Manipulatives are usually used in the laboratory. They are important tools in teaching because they are concrete, hands-on models that appeal to the senses particularly because they can be touched and manipulated by students (Schweyer, 2000). Physical manipulatives also relate to students' real experiences, since they are used in daily lives. Examples of these manipulatives include marbles, rubber bands, thermometers, inclined plane models, gears, wood, and aluminum.

Learning with Manipulatives

Manipulatives can be incorporated into classroom instruction in various ways to promote learning, as manipulative-based instructional strategies allow learners to
physically interact with concrete representations to learn targeted information (Carbonneau & Marley, 2012). To promote greater conceptual understanding, Heddens (1984) posited that instructional manipulatives may provide a bridge between the concrete and the abstract. He further suggested that there are two stages between the concrete and the abstract levels – semiconcrete and semiabstract – where semiconcrete represents a real situation such as pictures of real items, and semiabstract represents a symbolic representation of concrete items that do not look like the objects for which they stand. Bridging these stages and the gaps between concrete and abstract is crucial and can be done through the use of manipulatable objects with the assistance of teachers (Heddens, 1986).

Manipulatives were deemed to help students better understand abstract concepts in many domains, such as mathematics (McNeil, Uttal, Jarvin, & Sternberg, 2009; Sowell, 1989), reading comprehension (Glenberg, Gutierrez, Levin, Japuntich, & Kaschak, 2004), and elementary science (Bryan & Abell, 1999). The use of manipulatives has been around since ancient times, when people from different civilizations tried using physical objects to help them solve everyday math problems (Boggan, Harper, & Whitmire, 2010). Ancient civilizations such as those from Southwest Asia used counting boards made of wooden or clay trays covered with a thin layer of sand, to draw symbols for tallying an account or taking inventory (Boggan et al., 2010). In 1837, Friedrich Froebel, a German educator, introduced the world’s first kindergarten program, and developed different kinds of objects to assist kindergartners in recognizing patterns and appreciate geometric forms (Boggan et al., 2010). Meanwhile, Italian-born educator Maria Montessori in the early 1900s, introduced many other
materials to help preschool and elementary school students learn basic ideas through objects (Montessori, 2011). Since the 1900s, manipulatives have become essential tools for teaching, particularly mathematics-related subjects, so educators started investigating how influential such objects could be for learning by examining them side-by-side with other learning tools.

Jean Piaget’s learning model, which involves specific stages of operations, is perhaps the earliest theory of learning from which the importance of the use of manipulatives can validly be explained. According to Piaget, students, particularly children, are active learners and at the age from 7 to 12, which is the period of concrete operations, they can begin to think logically and start grappling with abstract and hypothetical concepts. He argued that children learn best through manipulation of concrete objects (Piaget & Inhelder, 1969).

As mentioned earlier, there has been a long history of using manipulatives in education. Piaget, Vygotsky, and Bruner provide psychological views and theories of learning using manipulatives in education, which are summarized in Table 2.1 (Helgoe, 2008; see also Bruner, 1966; Duckworth, 1964; Vygotsky, Rieber, & Hall, 1998).
Table 2.1

Psychological View of Manipulatives (adapted from Helgoe, 2008, p. 17)

<table>
<thead>
<tr>
<th>Researcher</th>
<th>Key Contributions</th>
<th>Role of the Learner</th>
<th>Role of the Object</th>
</tr>
</thead>
<tbody>
<tr>
<td>Piaget</td>
<td>Documented a genetic epistemology showing the relationships between child physiological development and learning. Learning progresses through stages: sensorimotor (birth to 2 years), preoperational (2 to 7 years), concrete operational (7 to 11 years), formal operational (11+ years). Emphasis is on individual cognitive development.</td>
<td>Child is an active participant as their growth and development allows. Learning readiness: Children must reach certain developmental levels before they can learn some concepts. Learning is discovery.</td>
<td>Objects are materials which provide different learning opportunities depending on the child’s developmental stage. Knowledge is developed from biological reflexes or “reflexive schemes” to move complex mental schemes as symbolic representations of ideas.</td>
</tr>
<tr>
<td>Vygotsky</td>
<td>Learning results from mediation of tool use and speech. Learning is a culturally based psychological process. The zone of proximal development is the difference between what a child can learn on his or her own and what he or she can learn by interaction with a more capable peer or teacher.</td>
<td>Children’s practical intelligence manifested in activity is a result of physical growth and development along with mastery of tools and signs, both psychological and physical.</td>
<td>Objects are tools with cultural meaning. Interaction with objects is part of the internalization of learning process.</td>
</tr>
<tr>
<td>Bruner</td>
<td>Provided a theory of instruction to codify a progression for learning. Knowing as doing. Humans represent the world in three ways: through action (procedural); through imagery (iconic); through symbols (symbolic). Learning occurs in a context of agency (taking control of your own learning), reflection, collaboration, culture.</td>
<td>Children learn by doing Curiosity and the drive for competence are motivating factors for learning.</td>
<td>Objects are materials for interaction, representation, and tools for extending human potential. The mind is an extension of the tools and objects and the jobs one does with them. Language is the instrument of thought.</td>
</tr>
</tbody>
</table>

Fundamentally, Piaget, Vygotsky, and Bruner all emphasized that the learners’ interactions with objects was a key part of learning and understanding concepts (Helgoe, 2008). Several research studies have shown the success of using manipulatives in math
and science curricula (e.g., Driscoll, 1983; Frederick, Edward & Shaw, 1999; Parham, 1983; Sowell, 1989; Suydam & Higgins, 1977).

A great deal of research tends to investigate how computer simulations of laboratory experiments can be used as a substitute for experiments that usually involve the use of physical objects (Gire et al., 2010; Zacharia & Constantinou, 2008; Zacharia, Michael, Olympiou, & Papasozomenou, 2012). Manipulatives that were used in learning science positively affect students’ conceptual understanding and learning outcomes, where they offered students the capabilities for experimentation – especially the virtual kind (Zacharia & Constantinou, 2008). Computer-simulated laboratory experiments are traditionally labeled as *virtual manipulatives*, and allow students to manipulate virtual instruments, objects, or materials needed for experiments (Gire et al., 2010; Zacharia et al., 2012; Zacharia & Constantinou, 2008). Virtual manipulatives simply involve the use of corresponding real-life instruments, objects, and materials in digital form. There have also been some arguments about the conditions under which the use of physical or virtual manipulatives in science experimentation may be preferable. Zacharia and Constantinou (2008) suggested that either type can be used if they improve opportunities for student learning in the course of conducting experiments. However, they concluded that virtual manipulative interactions are the ones that can provide students with opportunities to manipulate conceptual objects and study phenomena of very large or very small temporal and physical dimensions when physical manipulatives cannot.

**Virtual Manipulatives**

Virtual manipulatives refer to dynamic visual representations on a computer that can be manipulated in the same way as physical manipulatives (Moyer, Bolyard,
Spikell, 2002). By being able to interact with virtual objects, users have an opportunity to form meanings and see relationships with those objects as a result of their own actions (Moyer et al., 2002). Researchers further suggest that this kind of engagement and interactive capability that users have with virtual manipulatives differs from the act of merely pointing and clicking something on the computer screen to show results or answers. Therefore, virtual manipulatives, in their view, represent interactive, web-based visual representations of dynamic objects that offer opportunities for constructing knowledge (Moyer et al., 2002).

Zacharia and Constantinou (2008) found no significant difference between using virtual and physical manipulatives in supporting students’ understanding of concepts related to the topic of heat and temperature. They suggested that although constructivist learning theory emphasizes the importance of active learning and skill practicing, it does not require learning to be done through physical manipulation unless the target is to develop perceptual-motor skill.

On the other hand, Finkelstein et al. (2005) showed a difference between mastery of physics concepts and skills using virtual as opposed to physical laboratory simulations. Although they found that students in the virtual equipment groups outperformed students in the physical equipment groups, both on conceptual questions related to simple circuits and in the coordinated tasks for assembling a real circuit, they did not suggest that these simulations necessarily trumped the use of real equipment in terms of conceptual learning acquisition. However, it was evident that simulations that are well designed and applied in the right conditions and contexts could support and promote students’ learning experiences (Finkelstein et al., 2005).
There is, however, no guarantee in the use of manipulatives to improve learning (Baroody, 1989) and there are several studies that found that manipulatives did not assure success. A study done by Fennema (1972) showed that students in a manipulative group did not perform as well as those in a non-manipulative group on a transfer test. From the results, though, it was suggested that it is possible for students to learn better with the use manipulatives and that experiential background seems to play a crucial role in facilitating learning, especially for children of a young age (Fennema, 1972). Some teachers tend to view manipulatives as something that were used primarily for fun and fail to use them effectively (Hiebert & Wearne, 1992; Uttal, Scudder, & DeLoache, 1997). For example, a study done by Gentner and Ratterman (1991) has shown an unsuccessful result from using manipulatives. They asserted that it is not enough for children to advance their knowledge of mathematics by using manipulatives when there was a lack of relationships between manipulatives and other forms of mathematical expression.

**Learning from Text – Advance Organizers**

The importance of prior knowledge for learning has been deemed by many researchers as one of the most important prerequisites for learning (see Ausubel, Novak, & Hanesian, 1968; Weinert & Helmke, 1998). Prior knowledge, as Kujawa and Huske (1995) put it, refers to the combination of pre-existing attitudes, knowledge, and experiences of a person and the word “prior knowledge” has been used interchangeably with “background knowledge.” Vogt and Echevarria (2008) posited that learners develop understanding through the acquisition of newly acquired knowledge and their background knowledge.
When we consider the effect of prior knowledge on new knowledge construction, often times we look at how different types of instructional methods can reduce the cognitive demands in learners with different level of prior science knowledge. Lee, Plass, and Homer (2006) conducted a study to examine the cognitive requirements to process learning materials what are the ways to reduce any unnecessary cognitive demands so that learners can allocate the resources to construct new knowledge.

From a theoretical point of view, Alexander, Schallert, and Hare (1991) proposed a framework for knowledge terminology called general world knowledge, which essentially is prior knowledge that learners have that includes metacognitive knowledge, sociocultural knowledge, and tacit knowledge that excludes domain specific knowledge about certain subject matter. An example would be that learners might not know anything about the formal law of conservation of energy (domain specific about physics); however, learners may understand a phenomenon of energy changing form and that it cannot be created or destroyed. What would be the most beneficial way to make connections between the knowledge that learners already know and the incoming information that they have to learn and might have some informational background on the topic?

Ausubel (1960) introduced a concept called advance organizers, which could aid the learning and retention of unfamiliar but meaningful verbal material through the advance introduction of relevant concepts (organizers). His findings suggest that the use of appropriate advance organizers could lead to more effective retention and render unnecessary rote memorization processes (Ausubel, 1960). Corkill (1992) reviewed approximately 30 experiments regarding the use of advance organizers and discussed a
debate surrounding their facilitating effects. She concluded that although not all studies have found beneficial effects associated with advance organizers, they generally facilitate recall.

Similarly, Gurlitt, Dummel, Schuster, and Nückles (2012) examined the role of advance organizer to see which type, whether a structured and enhanced advance organizer or a less-structured advance organizer, better facilitates text-comprehension. The findings from this study suggested that advance organizers could be more than just an activation of existing knowledge, and that educators should think about how these can be used to scaffold prior specific knowledge at the beginning of instruction (Gurlitt et al., 2012).

**Constructivist Theory of Learning**

Constructivism, as Barbour, Rieber, Thomas, and Rauscher (2009) describe it, refers to a learning process where learners form their own knowledge through meaningful interactions with the world. According to Bruner (1966), prior knowledge greatly influences the construction of new knowledge in individual learners. Learners use a variety of cognitive processes, which include paying attention to important information, organizing that information in coherent representations, and incorporating these representations with existing knowledge (Mayer, 1999). Learning is essentially considered to be active, where learners must “seek and generate” relationships between the lesson context and prior knowledge (Hooper & Rieber, 1995, p. 8). The constructivist theory of learning implies that through the use of technology such as computers, students can have a good sense of the lessons or educational materials they are presented with in the classroom – i.e., those that they are able to see and control through computers.
(Mayer, 2003a, p. 128). According to Azevedo (2007), Wertheimer believes that constructivist learning through the use of technology via virtual manipulatives can help in facilitating not simply rote learning but also meaningful learning, which means that students not only learn through memorization, but also learn with understanding.

**Making Sense of Learning Materials**

Through a constructivist theory of learning, learners are able to make sense of educational materials being presented to them, allowing for the utilization of their cognitive capacity as well as their behavioral capacity (Blumenfeld et al., 1991). Hence, through constructivism, viewing what is presented to learners involves not only behavioral learning but also cognitive learning, which involves not only mentally acting in response to representations and symbols presented in the educational materials, but also understanding these symbols and applying them to their own circumstances (Mayer, 2003a). The key to constructive learning is putting into experience what is learned in the classroom. This means that materials presented in the classroom are made active in the minds of students and in some ways students are placed into a more active, as opposed to a more passive, learning experience.

Passive learning puts emphasis on the learners’ automated response to what is presented to them, while active learning stresses the learners’ cognitive understanding (Matthews, 1998). Besides, passive learning allows the learners to identify and recognize only what is presented to them, while active learning lets the learners comprehend the reason or the why of the thing presented in one way or another (Matthews, 1998).
Learning Through Experience

To some extent, constructive learning can be equated to experiential learning. Active learning, which is a component of constructive learning, requires that students are able to actively apply, at least in their minds, what they learn inside the classroom (Boris, 2011). Kolb, Boyatzis, and Mainemelis (2001) defined Experiential Learning Theory (ELT) as a holistic model of the learning process and a multilinear model of adult development. The theory has drawn heavily on the work of John Dewey, Kurt Lewin, and Jean Piaget when it has taken together philosophical pragmatism, social psychology, and cognitive development (Kolb, 1984). Kolb (1984) described learning in ELT as “the process whereby knowledge is created through transformation of experience. Knowledge results from the combination of grasping and transforming experience” (p. 51). Figure 1 illustrates the four-stage learning cycle where 1) concrete experience refers to perceiving new information through something tangible, concrete, relying on our senses and immersing ourselves in concrete reality, 2) reflective observation refers to processing experience by carefully watching whoever is involved in the experience and reflecting on what happens, 3) abstract conceptualization refers to perceiving or grasping new information through symbolic representation, thinking about, analyzing, and 4) active experimentation refers to learning through actively creating new experiences (Kolb et al., 2001).
Shull (2008) designed an experiential learning activity in the study of Fourier Transforms that involved mathematical concepts that are new to students. Since Fourier Transforms is applicable in different engineering aspects, Shull designed an experiential learning curriculum to help students understand the concepts by decreasing anxiety that might have interfered with their understanding. The experiential learning was designed to “actively engage the students, increase their excitement in learning about Fourier Transforms, make the material more relevant and connected to the real world, and present material in the hands-on format and in a less threatening environment” (Shull, 2008, p. 8). The students were divided into different working groups to study the Fourier Transform – image, focal plane, objects and reconstructed image – and were tasked to record their observations and draw their own conclusions that included the evidence that complex mathematical concepts could be understood through experiential learning (Shull, 2008). By doing this, students were able to experience hands-on manipulation of the data in the transformed plane and observe the effect on the object in the inverse of that plane.
The study showed that students can learn complex mathematical concepts using a combination of traditional and experiential methods (Shull, 2008).

Other evidence for learning through practical experiences is seen in learning science in museums. Griffin (1998) investigated how museum visits can be used to meet three major purposes for practical work, which are 1) to deepen understanding of scientific ideas, 2) to experience the scientific process, and 3) to acquire scientific research skills. She stated that by allowing personal interest and curiosity to drive students’ learning, students are able to gain more knowledge from their excursion by practicing scientific investigation with the help of teachers providing them appropriate teaching and learning approaches and strategies (Griffin, 1998).

**Intrinsic Motivation Through Virtual Manipulatives**

As a result of challenge, interest, curiosity and fantasy, motivation can be made to be intrinsic to the learner. From the point of view of Constructivist theory, intrinsically motivated learning involves goal-achievement in a game curriculum, which now becomes a source of challenge and interest in a learning game (Gee, 2008; Malone, 1981, p. 336). But for Graesser et. al (2008), intrinsically motivated learning, which is accompanied by engagement, is a result of confusion. Teachers are able to raise the interest of their students through computer game-based learning if they are able to arouse their curiosity. In other words, teachers produce a source of confusion in learning, in which they can make their students think about how they could solve problems and look for the missing parts of a particular subject matter they are dealing with. Also, motivated learning, through the use of computer-based technology, is when students are able to personally internalize the subject matters that are taught to them inside the classroom, which means
that they are able to apply it on their own while thinking about what they learned and understood in school (Cordova & Lepper, 1996).

Although the current study in this dissertation was not directly related to a game study (since a game was not used to its full potential), it is important to state a definition of what a game actually is, as well as discuss the affordances, the features of the environment, the design elements of a game, as well as how games can be used to facilitate learning.

**Defining Educational Games**

It is said that games and play are inevitably interwoven in a way that one affects the other (Becker, 2008). The interaction one has with games is fundamentally the act of play. Therefore, it is necessary to discuss what *Play* is and how it is associated with games. First, the definition and concept of Play is described. Then, in order to define Game, various characteristics of games are discussed, as these are central to efforts at arriving at a definition of Game.

Huizinga (1950), a pioneer thinker in game studies, summed up the characteristics of play in his work, *Homo Ludens*, saying that play is

> [A] free activity standing quite consciously outside *ordinary* life as being *not serious*, but at the same time absorbing the player intensely and utterly. It is an activity connected with no material interest, and no profit can be gained by it. It proceeds within its own proper boundaries of time and space according to fixed rules and in an orderly manner. It promotes the formation of social groupings, which tend to surround themselves with secrecy and to stress their difference from the common world by disguise or other means. (p. 13).

Essentially, games serve as a special place or a playground that exists apart from reality, and various things are permitted in that space that should not, or cannot, exist in real life (Huizinga, 1950). Huizinga (1950) defined such space and called it “the magic
circle” (p. 10). Although some fantasy elements or rules that take place in the game or the magic circle cannot happen in real life; we can, nevertheless, learn things from games that can be applied to real life (Becker, 2008).

Koster (2005) noted in his book, *A Theory of Fun for Game Design*, various characteristics of games and play ranging from a series of meaningful choices to a series of challenges in a situated environment. He defined games as puzzles to solve and noted that “games serve as very fundamental and powerful learning tools” (Koster, 2005, p. 36). Similarly, Hogle (1996) posited that games served as cognitive tools that allow players to become better thinkers and focus on higher order thinking skills rather than lower order thinking skills such as memorization and recall. Rieber, Smith, and Noah (1998) suggested that games may provide opportunities for learning through the use of higher thinking skills during gameplay. Examples include the classic matching games where one is asked to match identical items, or items in the same categories. This type of game can be seen in foreign language learning contexts in which the goal of the game is for players to match a word with its correct meaning.

Elias, Garfield, Gutschera and Whitley (2012) described characteristics of games as something that depend on its audience (i.e., the people who play it) as well as the game itself. They further stated that a characteristic is *systematic* if it depends on the game as a system such as rules, and *agential* if it depends on a player base. Another characteristic of games proposed by Gredler (2004) states that games are like an “experiential exercise that transports learners to another world” (p. 571). In a sense, learners are required to exercise their knowledge, skills, and strategies to play a game and advance to more challenging levels. Gredler’s discussion of “another world” is quite similar to what
Huizinga illustrated about the magic circle, wherein players enter a game space world where challenges and scenarios are simulated.

In this study, the definition of educational games is a combination of the previously mentioned characteristics, with relevant attributes such that games form a powerful learning tool that allows players to develop and utilize their knowledge and skills cognitively while transporting them into a simulated world where the things that they learn in the game can be applied to real life. More generally, as noted earlier, in this study games are defined as interactive multimodal learning environments where learners can virtually manipulate and interact with objects to meet a challenge.

**Overview of the Affordances of Games**

There has been an ongoing debate among researchers about the affordances of games in educational contexts and whether people can actually benefit from playing games. Researchers such as Krzywinska (2006) and Oblinger (2004) have argued that games do indeed demand some form of cognitive abilities from players, which perhaps other media (e.g., texts) does not. There are several researchers (e.g., Barab, Gresalfi, Dodge, & Ingram-Goble, 2007; Malone & Lepper, 1987) who also support this claim that games offer players different pedagogical stances from traditionally direct or guided instructional practices (Foster, 2009).

There are several attributes regarding the characteristics of games and what make games so unique and appealing for use in educational contexts. Although this study is not a study of games, manipulations (i.e., building and selecting virtual objects) are interactions that players experience in most games. Moreover, the physics concepts
targeted in this study were operationalized through a game environment. In the following sections, these attributes are discussed.

**User Control**

Winters, Green, and Costich (2008) acknowledged the important learning opportunities provided by computer-based learning environments (CBLEs) such as computer games, and found that self-regulatory learning processes may mediate the relationship between CBLEs and academic performance. Self-regulatory learning, according to Bandura (1991) is a general set of skills that relates to the ability of being aware of one’s performance and outcomes (e.g., monitoring one’s progress, keeping track of time, and planning and routinizing the work). Studies showed that students adapted self-regulatory learning processes in web-based learning, and that learner tasks and processes influenced self-regulatory learning processes. In the 33 studies they reviewed, they found that both learner and task characteristics, as well as types of learner support, were related to self-regulatory learning of students who used CBLEs. The study also found that academically successful students tended to use more effective strategies to learn in CBLEs, and students with prior knowledge tended to engage more in planning and monitoring than students without prior knowledge. Goal orientation may affect self-regulatory learning of students, but not learning outcomes. A high degree of learner control works better for students who are highly self-regulated than for those who are not. Finally, adaptive scaffolding in the form of a tutor might support the many areas of student self-regulatory learning as they learn in CBLEs.
Interactivity

Schrader and Bastiaens (2012) explored the characteristics of educational computer games and how learners learn from them, as well as learning outcomes. From the cognitive load and emotional perspectives of learners, the important variables in the design of computer games include: the combination of verbal and nonverbal information using mixed modalities of presentation, the opportunity for the learners to actively interact with the game, and allowing the learners to construct their own solutions for the optimum learning experience. Moreover, the complexity of the game needs to be appropriate for the level of user. Different components of a game do not work in isolation; instead they are interconnected with each other. Learners need to consider these components simultaneously, process the information, and understand the interconnection cognitively in order to analyze the information offered in these games. They generate a hypothesis regarding the learning objective, and repeatedly test it when they receive error feedback. Consequently, learners modify the gaming and learning goals, plan their strategies, direct their efforts to successful gaming and learning, and reflect on whether they understand what they are learning. Additionally, learners have to simultaneously regulate the experimental tasks by manipulating or controlling the technical features using a mouse or a joystick.

Engagement

According to Fredricks, Blumenfeld, and Paris (2004) there are three types of engagement: behavioral, emotional, and cognitive. The relationship between these types of engagement are intertwined and greatly related to positive gains in learning outcomes. For example, a student who is cognitively and emotionally engaged in classroom activity
tends to be more willing to do the work and put forward the effort necessary to understand and master complex concepts. In turn, this student is behaviorally engaged, which leads to being more attentive in class and fully participating in learning activities.

Many educators have opted to use computer games as an alternative method of delivering lessons to students in order to increase engagement and classroom participation. However, very few studies have examined which features of a game enable students to remain engaged while learning. Ke and Abras (2013) conducted a descriptive case study to analyze the game-based learning of students with learning needs. The study was conducted in two middle schools of a Southwest state in the USA. The results of the study suggested that appropriately designed games could promote engagement and learning for students with special needs. The features of the game that promoted engagement for students with special needs included: simplicity with instant rewards, visualizations to enable the students to process information, giving players some control over the game (such as being able to create a virtual identity or avatar), and active and productive inputs to encourage play action. Moreover, embedding skill practice into the game could also engage students with special learning needs.

In the current study, different types of manipulation (i.e., building and selecting) are considered to have different degrees of cognitive engagement in a manipulation task. How these two different types of engagement affect participants’ learning outcomes was examined in this study.
How Video Games Facilitate Learning

Below, a brief review of the potential of video games to facilitate learning is presented. This is done because, in the context of the study reported here, physics concepts were operationalized through a game environment. Manipulation – the way that players interact with virtual objects – is an integral part of gameplay and can also influence learning.

Computer games are useful instruments for learning specific strategies and for acquiring knowledge in a particular content (Gros, 2007). Using educational computer games instead of employing a traditional lecture-based approach in teaching could nurture the development of various mental skills such as critical/analytical thinking and problem-solving skills for students (Papastergiou, 2009). Similarly, game-based learning approaches to teaching involve the same, but with more innovative educational content and processes to ensure students’ active, multi-sensory, experiential, problem- and assessment-based (i.e., through challenges, scoring and levels in the game) learning – and yet students find such an approach more enjoyable and more of an interesting learning environment (Papastergiou, 2009). Correspondingly, some authors (Cordova & Lepper, 1996; Malone 1981; Jenkins et al., 2009) find such game-based learning highly motivating for students as they can easily contextualize, personalize, situate and apply what they learn and understand through educational games, and are stimulated with the challenge and curiosity that such educational games bring with them (Malone, 1981).
Learning in Game-Like Environments

Game-based environments have found positive feedback for teachers and students alike, and what interests teachers the most is the fact that game-based learning has been effective in teaching problem-solving techniques and resulted in highly engaged learners. While game-based learning has been used for some time, recent developments have seen game-based research come more to the forefront (Lester et al., 2014). The effectiveness of games for learners, however, had been attributed to the great promise games hold in motivating learners with challenges and rapid feedback. From this rapid feedback, students are able to adjust their choices, as they have to do in real life, in order to succeed in the game. Such immediate decision-making often mirrors the kind of decisions people have to make in real life.

Through game-based environments in science instruction, teachers are able to assess students' visual-spatial aptitude and skills. This allows them to further enhance lessons in order to fill students' learning gaps related to knowledge acquisition, content understanding, and motivation (Lester et al., 2014). Upon witnessing the effect of game-like instructions on students, Smetana and Bell (in Lester et al., 2014) introduced implementation guidelines that incorporated timely and innovative technologies to educational institutions. Traditional techniques and strategies of teaching were encouraged and supplemented with newly available technologies. The supplementary role of game-based instructional technologies was also supported in the Mott et al.'s, study (cited in Lester et al., 2014). Mott and colleagues explained that readers could be transported to another world by traditional instruction strategies, but with computer games, students could actually experience what they were reading or hearing about.
One of the more known and promising skills enhanced with games is their ability to foster problem-solving skills (Lester et al., 2014). Although students are just faced with simulated situations, they are trained to think and make decisions quickly, and are also trained to act quickly on their decisions, as games often require fast action. Inaction often results in a lack of success in games, as opponents are able to catch up or even overtake less adept players. In this environment, players are trained to think quickly, analyze even more quickly, and act proactively.

**Simulations, Games, Manipulatives: Effective Teaching Aids in Physics**

Students, particularly in the case of children, are said to be more responsive, with higher level of interest, when they are bound to achieve specific goals, provided with a challenge, and when their imagination and curiosity are aroused (Dickey 2005; Gee, 2008). From Habgood and Ainsworth's (2011) point of view, games, including simulations, apply to a wide range of digital and non-digital applications. Simulation, through games, has been considered an important element in effective teaching, and educational computer games can bring about intrinsically motivated learners as students become more interested and motivated to learn using gaming activities (Habgood & Ainsworth, 2011).

In physics education, studies have found that computer laboratory simulation can provide equally interactive and highly effective learning experiences when compared to physical laboratories, and can enhance or even correct students' understanding (Gire et al., 2010; Zacharia & Constantinou, 2008). Students, for instance, are able to grasp important physics concepts such as changes in temperature through virtual simulations without the safety concerns of a real life experiment (Zacharia & Constantinou, 2008).
Computerized laboratory simulation using virtual manipulatives have also created a better, and more calculated understanding of physical objects such as pulleys, and have effectively taught the concepts effort, force, and mechanical advantage (Gire et al., 2010).

**Interaction in Computer Games: Manipulations of Virtual Objects**

Using virtual manipulatives, students are able to estimate, sometimes very closely, activities in real life. In the case of physics, some software can be used to simulate laboratory activities, such as THERMO, which was used for Heat and Temperature experimentation (Zacharia & Constantinou, 2008). However, some computer games, such as Minecraft, have been converted into educational tools. Minecraft, as one of the most popular games of all time and having sold more than 20 million copies, has been critically acclaimed by gamers all over the world (MacQuarrie, 2013). Minecraft is a sandbox environment with infinite 3D cubes. What is relevant for learners in physics as well as in other science subjects is the idea of finding natural resources, building and crafting tools, as well as finding food and other necessities to protect players from monsters (MacQuarrie, 2013). By being able to manipulate as well as interact with game components through clicking, assembling, and disassembling, players of Minecraft are able to have an idea of how physical virtual objects function in Minecraft’s virtual world. As Marley and Carbonneau (2014) stated about the classroom applications of manipulatives, rather than examining whether instruction with manipulatives is better than conventional instructional approaches, researchers should examine the value added by various instructional factors that could accompany instructional manipulatives.
Conclusion

The literature review presented above has attempted to summarize the theoretical and empirical support for using virtual manipulatives in physics education, and has related this to digital game environments. The review has shown that manipulatives are effective in learning and that interacting and manipulating virtual objects in both digital and non-digital environments can promote students’ understanding of concepts in the domain of physics. The review also emphasized the importance of prior knowledge on learning new information and how advance organizers were used to enhance retention and facilitate knowledge acquisition. Since the physics concepts to be learned in the study reported here were operationalized through a game-like environment, it was necessary to review the characteristics and attributes of games as related to the current study.

The next chapter presents the procedures and methods used in the study reported here, as informed by the literature presented above.
III - METHODOLOGY

This chapter details the methods employed in this study. The first section states the research questions and hypotheses of this research. The second section describes participants and research design. The third section explains instruments and measures used in the study. The fourth section details the procedure, and the final section describes the data analysis procedures corresponding to the research questions of the study.

Hypotheses

The study was designed to examine (1) the effects of a text-based pre-lesson and (2) the effects of manipulating virtual objects in a game-like environment on learning the physics concepts of force, distance, and conservation of energy. In this study, two versions of the lesson and two types of manipulation were provided for participants in different conditions. One version of the lesson presented descriptive information of the physics concepts (normally seen in textbooks and classroom lessons) before a manipulation task, while the other version of the lesson presented the information in a narrative, story format. One type of manipulation task (building condition) allowed participants to assemble and deconstruct the virtual mechanical blocks to build trebuchets in the gaming environment whereas the selecting condition only allows users to interact with the given/pre-existing virtual objects. The selecting group’s interactions consisted of choosing pre-assembled trebuchet, counting number of blocks (i.e., the length of an arm
that would throw a projectile), examining projectile’s range on each trebuchet, and observing what happens. The lessons appear in Appendix B and C.

Hypothesis 1. The text-based pre-lesson will positively affect participants’ learning outcomes as measured by the post-tests. Moreover, the narrative type of lesson was expected to have a more positive effect on participants’ learning outcome than the descriptive lesson.

Hypothesis 2. Being able to interact with and manipulate virtual objects in a game-like environment will positively affect participants’ learning outcomes as measured by the post-tests. Moreover, the building condition expected to have a more positive effect on participants’ learning outcome than the selecting condition.

Hypothesis 3. There is an interaction between providing a lesson prior to a gaming activity and types of manipulation. That is, the effect of types of manipulation is different for participants who read a lesson and participants who do not read a lesson.

Participants and Design

Participants in this study were recruited from two different universities. One was a large private university in New York City; the other one was a public (national) research university in Bangkok, and Thailand’s second oldest institute of higher education. The participants from the university in Thailand were currently enrolled in an international program that required an English proficiency score\(^1\) relatively comparable to the average requirements of many universities in the United States (Clark, 2014). A total of thirty-two (n = 32) participants were recruited from the university in the United States.

\(^{1}\) The admission requirements for the international program in terms of English proficiency score is as follows (only one is required): TOEFL 61, IELTS 5.5, TU-GET 500, CU-TEP 61, SAT (critical reading) 400.
and a total of ninety-four (n = 94) participants were recruited from the university in Thailand. Although the number of participants from each location was different, a statistical analysis was done to ensure statistical equivalence between experimental groups in participants’ age, gender, ethnicity, education level, learning performance (pre-intervention score of physics concepts targeted in this study), and English language reading comprehension. The details of this analysis are discussed in the following chapter.

One hundred twenty-six (n = 126) adults participated in this study and 121 adults (n = 121) completed all five phases. Five participants did not complete a manipulation task (although they completed the pre-intervention survey, lesson reading, and assessment 1), therefore the total number of participants was one hundred twenty-one (n = 121) in the analyses related to the manipulation task. Therefore, the analysis for RQ1 is based on 126 participants, while the other questions are based on 121 participants.

Participants were randomly assigned to one of the four experimental groups (DB, NB, DS, and NS, as detailed below and previously shown in Table 1.1, and reprinted below in Table 3.1. For each group, the number of participants is shown relative to the two countries from which they were recruited.

Table 3.1

<table>
<thead>
<tr>
<th>Lesson type on physics concepts</th>
<th>Type of Manipulation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Building (B)</td>
</tr>
<tr>
<td>Descriptive (D)</td>
<td>DB (n = 30)</td>
</tr>
<tr>
<td>(USA = 10, Thailand = 20)</td>
<td>(USA = 7, Thailand = 27)</td>
</tr>
<tr>
<td>Narrative (N)</td>
<td>NB (n = 29)</td>
</tr>
<tr>
<td>(USA = 8, Thailand = 21)</td>
<td>(USA = 7, Thailand = 26)</td>
</tr>
</tbody>
</table>
These groups were based on two independent variables: lesson type and types of manipulation, with the following experimental conditions.

**Descriptive lesson with Building condition (DB)**

Participants in this group read a lesson that presented descriptive information on the concepts of force, distance, and conservation of energy. The participants then completed three exercises that required them to build and assemble variations of virtual objects in a game-like environment. The exercises pertained to the physics concepts and information/content they previously received from the lesson.

**Narrative lesson with Building condition (NB)**

Participants in this group read a lesson in a narrative format that includes the concepts of force, distance, and conservation of energy. Participants then completed three exercises that required them to build and assemble variations of virtual objects in a game-like environment. The exercises pertained to the physics concepts regarding force, distance, and conservation of energy.

**Descriptive lesson with Selecting condition (DS)**

Participants in this group read a lesson that presented descriptive information on the concepts of force, distance, and conservation of energy. Then, participants completed three exercises that allowed them to interact with the same virtual objects as the DB group, but without being able to assemble or deconstruct the virtual objects' components. The exercises also pertained to the physics concepts and information/content they previously received from the lesson.
Narrative lesson with Selecting condition (NS)

Participants in this group read a lesson in a narrative format that includes the concepts of force, distance, and conservation of energy. Participants completed three exercises afterward that only allowed them to interact with the completed version of virtual objects without being able to assemble or deconstruct the components of those virtual objects. The exercises also pertained to the physics concepts and information/content they previously received from the lesson.

Instruments and Measures

To conduct the study, a number of instruments and measures were used. Each of these instruments and the corresponding measures is presented below.

Descriptive and Narrative Physics Lesson

Depending on the experimental condition they were in (e.g., DB, NB, DS, and NS), participants were asked to either read a descriptive lesson or a narrative lesson. For the descriptive lesson (see Appendix B), the concepts of force, distance, and conservation of energy were explained descriptively in a chronological order starting with the different types of lever, mechanical advantage/disadvantage, lever in a context of medieval engineering e.g., learning about different types of catapult and the physics behind the launching/throwing mechanisms, physics of a trebuchet (the type of catapult that is the main focus of the lesson and subsequently in the interactive learning task), and conservation of energy. According to situational learning theory, learning is made possible not simply through teaching materials or text used, but more importantly through situations, events, and contexts in which those materials or texts are presented in a
tangible form that can be interpreted and learned by students (Barton & Hamilton, 2000; Handley et al., 2007). Therefore, in this study the physics concepts were taught through a situated event such as medieval engineering. A trebuchet, which is a missile-throwing siege weapon used in medieval times, can be easily constructed and has been widely used in physics classrooms to teach concepts like force, distance, energy types, and simple machines. Essentially, participants can build, test, and investigate force and motion through different trebuchet models. In short, the text lessons presented concepts using trebuchet examples and, as described below, the manipulation tasks involved trebuchets as well.

The narrative format of the lesson (see Appendix C) was also in the context of medieval engineering. It began with a depiction of the historical siege engine from 1210 that was first used to conquer Minerve, a town in southern France that was deemed to be impregnable. The main difference between the two versions of the lesson was that the content in the narrative format did not give readers background (i.e., starting with different types of levers and the principle of mechanical advantage) or explicitly explain the physics concepts behind the mechanism of the trebuchet. The lesson was similar to the kind of lesson most students would get in schools, and the content of both the descriptive and narrative lessons had been approved by science teachers as appropriate for college level and above. The length of these two types of lesson was comparable, as the descriptive format had 1,335 words, while the narrative format had 1,323 words. This was done in order to make similar the duration of time spent reading the material.
Computer Game

The computer game used in the study, Besiege, was developed by Spiderling Studios in the United Kingdom. Besiege is a physics-based construction game about medieval engineering that allows players to construct medieval siege engines in order to complete tasks posed in each level of the game. The tasks include destroying battalions of soldiers or fortress-type structures, transporting resources, or defending a modeled creation from your enemies (Noordin, 2015). For the purposes of this study, participants were not asked to play through every level in the game, and only the first level in the game was used in this study (see Figure 2). The physics concepts were operationalized through the game-like environment and the physics engine in the game.

Figure 2. Starting screen of the first level.

Besiege is block-based and allows players to add, delete, or manipulate one block at a time. There are different kinds of blocks provided in the game and these blocks are categorized into eight groups (basic blocks, locomotion, mechanical, weaponry, flight,
armor, hybrid, and uncategorized). For example, a wooden block (from basic blocks group) is useful for building the basic structure of a machine and it can be attached to other blocks on all six sides. In this study, 10 blocks from five groups (basic blocks, mechanical, weaponry, flight, and armor) were chosen for participants to use in a manipulation task and the blocks list was also given in conjunction with the controls list. Divided into a categorical format, the blocks list helped participants to easily identify and locate any block needed to complete the exercises. Although participants in the Building condition directly manipulated all ten blocks and participants in the Selecting condition did not, it was still crucial to give participants in both groups the same exposure to all materials used in the activity. The controls list (see Figure 3) and the blocks list (see Figure 4) were given to the participants on paper to use as a reference for helping them navigate the game-like environment.

![Figure 3. Controls list – helped participants to navigate in Besiege.](image)
Figure 4. Blocks list – helped participants to easily find any block in each category.

**Playbook**

Participants were provided with a playbook, which served as a guided instructional manual that includes one example and three exercises. The two manipulation conditions varied on the types of virtual manipulation: 1) Building condition within the game-like environment, and 2) Selecting condition within the game-like environment. There were two versions of the playbook, one corresponding to the Building condition and the other to the Selecting condition of the manipulation activity. The playbook served as a guided instructional manual as well as a reflection/experimentation notebook to be used in conjunction with the computer game.
and was related to a tutorial video (explained in the following section). Participants were asked and encouraged to take notes on what they observed from their respective manipulation task, relative to each projectile’s range and the projectile's trebuchet.

There were a total of one example and three exercises in both the Building and Selecting versions of playbook. Each exercise focused on different physics concepts, as follows.

Exercise 1: Counterweight and payload arm length. In this exercise, there were five trebuchets (including one example) that participants were required to either build or manipulate by selection. These five trebuchets were different in terms of their arm length specifications. Participants were asked to examine the projectile’s range on these trebuchets in pairs. For example, Trebuchet Ex1_A1 and Ex1_A2 had the same payload arm length but were different in their counterweight arm length. Participants had to examine how the differing lengths of the counterweight arm affected the projectile’s range on each trebuchet. After examining each trebuchet, participants were required to record their thoughts in the reflection sheet. At the end of each pair examination, a mid-point reflection asked participants to reflect on what they had observed. An example of the reflection question follows: In the 2 trebuchets you just tested, the length of payload arm is constant (8 blocks) and the counterweight is constant (15 units in mass). The only difference is the length of the counterweigh arm (2 blocks and 5 blocks), what generalization can you draw from what you observed? Figures 5 and 6 show the reflection sheet section as well as the instructions for how to fill it out for both the Building and Selecting versions, respectively.
As shown in Figure 6, the example exercise for the Building version asked the participants to follow the instructions to put together blocks and build their first trebuchet, while the Selecting version asked the participants to watch a demonstration of how the blocks were assembled to create the trebuchet. Once the example trebuchet was
completed, participants in both Building and Selecting versions were asked to test the machine and examine the projectile’s range.

Because the Building condition required participants to virtually put mechanical parts (blocks) together to create a trebuchet corresponding to each model’s specification, the total arm length was given and the number of blocks needed for each arm was specified. In contrast, the Selecting condition did not require participants to put mechanical parts together to create a trebuchet, but rather, focus on manipulating pre-made trebuchets with different arm-length variations. This is why participants in this version were asked to count the number of blocks on each arm instead of putting them together. The exercise ended with the final reflection question: Does different counterweight and payload length of the arm affect the projectile’s range? How so?

Exercise 2: Fulcrum position. In this exercise, participants were required to manipulate three trebuchets. Although the total arm length was the same across all three trebuchets (total arm length was 13 blocks), the key difference between them was the fulcrum position. Participants were asked to manipulate and examine the projectile’s range before comparing the three trebuchets. After examining each trebuchet, participants were instructed to write down their thoughts of each experiment in the reflection sheet section just like in Exercise 1. This exercise, though, ended with the final reflection question (there was no mid-point reflection question): Given the overall arm length constant, does changing the fulcrum position affect the projectile’s range? How so?

Exercise 3: Counterweight. In this exercise, participants were required to manipulate four trebuchets, and all four were different in terms of the counterweight and arm length. Participants were asked to manipulate and examine the projectile’s range on
these trebuchets in pairs. For example, Trebuchet Ex3_A1 and Ex3_A2 had the same payload arm length and counterweight arm length but were different in the counterweight (e.g., 15 units in mass versus 20 units in mass). Participants had to examine how the difference in the counterweight affected the projectile’s range on each trebuchet. After examining each trebuchet, participants were required to write down their thoughts about each experiment in the reflection sheet. At the end of each pair examination, a mid-point reflection asked participants to reflect on what they had observed. The exercise ended with the final reflection question: So does different weight of the counterweight affect the projectile’s range? How so?

The variations of length of counterweight arm, length of payload arm, total arm length, and weight of counterweight are displayed in the table 3.2 below. This is a list of all trebuchets used in the study for both the Building and Selecting conditions.

Table 3.2

<table>
<thead>
<tr>
<th>Trebuchet (ID name)</th>
<th>Length of counterweight arm (blocks)</th>
<th>Length of payload arm (blocks)</th>
<th>Total arm length (blocks)</th>
<th>Counterweight (unit in mass)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Example 1</td>
<td>3</td>
<td>8</td>
<td>11</td>
<td>15</td>
</tr>
<tr>
<td>Ex1_A1</td>
<td>2</td>
<td>8</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>Ex1_A2</td>
<td>5</td>
<td>8</td>
<td>13</td>
<td>15</td>
</tr>
<tr>
<td>Ex1_B1</td>
<td>4</td>
<td>7</td>
<td>11</td>
<td>15</td>
</tr>
<tr>
<td>Ex1_B2</td>
<td>4</td>
<td>10</td>
<td>14</td>
<td>15</td>
</tr>
<tr>
<td>Ex2_A1</td>
<td>3</td>
<td>10</td>
<td>13</td>
<td>15</td>
</tr>
<tr>
<td>Ex2_A2</td>
<td>4</td>
<td>9</td>
<td>13</td>
<td>15</td>
</tr>
<tr>
<td>Ex2_A3</td>
<td>5</td>
<td>8</td>
<td>13</td>
<td>15</td>
</tr>
<tr>
<td>Ex3_A1</td>
<td>3</td>
<td>10</td>
<td>13</td>
<td>15</td>
</tr>
<tr>
<td>Ex3_A2</td>
<td>3</td>
<td>10</td>
<td>13</td>
<td>20</td>
</tr>
<tr>
<td>Ex3_B1</td>
<td>4</td>
<td>9</td>
<td>13</td>
<td>15</td>
</tr>
<tr>
<td>Ex3_B2</td>
<td>4</td>
<td>9</td>
<td>13</td>
<td>20</td>
</tr>
</tbody>
</table>
**Tutorial Video**

The rationale for having a tutorial video for the manipulation task instead of a step-by-step paper-based guidebook is based on the cognitive theory of multimedia learning. A carefully produced tutorial video could help cut out some of the unnecessary information regarding learning how to navigate an unfamiliar interface and environment. Mayer (2014) defined multimedia learning as a learner’s mental representation constructed from both words and pictures. He stated that instructional methods using multimedia should be carefully constructed/crafted in order to guide cognitive processes appropriately during learning without overloading the learner’s cognitive system. This means that merely adding images or animations to words or text-based instruction does not always enhance learning (Mayer, 2014).

Generally, learners can experience three kinds of cognitive demands during learning (Clark, Nguyen & Sweller, 2006; Sweller, 1999). DeLeeuw and Mayer (2008) proposed the triarchic model of cognitive load that represents these different demands in cognitive processing. Mayer (2009) summarized these demands in table 3.3.

**Table 3.3**

<table>
<thead>
<tr>
<th>Type</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extraneous</td>
<td>Cognitive processing that does not serve the instructional goal; caused by confusing instructional design.</td>
</tr>
<tr>
<td>(extraneous cognitive load</td>
<td></td>
</tr>
<tr>
<td>by Sweller, 1999)</td>
<td></td>
</tr>
<tr>
<td>Essential</td>
<td>Cognitive processing required to represent the essential material in working memory; caused by the complexity of the material.</td>
</tr>
<tr>
<td>(intrinsic cognitive load</td>
<td></td>
</tr>
<tr>
<td>by Sweller, 1999)</td>
<td></td>
</tr>
<tr>
<td>Generative</td>
<td>Cognitive processing required for deeper understanding; caused by the motivation of the learners.</td>
</tr>
<tr>
<td>(germane cognitive load</td>
<td></td>
</tr>
<tr>
<td>by Sweller, 1999)</td>
<td></td>
</tr>
</tbody>
</table>
Fundamentally, learning materials, or in this case a tutorial video, should be designed in a way that minimizes extraneous cognitive load, manages essential cognitive load, and promotes generative cognitive load in order to supplement the meaningful learning process in the manipulation task.

Just like the computer game and the playbook, there were two versions of the tutorial video, corresponding to the Building and Selecting conditions of the manipulation activity. The tutorial video started with an overview of the manipulation activity, introduced the playbook and how to use it to complete all exercises, and provided step-by-step instruction on how to build or manipulate the trebuchets. From time to time, the tutorial video required participants to pause and then apply what was shown in the video tutorial, by manipulating objects in the game environment (see Figure 7).

Figure 7. Participants in Building group see this type of screen (pausing with some instructions) throughout the video.
Pre-Intervention Survey and Post-Intervention Assessments

The study used three assessments (Pre-intervention survey, assessment 1 – a post assessment after the reading task, and assessment 2 – a post assessment after the manipulation task). The measures used in the pre-intervention survey were divided into two categories: demographic information and pre-intervention physics-concepts test. In total, five measures were collected: age, gender, ethnicity, educational level, and performance on a test of physics knowledge as related to the study. These measures were also useful in terms of describing the participants and for analyses to determine equivalence across experimental groups. The Pre-intervention survey (see Appendix D) consisted of 29 questions (9 demographic information questions and 20 pre-intervention test questions on the physics concepts of force, distance, and conservation of energy). Both assessment 1 and assessment 2 consisted of 20 questions and the questions were similar to the pre-intervention test on physics concepts.

Procedure

As mentioned in the Participants and Design section, participants were recruited by flyers and word-of-mouth. Participants were asked to read and sign an electronic consent form – a consent form to participate in an online pre-intervention survey (see Appendix J) in addition to completing the online Pre-intervention survey. If participants agreed to continue and sign the consent form, the experiment began with the Pre-intervention survey. Upon completion of the survey, participants were given an option to sign up for an on-site experimental session at their earliest convenience.

The research was conducted in a computer lab set-up at the universities in both New York and Bangkok. A maximum of ten participants participated at one time,
although there were occasions where only one or two participants were present. The on-site experimental session lasted approximately one hour and forty-five minutes, although no time limit was enforced. Participants who successfully completed the experiment were compensated $15 USD at the New York location and 300 Baht at the Bangkok location.

The on-site experimental session was divided into five phases (see Figure 8): Consent form & Setup, Reading task, assessment 1, Manipulation task, and assessment 2. The following section describes each of these phases in detail.

Figure 8. The five-phase of an on-site experimental session and estimated time.

**Phase 1: Consent form and Setup**

Upon arriving at the research lab, participants were greeted and directed to the computer station. Before beginning an on-site experimental session, the researcher briefly described procedures, answered questions, and handed out a consent form to participate
at an on-site experimental session. Once participants agreed to participate and signed the on-site consent form (see Appendix K and L), they were randomly assigned to one of the four experimental conditions (i.e., DB, NB, DS, and NS). This phase lasted approximately twenty minutes.

Phase 2: Reading task

Participants assigned to the group with a descriptive lesson (i.e., DB and DS) read a physics lesson regarding force, distance, and conservation of energy in the context of historical siege machines (see Appendix B). The lesson included topics such as levers, mechanical advantage, different types of catapults, and the physics of trebuchets. The other groups (i.e., NB and NS) were given a narrative to read. The narrative was also in the context of medieval engineering, but without an explicit explanation of the physics concepts (see Appendix C). Participants were given approximately ten minutes to read through both types of lesson once. Participants who did not finish reading (n = 4) after ten minutes were told to stop before the researcher moved on to the next phase.

Phase 3: Assessment 1

After reading the lesson/narrative, participants were asked to do assessment 1, which consisted of 20 multiple-choice questions (see Appendix D) and examined participants’ knowledge of physics concepts regarding force, distance, and conservation of energy. No time limit was given. However, most participants took approximately fifteen minutes to complete the assessment.
Phase 4: Manipulation task

After completing assessment 1, the researcher explained the manipulation task to the participants. Participants in the building group (i.e., DB and NB) completed three exercises related to the physics concepts, one in each area related to force, distance, and conservation of energy. Participants in these groups were required to build various trebuchets by assembling virtual mechanical blocks in a game-like environment of a physics-based construction game called Besiege. Participants who were in the selecting group (i.e., DS and NS) also completed three exercises related to the physics concepts of force, distance, and conservation of energy. Instead of being able to assemble and deconstruct the virtual mechanical blocks, participants in the selecting groups were only allowed to interact with pre-assembled virtual objects (i.e., trebuchet) in a game-like environment of the same physics-based construction game. This group's interactions consisted of selecting pre-assembled trebuchet, counting number of blocks, and examining projectile’s range on each trebuchet. Participants in both groups were given instructions in a tutorial video on how to navigate through the game and how to complete the exercises. As noted earlier, a controls list and blocks list were given as references, as was a playbook. As shown in Figure 9, there are seven selections of a trebuchet’s frame (that consisted of a base, a fulcrum, and a launching mechanism) in the Building condition. Each one corresponded to a given trebuchet's specification as stated in each exercise in the playbook. The selecting condition, on the other hand, consisted of twelve selections of a pre-assembled trebuchet (Figure 10). Participants were asked to choose pre-assembled trebuchet, counting number of blocks (i.e., the length of an arm that would
throw a projectile), and fire each pre-assembled trebuchet to examine a projectile’s range in an example exercise and additional three exercises.

**Figure 9. Trebuchet selections for Building condition.**

**Figure 10. Trebuchet selections for Selecting condition.**
In the example exercise, participants were asked to watch a tutorial video, which introduced them to the control interface as well as how to navigate through the game. For the Building group, participants were asked to build their first trebuchet, called Example 1 trebuchet, by following the instructions from the tutorial video, while participants in the Selecting group were asked to watch how the trebuchet was built. The step-by-step instructions started with a frame as shown in Figure 11.

![Figure 11. Starting frame of an example trebuchet.](image)

After participants in the Building group successfully built the trebuchet from the example (in order to familiarize themselves with the control and interface, this activity acted as a training exercise) and the participants in the Selecting group finished watching how the example trebuchet was built, they began the three exercises. In the first exercise, participants were asked to manipulate four trebuchets with different arm length specifications to examine a projectile’s range. Figure 12 depicts a projectile of a trebuchet when launched.
Then, participants were asked to fill out a reflection sheet after building (or selecting), and testing each trebuchet. The reflection sheet was intended to help participants reflect on what they had observed, their thoughts on modifying the trebuchet (if any), and what hypotheses they could draw from the virtual experiment.

After participants were done with Exercise 1, they continued to Exercise 2 and Exercise 3. This phase took approximately 45 minutes to complete.

**Phase 5: Assessment 2**

In the final phase of the experiment, after participants were finished with the example exercise and additional three manipulation exercises in the manipulation task, they were asked to complete the final assessment, which was assessment 2. Assessment 2 consisted of 20 questions, and was similar to the pre-intervention survey and assessment 1 (see Appendix E). It examined the participants’ knowledge of physics concepts regarding force, distance, and conservation of energy. No time limit was given; however, most participants took approximately 15 minutes to complete assessment 2. After participants completed the second assessment, the experiment concluded. Participants were thanked and compensated for their time.
Data Analysis and Methods

The study's data were analyzed using t-test and factorial ANOVA to compare means of the test scores between four experimental groups. The means of test scores compared were 1) pre-intervention score and assessment 1 score, and 2) assessment 1 and 2 scores. A summary of the analyses conducted relative to the study's research questions appear in Table 3.4.

Table 3.4

<table>
<thead>
<tr>
<th>Research Question</th>
<th>Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>RQ 1. How does receiving a lesson on physics concepts before a manipulation task affect the participants’ learning outcomes as measured by post-tests?</td>
<td>RQ 1.1 Is there a difference in learning outcomes before and after reading a lesson?</td>
</tr>
<tr>
<td></td>
<td>RQ 1.2 Is there a difference in learning outcomes between the descriptive lesson group (DB and DS) and the narrative lesson group (NB and NS) before and after reading a lesson?</td>
</tr>
<tr>
<td>RQ 2.1 Is there a difference in learning outcomes before and after engaging in a manipulation task in all groups?</td>
<td>Paired sample t-test using the mean differences of assessment 1 and assessment 2 test scores.</td>
</tr>
<tr>
<td>RQ 2.2 Is there a difference in learning outcomes between the building condition lesson group (DB and NB) and the selecting condition lesson group (DS and NS) before and after engaging in a manipulation task?</td>
<td>Independent sample t-test using the mean differences of assessment 1 and assessment 2 test scores for participants in the building and selecting groups.</td>
</tr>
<tr>
<td>RQ 3.1 Is there a difference in learning outcomes between the groups that read the descriptive lesson followed by a manipulation task (either building or selecting conditions) in a game-like environment (i.e., DB vs. DS)?</td>
<td>Independent sample t-test using the mean differences of pre-intervention and assessment 1 test scores for participants in the DB and DS groups.</td>
</tr>
</tbody>
</table>
To answer the research questions, both descriptive and inferential statistics were used. A preliminary analysis was conducted to verify that the four experimental groups were equivalent in terms of their demographic information (age, gender, ethnicity, educational level, and prior knowledge regarding the target physics concepts. For the primary analysis, a t-test was used to look for statistical differences between before and after the intervention within the type of lesson group and before and after the intervention within different types of manipulation group. An Analysis of Variance (ANOVA) was
used to look for statistical differences between the four experimental groups (i.e., DB, NB, DS, and NS). The results are shown in the following chapter.

**Analysis Addressing Lesson Type**

In this study, the effect of reading the lesson type (i.e., descriptive or narrative) on knowledge gain was examined. The descriptive lesson represented a typical type of lesson that students encounter in physics textbooks. The physics concepts were anchored in a medieval engineering context, but still presented formulas and descriptive information. Learning outcome was measured by comparing the difference in participants’ knowledge as shown from their pre-intervention test score to their score on assessment 1, which took place before the manipulation tasks. First, a paired sample t-test was used to examine the effect of reading the lesson. Then, an independent sample t-test was used to determine the effect of different types of lesson.

**Analysis Addressing of Types of Manipulation**

After participants completed the reading task and assessment 1, they continued to the manipulation task and then completed assessment 2. The possible effect of manipulation (after reading a given lesson) was measured by analyzing the change in test scores from assessment 1 to 2. First, a paired sample t-test was used to determine the effect of before and after engaging in a manipulation task. Then, an independence sample t-test was used to determine the effect of different types of manipulation. Lastly, a 2x2 factorial ANOVA was conducted to examine the effect of different types of lesson and types of manipulation on the test score between four experimental groups. The following chapter presents the results of the analyses noted in this chapter.
The purpose of the study was to examine the effects of manipulation of virtual objects and supplemental lesson types in a game-like environment. Although 126 adults consented to participate, only 121 adults completed the study. Participants were randomly assigned to one of four experimental conditions (see Table 4.1). These groups were based on two independent variables: lesson types and types of manipulation. A brief reminder of the four conditions follows.

Descriptive lesson with Building condition (DB): Participants in this group read a lesson that presented descriptive information on the concepts of force, distance, and conservation of energy. The participants then completed three exercises that required them to build and assemble variations of virtual objects in a game-like environment. The exercises pertained to the physics concepts and information/content they previously received from the lesson.

Narrative lesson with Building condition (NB): Participants in this group read a lesson in a narrative format that includes the concepts of force, distance, and conservation of energy. Participants then completed three exercises that required them to build and assemble variations of virtual objects in a game-like environment. The exercises pertained to the physics concepts regarding force, distance, and conservation of energy.

Descriptive lesson with Selecting condition (DS): Participants in this group read a lesson that presented descriptive information on the concepts of force, distance, and conservation of energy. Then, participants completed three exercises that allowed them to
interact with the same virtual objects as the DB group, but without being able to assemble or deconstruct the virtual objects' components. The exercises also pertained to the physics concepts and information/content they previously received from the lesson.

Narrative lesson with Selecting condition (NS): Participants in this group read a lesson in a narrative format that includes the concepts of force, distance, and conservation of energy. Participants completed three exercises afterward that only allowed them to interact with the completed version of virtual objects without being able to assemble or deconstruct the components of those virtual objects. The exercises also pertained to the physics concepts and information/content they previously received from the lesson.

Table 4.1

Number of Participants by Group (For Each Group, the Number of Participants are Shown Relative to the Two Countries from which They were Recruited.)

<table>
<thead>
<tr>
<th>Lesson type on physics concepts</th>
<th>Type of Manipulation</th>
<th>Building (B)</th>
<th>Selecting (S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Descriptive (D)</td>
<td>DB (n = 30)</td>
<td>(USA = 10, Thailand = 20)</td>
<td>DS (n = 34)</td>
</tr>
<tr>
<td>Narrative (N)</td>
<td>NB (n = 29)</td>
<td>(USA = 8, Thailand = 21)</td>
<td>NS (n = 33)</td>
</tr>
</tbody>
</table>

This chapter is organized into two main sections. The first section presents the results from preliminary analyses, which examined the assumption that the groups were equal at the beginning of the study regarding their demographics (age, gender, ethnicity, and education level) and pre-intervention test score (performance on a test of physics knowledge as related to the study). The second section presents the results from primary analyses addressing the three main hypotheses of the study and outlines the results of the
effects of two factors (lesson type and types of manipulation). In that section, the analysis is organized into three sub-sections based on this study's three research questions.

**Preliminary Analysis**

A number of pre-intervention measures were collected in an effort to ensure relative equivalency between experimental groups. These measures assessed knowledge about the concepts to-be-learned in the experiment, as well as demographic information before the interventions. In total, five measures were collected: age, gender, ethnicity, educational level, and performance on a test of physics knowledge as related to the study. In total, 88 females and 38 males participated in the study. Although the majority of participants were female, this is representative of the School of Global Studies and Graduate School of Education, where the study was conducted. The distribution of participants by gender and average age by group is shown in Table 4.2; specific details about recruitment and location of the subject pool were provided in Chapter III.

### Table 4.2

<table>
<thead>
<tr>
<th>Condition</th>
<th>N</th>
<th>Gender</th>
<th>Age</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Female</td>
<td>Male</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DB</td>
<td>30</td>
<td>21</td>
<td>9</td>
<td>22.13</td>
<td>18</td>
</tr>
<tr>
<td>NB</td>
<td>29</td>
<td>18</td>
<td>11</td>
<td>21.35</td>
<td>18</td>
</tr>
<tr>
<td>DS</td>
<td>34</td>
<td>28</td>
<td>6</td>
<td>24.27</td>
<td>18</td>
</tr>
<tr>
<td>NS</td>
<td>33</td>
<td>21</td>
<td>12</td>
<td>22.91</td>
<td>18</td>
</tr>
<tr>
<td>Total</td>
<td>126</td>
<td>88</td>
<td>38</td>
<td>22.73</td>
<td>18</td>
</tr>
</tbody>
</table>

In terms of ethnicity, participants were Asian (80.95%), White (6.35%), African American (5.56%), Mixed Race (5.56%), and unknown (1.58%). There was a comparable split between participants who were still in college (50.80%) and those who had a college
degree or were in graduate school (49.20%). The mean age of the participants was 22.73 years ($SD = 5.50$). The youngest participant was 18 and the oldest was 42 years old.

In order to analyze participants’ demographic information, a chi-square test of independence was performed to see whether there was any significant relationship within age, gender, ethnicity, and education level among four experimental groups. From the analysis (see Table 4.3), no statistical significance was found among the four experimental groups in terms of age ($X^2 (6) = 7.21, p = .30$), gender ($X^2 (3) = 3.96, p = .27$), ethnicity ($X^2 (12) = 6.19, p = .91$), and educational level ($X^2 (18) = 10.61, p = .91$).

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Pearson Chi-Square</th>
<th>df</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>126</td>
<td>7.213</td>
<td>6</td>
<td>.302</td>
</tr>
<tr>
<td>Gender</td>
<td>126</td>
<td>3.962</td>
<td>3</td>
<td>.266</td>
</tr>
<tr>
<td>Ethnicity</td>
<td>126</td>
<td>6.190</td>
<td>12</td>
<td>.906</td>
</tr>
<tr>
<td>Education Level</td>
<td>126</td>
<td>10.610</td>
<td>18</td>
<td>.910</td>
</tr>
</tbody>
</table>

Then, a one-way analysis of variance (ANOVA) was performed to see if there is a significant difference in participants’ pre-intervention test score between the four experimental groups. No statistically significant difference was found in pre-intervention test score between four experimental groups, $F (3, 122) = 0.56, p = .65$. In addition, Levene’s test for homogeneity of variances failed to detect any significant difference between the experimental group variance, $F (3,122) = 0.53, p = .67$. The mean of pre-intervention test score of all participants ($n = 126$) is 8.78 with a standard deviation of 3.67. The descriptive statistics of the pre-intervention test score by group is shown in Table 4.4 as well as by country of recruitment as shown in Table 4.4.1.
Table 4.4

Descriptive Statistics of Pre-Intervention Test Score

<table>
<thead>
<tr>
<th>Condition</th>
<th>N</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>DB</td>
<td>30</td>
<td>8.80</td>
<td>3.77</td>
</tr>
<tr>
<td>NB</td>
<td>29</td>
<td>9.48</td>
<td>3.56</td>
</tr>
<tr>
<td>DS</td>
<td>34</td>
<td>8.62</td>
<td>4.05</td>
</tr>
<tr>
<td>NS</td>
<td>33</td>
<td>8.30</td>
<td>3.31</td>
</tr>
<tr>
<td>Total</td>
<td>126</td>
<td>8.78</td>
<td>3.67</td>
</tr>
</tbody>
</table>

Table 4.4.1.

Descriptive Statistics of Pre-Intervention Test Score by Condition and Country

<table>
<thead>
<tr>
<th>Condition</th>
<th>Country</th>
<th>N</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>DB</td>
<td>USA</td>
<td>10</td>
<td>10.30</td>
<td>3.47</td>
</tr>
<tr>
<td></td>
<td>Thailand</td>
<td>20</td>
<td>7.65</td>
<td>3.35</td>
</tr>
<tr>
<td>NB</td>
<td>USA</td>
<td>8</td>
<td>11.00</td>
<td>3.12</td>
</tr>
<tr>
<td></td>
<td>Thailand</td>
<td>21</td>
<td>9.10</td>
<td>4.04</td>
</tr>
<tr>
<td>DS</td>
<td>USA</td>
<td>7</td>
<td>9.86</td>
<td>3.24</td>
</tr>
<tr>
<td></td>
<td>Thailand</td>
<td>27</td>
<td>8.19</td>
<td>3.87</td>
</tr>
<tr>
<td>NS</td>
<td>USA</td>
<td>7</td>
<td>11.71</td>
<td>3.73</td>
</tr>
<tr>
<td></td>
<td>Thailand</td>
<td>26</td>
<td>7.65</td>
<td>3.06</td>
</tr>
</tbody>
</table>

From the results of the preliminary analysis, the four demographic variables and the initial pre-intervention test score measures indicate that there is no statistical difference between the four experimental groups in terms of age, gender, ethnicity, educational level, and pre-intervention score.

**Primary Analysis by Research Question**

The primary analysis is divided into three sub-sections based on the three research questions of this study that examined two factors: lesson type (descriptive vs. narrative) and types of manipulation (building vs. selecting). In addition, how these two factors affect low- and high-prior knowledge participants was also investigated. From a
theoretical point of view, Kintsch (1998) posited that prior knowledge is likely to have a large influence on text comprehension because often times information shown in the text is insufficient for the construction of a coherent mental representation of the situation illustrated by the text. Hence, it required the contribution of readers’ prior knowledge to make meaning of the text they read. A group of researchers (Ozuru, Dempsey, & McNamara, 2007) conducted a study to examine how individual differences such as topic-relevant prior knowledge (readers’ pre-existing knowledge related to the text content) influence comprehension processes when reading science texts. The results revealed that overall comprehension was positively correlated with participants’ prior knowledge (Ozuru et al., 2007). Chi, Feltovich, and Glaser (1981) also support these findings, Moreover, findings from a study conducted by Glasson (1989) on the effects of hands-on and teacher demonstration laboratory methods on science achievement in relation to reasoning ability and prior knowledge suggested that prior knowledge significantly predicted students’ performance on declarative knowledge and procedural knowledge tests in favor of hands-on laboratory method. Therefore, within each research question, an additional analysis was performed to examine a possible difference in learning outcomes between participants in low-prior knowledge (LP) and high-prior knowledge (HP) groups. Participants in the LP group are those whose pre-intervention test score is lower than 50% of the possible test score, which means that they got less than half of the questions right (there are 20 questions on the pre-intervention test). Conversely, participants in the HP group are those whose intervention test score is 50% or higher of the possible test score, which means that they got half or more than half of all the questions right. This break point (50%) was chosen because the mean of pre-
intervention test score of all participants \((n = 126)\) is 8.78. Therefore for this study, it seems appropriate that participants whose pre-intervention test score between 0-9 (lower than 50%) were placed in the LP group and those whose pre-intervention test score between 10-20 (50% or higher) were placed in the HP group. Table 4.5 shown below is the distribution of participants by group and their related descriptive statistics.

Table 4.5

Descriptive Statistics of Pre-Intervention Test Score for the LP and HP Groups

<table>
<thead>
<tr>
<th></th>
<th>Low-Prior Knowledge group (LP)</th>
<th>High-Prior Knowledge group (HP)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(N)</td>
<td>(M)</td>
</tr>
<tr>
<td>DB</td>
<td>20</td>
<td>6.75</td>
</tr>
<tr>
<td>NB</td>
<td>13</td>
<td>6.38</td>
</tr>
<tr>
<td>DS</td>
<td>21</td>
<td>6</td>
</tr>
<tr>
<td>NS</td>
<td>21</td>
<td>6.33</td>
</tr>
<tr>
<td>Total</td>
<td>75</td>
<td></td>
</tr>
</tbody>
</table>

Table 4.5.1 presents the descriptive statistics for low and high prior-knowledge groups by country of recruitment.

Table 4.5.1

Descriptive Statistics of Pre-Intervention Test Score for the USA and Thailand Groups

<table>
<thead>
<tr>
<th></th>
<th>Low-Prior Knowledge group (LP)</th>
<th>High-Prior Knowledge group (HP)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(N)</td>
<td>(M)</td>
</tr>
<tr>
<td>DB</td>
<td>USA</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Thailand</td>
<td>17</td>
</tr>
<tr>
<td>NB</td>
<td>USA</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Thailand</td>
<td>12</td>
</tr>
<tr>
<td>DS</td>
<td>USA</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Thailand</td>
<td>16</td>
</tr>
<tr>
<td>NS</td>
<td>USA</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Thailand</td>
<td>19</td>
</tr>
<tr>
<td>Total</td>
<td>75</td>
<td></td>
</tr>
</tbody>
</table>
Research Question 1: Lesson type

How does receiving a lesson on physics concepts before a manipulation task affect the participants’ learning outcomes as measured by post-tests?

This research question explored the effect of reading a lesson, regardless of type and before a manipulation task, on knowledge about the physics concepts related to this study. Fundamentally, the first research question seeks to understand 1) the effect of reading a lesson – by examining the possible difference between pre-intervention and assessment 1 test scores, and through sub-analyses, 2) the effect of different types of lessons by examining the possible difference between the descriptive lesson and narrative lesson group's assessment 1 test score. An additional analysis examined these questions from the perspective of low and high prior-knowledge participants, as well.

RQ 1.1 Is there a difference in learning outcomes after reading a lesson?

In order to determine the effect of before and after reading the lesson in all groups \((n = 126)\), a paired sample t-test was conducted to examine the mean differences of pre-intervention and assessment 1 test scores. As shown in table 4.6, there was a statistically significant difference between the pre-intervention \((M = 8.78, SD = 3.67)\) and assessment 1 test scores \((M = 10.75, SD = 2.97)\) at the .05 level of confidence \((t = -7.21, df = 125, n = 126, p < .05, 95\% CI for mean difference -2.52 to -1.43, r = .59)\). These results suggest that having read a lesson has a positive effect on learning outcome.
Table 4.6

Results of t-test and Descriptive Statistics for Test Score Before and After Reading the Lesson

<table>
<thead>
<tr>
<th></th>
<th>Before reading</th>
<th>After reading</th>
<th>95% CI for Mean Difference</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Test score</td>
<td>8.78</td>
<td>10.75</td>
<td>-2.519, -1.433</td>
<td>.588</td>
<td>-2.109*</td>
<td>125</td>
</tr>
</tbody>
</table>

* p < .05.

An additional analysis was performed to examine the mean differences of pre-intervention and assessment 1 test scores between participants in the USA and Thailand groups. As shown in table 4.6.1 and 4.6.2, for the USA group there was a statistically significant difference between the pre-intervention (M = 10.69, SD = 3.30) and assessment 1 test scores (M = 11.78, SD = 2.81) at the .05 level of confidence (t = -2.109, df = 31, n = 32, p = .043, 95% CI for mean difference -2.151 to -0.036, r = .55). For the Thailand group there was a statistically significant difference between the pre-intervention (M = 8.13, SD = 3.58) and assessment 1 test scores (M = 10.40, SD = 2.95) at the .05 level of confidence (t = -7.156, df = 93, n = 394, p < .05, 95% CI for mean difference -2.908 to -1.645, r = .57). These results suggest that having read a lesson has a positive effect on learning outcome for participants in both USA and Thailand groups.

Table 4.6.1

Results of t-test and Descriptive Statistics for Test Score Before and After Reading the Lesson for the USA Group

<table>
<thead>
<tr>
<th></th>
<th>Before reading</th>
<th>After reading</th>
<th>95% CI for Mean Difference</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Test score</td>
<td>10.69</td>
<td>11.78</td>
<td>-2.151, -0.036</td>
<td>.549</td>
<td>-2.109*</td>
<td>31</td>
</tr>
</tbody>
</table>

* p < .05.
Table 4.6.2

Results of t-test and Descriptive Statistics for Test Score Before and After Reading the Lesson for the Thailand Group

<table>
<thead>
<tr>
<th></th>
<th>Before reading</th>
<th>After reading</th>
<th>95% CI for Mean Difference</th>
<th></th>
<th></th>
<th>df</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
<td>n</td>
<td>r</td>
</tr>
<tr>
<td>Test score</td>
<td>8.13</td>
<td>3.58</td>
<td>10.40</td>
<td>2.95</td>
<td>94</td>
<td>-2.908, -1.645</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* p < .05.

Low-Prior knowledge (LP) group. To examine the effect of reading a lesson in the LP group (n = 75), a paired sample t-test was conducted to examine the mean differences of pre-intervention and assessment 1 test scores. As shown in table 4.7, there was a statistically significant difference between the pre-intervention (M = 6.36, SD = 2.17) and assessment 1 test scores (M = 9.73, SD = 2.64) at the .05 level of confidence (t = -10.39, df = 74, n = 75, p < .05, 95% CI for mean difference -4.02 to -2.73, r = .33). This is also true where there was a statistically significant difference between the pre-invention and assessment 1 test score of participants in the USA and Thailand groups. These results suggest that having read a lesson has a positive effect on learning outcome for participants in low-prior knowledge group.

Table 4.7

Results of t-test and Descriptive Statistics for Test Score Before and After Reading the Lesson for the LP Group

<table>
<thead>
<tr>
<th></th>
<th>Before reading</th>
<th>After reading</th>
<th>95% CI for Mean Difference</th>
<th></th>
<th></th>
<th>df</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
<td>n</td>
<td>r</td>
</tr>
<tr>
<td>Test score</td>
<td>6.36</td>
<td>2.17</td>
<td>9.73</td>
<td>2.64</td>
<td>75</td>
<td>-4.02, -2.73</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* p < .05.

High-Prior knowledge (HP) group. To examine the effect of reading a lesson in the HP group (n = 51), a paired sample t-test was conducted to examine the mean differences of pre-intervention and assessment 1 test scores. No statistical significance
was found between pre-intervention \((M = 12.33, SD = 2.25)\) and assessment 1 \((M = 12.25, SD = 2.80)\) test scores \((p = .79)\) and the same significant results were not found for the participants in the USA and Thailand groups. Therefore, these results suggest that having read a lesson does not have a positive effect on learning outcome for participants in the high-prior knowledge group. Table 4.8 reports the results and descriptive statistics for the HP group.

Table 4.8

Results of t-test and Descriptive Statistics for Test Score Before and After Reading the Lesson for the HP Group

<table>
<thead>
<tr>
<th>Before reading</th>
<th>After reading</th>
<th>95% CI for Mean Difference</th>
<th>(r)</th>
<th>(t)</th>
<th>(df)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(M)</td>
<td>(SD)</td>
<td>(M)</td>
<td>(SD)</td>
<td>(n)</td>
<td></td>
</tr>
<tr>
<td>Test score</td>
<td>12.33</td>
<td>2.25</td>
<td>12.25</td>
<td>2.80</td>
<td>51</td>
</tr>
</tbody>
</table>

RQ 1.2 Is there a difference in learning outcomes between the descriptive lesson group (DB and DS) and the narrative lesson group (NB and NS) after reading a lesson?

To determine if the different lessons had an effect on participants’ test score, first, the four experimental groups were collapsed into two groups based on lesson type. Participants who read the descriptive lesson (DB and DS) were combined to be one descriptive group \((n = 62)\), and the groups that read the narrative lesson (NB and NS) were combined to be one narrative group \((n = 64)\). An independent sample t-test was conducted to compare the mean differences of pre-intervention and assessment 1 test scores between the descriptive lesson group and the narrative lesson group. Levene’s test for homogeneity of variances failed to detect any significant difference between the group variances, \(F(1, 124) = 2.33, p = .13\). As shown in table 4.9 below, there is a
significant difference between the descriptive lesson group \((M = 1.32, SD = 3.30)\) and narrative lesson group \((M = 2.61, SD = 2.73)\) at the .05 level of significance \((t = -2.40, df = 124, p = .018, 95\% CI for mean difference -2.35 to -.22)\). These results suggest that participants who read the narrative lesson performed better than those who read the descriptive lesson. These significant results were also found in participants in the USA group, where there is significant difference between the descriptive lesson group \((n = 15, M = -.33, SD = 2.35)\) and narrative lesson group \((n = 17, M = 2.35, SD = 2.87)\) at the .05 level of significance \((t = -2.87, df = 30, p = .007, 95\% CI for mean difference -2.69 to 0.94)\). However, no statistically significant difference was found between the descriptive \((n = 47, M = 1.83, SD = 3.37)\) and narrative \((n = 47, M = 2.72, SD = 2.73)\) lessons for the Thailand group \((p = .16)\).

Table 4.9

Results of t-test and Descriptive Statistics for the Mean Difference in Test Score by Lesson Type

<table>
<thead>
<tr>
<th>Type of lesson</th>
<th>Descriptive</th>
<th>Narrative</th>
<th>95% CI for Mean Difference</th>
<th>(t)</th>
<th>(df)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(M)</td>
<td>(SD)</td>
<td>(n)</td>
<td>(M)</td>
<td>(SD)</td>
</tr>
<tr>
<td>Mean Differences</td>
<td>1.32</td>
<td>3.30</td>
<td>62</td>
<td>2.61</td>
<td>2.73</td>
</tr>
</tbody>
</table>

* \(p < .05\).

Low-Prior knowledge (LP) group. To determine if different type of lesson had an effect on participants’ test score in the LP group, the four experimental groups were collapsed into two groups of low-prior knowledge participants based on lesson type: descriptive group \((DB\) and \(DS; n = 34)\), and narrative group \((NB\) and \(NS; n = 41)\). An independent sample t-test was conducted to compare the mean differences of pre-intervention and assessment 1 test scores between the descriptive lesson group and the narrative lesson group. From the analysis, Levene’s test for homogeneity of variances
failed to detect any significant difference between the group variances, $F(1, 73) = 2.03$, $p = .16$. No statistically significant difference was found between the descriptive ($M = 3.12$, $SD = 3.19$) and narrative ($M = 3.59$, $SD = 2.48$) lessons for the low-prior knowledge groups ($p = .48$).

High-Prior knowledge (HP) group. To determine if different type of lesson had an effect on participants’ test score in the HP group, an independent sample t-test was performed to compare the mean differences of pre-intervention and assessment 1 test scores between the descriptive lesson group (DB and DS; $n = 28$) and the narrative lesson group (NB and NS; $n = 23$). From the analysis, Levene’s test for homogeneity of variances failed to detect any significant difference between the group variances, $F(1, 49) = 1.58$, $p = .22$. As shown in table 4.10 below, there is a significant difference in the mean differences of test scores between the descriptive lesson group ($M = -.86$, $SD = 1.76$) and the narrative lesson group ($M = .87$, $SD = 2.30$) at the .05 level of significance ($t = -3.04$, $df = 49$, $p = .004$, 95% CI for mean difference -2.87 to -0.58). These results suggest that participants in the HP group who read the narrative lesson perform better than those who read the descriptive lesson.

Table 4.10

<table>
<thead>
<tr>
<th>Type of lesson</th>
<th>95% CI for Mean Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Descriptive</td>
<td>Narrative</td>
</tr>
<tr>
<td>$M$</td>
<td>$SD$</td>
</tr>
<tr>
<td>Mean Differences</td>
<td>-.86</td>
</tr>
</tbody>
</table>

* $p < .05$.

In summary, to answer the first research question: How does receiving a lesson on physics concepts before a manipulation task affect the participants’ learning outcomes as
measured by post-tests?, the results suggested that a text-based lesson supplement (regardless of which type) positively affected participants’ learning outcomes when it was given before a post-reading assessment (assessment 1) and a manipulation task for the LP group, but not for HP group. These significant results were also found in the USA and the Thailand groups. The narrative lesson was found to have a statistically significant, positive impact on participants’ learning outcome and the results suggested that participants in the HP group who read a narrative lesson perform better than those who read a descriptive type of lesson; however, this was not the case for the Thailand group where type of lesson did not positively or negatively affect the learning outcomes. On the other hand, participants in the LP group who read a narrative lesson did not perform better or worse than those who read a descriptive lesson. This concludes the analysis of the study’s research question one.

**Research Question 2: Type of manipulation**

*How do different types of manipulation (building or selecting) of virtual objects in a game-like environment affect participants’ learning outcomes as measured by post-tests?*

This second research question looked at how manipulation task affects learning outcome and also how different type of manipulation of virtual objects in a game-like environment affect participants’ learning performance as measured by test score. Fundamentally, the second research question seeks to understand 1) the effect of engaging in a manipulation task by examining the possible difference between assessment 1 and assessment 2 test scores, and 2) the effect of different types of
manipulation by examining the possible difference between the building and selecting groups’ assessment 2 test score.

**RQ 2.1 Is there a difference in learning outcomes after engaging in a manipulation task in all groups?**

To determine the effect of before and after engaging in a manipulation task after reading a descriptive or a narrative lesson, a paired sample t-test was conducted to examine the mean differences of assessment 1 and assessment 2 test scores. As shown in table 4.11, there was a significant difference between assessment 1 ($M = 10.76, SD = 2.30$) and assessment 2 ($M = 12.34, SD = 3.38$) scores at the .05 level of significance ($t = -6.19, df = 120, n = 121^1, p < .05, 95\% CI for mean difference -2.08 to -1.07, r = .62$). These results suggest that engaging in a manipulation task after reading either a descriptive or narrative lesson has a positive effect on the test score.

Table 4.11

<table>
<thead>
<tr>
<th>Test score</th>
<th>Before a manipulation task</th>
<th>After a manipulation task</th>
<th>95% CI for Mean Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>10.76</td>
<td>2.997</td>
<td>12.34</td>
<td>3.378</td>
</tr>
</tbody>
</table>

* $p < .05$.

An additional analysis was performed to examine the mean differences of assessment 1 and assessment 2 test scores between participants in the USA and Thailand groups. From the results, for the Thailand group there was a significant difference

---

$^1$ Five participants did not complete a manipulation task (although they completed the pre-intervention survey, lesson reading, and assessment 1; therefore the total number of participants went down from 126 to 121.)
between assessment 1 ($M = 10.43$, $SD = 2.99$) and assessment 2 ($M = 12.28$, $SD = 3.36$) scores at the .05 level of significance ($t = -6.47$, $df = 89$, $n = 90$, $p < .05$, 95% CI for mean difference -2.41 to -1.28, $r = .64$). However, no statistically significant difference was found between assessment 1 and assessment 2 scores for the USA group ($p = .138$).

Low-Prior knowledge (LP) group. To examine the effect of engaging in a manipulation task in the LP group, a paired sample t-test was conducted to examine the mean differences of assessment 1 and assessment 2 test scores. As shown in table 4.12, there was a statistically significant difference between the assessment 1 ($M = 9.74$, $SD = 2.68$) and assessment 2 test scores ($M = 11.42$, $SD = 3.04$) at the .05 level of confidence ($t = -4.83$, $df = 71$, $n = 72$, $p < .05$, 95% CI for mean difference -2.38 to -.99, $r = .47$). These results suggest that engaging in a manipulation task has a positive effect on learning outcome for participants in the low-prior knowledge group. These significant results were also found in the Thailand group, but in for the USA group.

Table 4.12

Results of t-test and Descriptive Statistics for Test Score Before and After Having Engaged in a Manipulation Task in the LP Group

<table>
<thead>
<tr>
<th></th>
<th>Before a manipulation task</th>
<th>After a manipulation task</th>
<th>95% CI for Mean Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test score</td>
<td>$M$</td>
<td>$SD$</td>
<td>$M$</td>
</tr>
<tr>
<td></td>
<td>9.74</td>
<td>2.68</td>
<td>11.42</td>
</tr>
</tbody>
</table>

* $p < .05$.

High-Prior knowledge (HP) group. To examine the effect of engaging in a manipulation task in the HP group, a paired sample t-test was conducted to examine the mean differences of assessment 1 and assessment 2 test scores. As shown in table 4.13, there was a statistically significant difference between the assessment 1 ($M = 12.27$, $SD = 3.03$) and assessment 2 test scores ($M = 13.89$, $SD = 3.38$) at the .05 level of confidence ($t = 4.39$, $df = 71$, $n = 72$, $p < .05$, 95% CI for mean difference 1.4 to 2.67, $r = .57$). These results suggest that engaging in a manipulation task has a positive effect on learning outcome for participants in the high-prior knowledge group. These significant results were also found in the Thailand group, but not in the USA group.

Table 4.13

Results of t-test and Descriptive Statistics for Test Score Before and After Having Engaged in a Manipulation Task in the HP Group

<table>
<thead>
<tr>
<th></th>
<th>Before a manipulation task</th>
<th>After a manipulation task</th>
<th>95% CI for Mean Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test score</td>
<td>$M$</td>
<td>$SD$</td>
<td>$M$</td>
</tr>
<tr>
<td></td>
<td>12.27</td>
<td>3.03</td>
<td>13.89</td>
</tr>
</tbody>
</table>

* $p < .05$. 

High-Prior knowledge (HP) group. To examine the effect of engaging in a manipulation task in the HP group, a paired sample t-test was conducted to examine the mean differences of assessment 1 and assessment 2 test scores. As shown in table 4.13, there was a statistically significant difference between the assessment 1 ($M = 12.27$, $SD = 3.03$) and assessment 2 test scores ($M = 13.89$, $SD = 3.38$) at the .05 level of confidence ($t = 4.39$, $df = 71$, $n = 72$, $p < .05$, 95% CI for mean difference 1.4 to 2.67, $r = .57$). These results suggest that engaging in a manipulation task has a positive effect on learning outcome for participants in the high-prior knowledge group. These significant results were also found in the Thailand group, but not in the USA group.
2.83) and assessment 2 test scores ($M = 13.69$, $SD = 3.42$) at the .05 level of confidence ($t = -3.86, df = 48, n = 49, p < .05$, 95% CI for mean difference -2.17 to -.69, $r = .67$). These results suggest that engaging in a manipulation task has a positive effect on learning outcome for participants in the high-prior knowledge group. These significant results were also found in the Thailand group, but not in the USA group.

Table 4.13

<table>
<thead>
<tr>
<th></th>
<th>Before a manipulation task</th>
<th>After a manipulation task</th>
<th>95% CI for Mean Difference</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Test score</td>
<td>$M$</td>
<td>$SD$</td>
<td>$M$</td>
<td>$SD$</td>
</tr>
<tr>
<td>Test score</td>
<td>12.27</td>
<td>2.83</td>
<td>13.69</td>
<td>3.42</td>
</tr>
</tbody>
</table>

* $p < .05$.

**RQ 2.2 Is there a difference in learning outcomes between the building condition lesson group (DB and NB) and the selecting condition lesson group (DS and NS) after engaging in a manipulation task?**

To determine if different types of manipulation in a manipulation task influenced learning outcome, participants were grouped based on the different types of manipulation: building and selecting. Therefore, groups that were engaged in a building task of virtual objects (DB and NB) were combined to be one Building group ($n = 58$), and the group engaged in a selecting of virtual objects (DS and NS) were combined to be one Selecting group ($n = 63$).

An independent sample t-test was conducted to compare the mean differences of assessment 1 and assessment 2 test scores between the Selecting group and the Building group. Levene’s test for homogeneity of variances failed to detect any significant
difference between the group variances, \( F(1, 119) = .45, p = .50 \). The results revealed no statistically significant difference in the mean differences of test scores for different types of manipulation, \( t(119) = .88, p = .38 \). Table 4.14 reports the relevant means and standard deviations.

Table 4.14

Results of t-test and Descriptive Statistics for Mean Differences of Test Scores by Different Types of Manipulation

<table>
<thead>
<tr>
<th>Types of manipulation</th>
<th>Building</th>
<th>Selecting</th>
</tr>
</thead>
<tbody>
<tr>
<td>( N )</td>
<td>( M )</td>
<td>( SD )</td>
</tr>
<tr>
<td>Mean differences of test score</td>
<td>58</td>
<td>1.34</td>
</tr>
</tbody>
</table>

These results suggest that participants who were engaged in a selecting task (regardless of the type of lesson they previously received) did not perform better or worse than those who were engaged in building task. In addition, no statistically significant difference was found in the USA and Thailand groups.

Low-Prior knowledge (LP) group. To determine if different types of manipulation had an effect on participants’ test score in the LP group, the four experimental groups were collapsed into two groups based on different types of manipulation: building condition (DB and DS; \( n = 32 \)) and selecting condition (NB and NS; \( n = 40 \)). An independent sample t-test was conducted to compare the mean differences of the assessment 1 and assessment 2 test scores between the building group and the selecting group. Levene’s test for homogeneity of variances failed to detect any significant difference between the group variances, \( F(1, 70) = .14, p = .71 \). No statistically significant difference was found between the building group (\( M = 1.60, SD = 3.13 \)) and the selecting group (\( M = 1.75, SD = 2.85 \)) in mean differences of test scores (\( p = .83 \))


High-Prior knowledge (LP) group. To determine if different types of manipulation had an effect on participants’ test score in the HP group, the four experimental groups were collapsed into two groups based on different types of manipulation: building (DB and DS; \( n = 23 \)) and selecting (NB and NS; \( n = 26 \)). An independent sample t-test was conducted to compare the mean differences of the assessment 1 and assessment 2 test scores between the building group and the selecting group. Levene’s test for homogeneity of variances failed to detect any significant difference between the group variances, \( F(1, 47) = .58, p = .45 \). No statistically significant difference was found between the building group (\( M = 1.04, SD = 2.76 \)) and the selecting group (\( M = 1.87, SD = 2.36 \)) in mean differences of test scores (\( p = .27 \)).

In summary, to answer the second research question: *How do different types of manipulation (building/selecting) of virtual objects in a game-like environment in a manipulation task affect participants’ learning outcomes as measured by post-tests?*, the results suggested that having engaged in a manipulation task after reading either a descriptive or narrative lesson had a positive effect on the test score. However, the significant results were found only in the Thailand group, but not in the USA group. Moreover, the results revealed no statistically significant difference in test score for different types of manipulation. This means that participants who were engaged in a selecting task (regardless of the type of lesson they previously received) did not perform better or worse than those who were engaged in a building task. This concluded the analysis of the study’s research question two.
Research Question 3: Examining a possible interaction between a text-based pre-lesson and a manipulation task

How does reading a lesson followed by engaging in a manipulation task affect participants’ learning outcomes as measured by post-tests?

RQ 3.1 Is there a difference in learning outcomes between the groups that read the descriptive lesson followed by a manipulation task (either building or selecting conditions) in a game-like environment (i.e., DB vs. DS)?

An independent sample t-test was conducted to compare the mean differences of pre-intervention and assessment 1 test scores between the group that received the descriptive lesson followed by a building task (DB; \( n = 30 \)) and the group that received the descriptive lesson followed by a selecting task (DS; \( n = 34 \)). Levene’s test for homogeneity of variances failed to detect any significant difference between the group variances, \( F(1, 62) = .50, p = .48 \). The results revealed no statistically significant difference in the mean differences of test scores between these two groups, \( t(62) = .52, p = .60 \).

Low-Prior knowledge (LP) group. To determine if there is a difference in learning outcome in the LP group, an independent sample t-test was conducted to compare the mean differences of pre-intervention and assessment 1 test scores between the DB group \( (n = 20) \) and the DS group \( (n = 21) \). Levene’s test for homogeneity of variances failed to detect any significant difference between the group variances, \( F(1, 39) = 1.20, p = .28 \). The results revealed no statistically significant difference in the mean differences of test scores between these two groups, \( t(39) = -.09, p = .93 \).
High-Prior knowledge (HP) group. To determine if there is a difference in learning outcome in the HP group, an independent sample t-test was conducted to compare the mean differences of pre-intervention and assessment 1 test scores between the DB group \((n = 10)\) and the DS group \((n = 13)\). Levene’s test for homogeneity of variances failed to detect any significant difference between the group variances, \(F(1, 21) = 1.18, p = .29\). The results revealed no statistically significant difference in the mean differences of test scores between these two groups, \(t(21) = .78, p = .44\).

**RQ 3.2 Is there a difference in learning outcomes between the groups that read a narrative on physics concepts followed by a manipulation task (either building or selecting conditions) in a game-like environment (i.e., NB vs. NS)?**

Similar to the analysis performed in RQ 1.3, to determine if there is a difference in learning outcome, an independent sample t-test was conducted to compare the mean differences of pre-intervention and assessment 1 test scores between the group that received the narrative lesson followed by a building task (NB; \(n = 29\)) and the group that received the narrative lesson followed by a selecting task (NS; \(n = 33\)). Levene’s test for homogeneity of variances failed to detect a significant difference between the group variances, \(F(1, 60) = 1.50, p = .23\). The results revealed no statistically significant difference in test score between these two groups, \(t(60) = -1.19, p = .24\).

Low-Prior knowledge (LP) group. To determine if there is a difference in learning outcome in the LP group, an independent sample t-test was conducted to compare the mean differences of pre-intervention and assessment 1 test scores between the NB group \((n = 13)\) and the NS group \((n = 21)\). Levene’s test for homogeneity of variances failed to detect a significant difference between the group variances, \(F(1, 32) = .05, p = .82\). The
results revealed no statistically significant difference in test score between these two groups, \( t(32) = -.61, p = .55 \).

High-Prior knowledge (HP) group. To determine if there is a difference in learning outcome in the HP group, an independent sample t-test was conducted to compare the mean differences of pre-intervention and assessment 1 test scores between the NB group \( (n = 16) \) and the NS group \( (n = 12) \). From the analysis, Levene’s test for homogeneity of variances failed to detect a significant difference between the group variances, \( F(1, 26) = .65, p = .43 \). The results revealed no statistically significant difference in test score between these two groups, \( t(26) = .37, p = .72 \).

RQ 3.3 Is there a difference in learning outcomes between the groups that read the lesson (in either version) on physics concepts followed by a building manipulation task in a game-like environment (i.e., DB vs. NB)?

An independent sample t-test was conducted to compare the mean differences of assessment 1 and assessment 2 test scores between the group that received the descriptive lesson followed by a building task (DB), \( (n = 29) \) and the group that received the narrative lesson also followed by a building task (NB), \( (n = 29) \). Levene’s test for homogeneity of variances failed to detect any significant difference between the group variances, \( F(1, 56) = .49, p = .49 \). As shown in table 4.15 below, the results revealed no statistically significant difference in mean differences of test scores between these two groups, \( t(56) = -.89, p = .38 \). Table 4.15 reports the relevant means and standard deviations.
Table 4.15

Results of t-test and Descriptive Statistics for Mean Differences of Test Scores for DB and NB Groups

<table>
<thead>
<tr>
<th>Group</th>
<th>M</th>
<th>SD</th>
<th>n</th>
<th>M</th>
<th>SD</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Read</td>
<td>1.00</td>
<td>2.70</td>
<td>29</td>
<td>1.69</td>
<td>3.21</td>
<td>29</td>
</tr>
</tbody>
</table>

Low-Prior knowledge (LP) group. To determine if there is a difference in learning outcome in the LP group, an independent sample t-test was conducted to compare the mean differences of assessment 1 and assessment 2 test scores between the group that received a descriptive lesson followed by a building task (DB), \( n = 19 \) and the group that received a narrative lesson also followed by a building task (NB), \( n = 13 \). Levene’s test for homogeneity of variances failed to detect any significant difference between the group variances, \( F(1, 30) = .03, p = .88 \). The results revealed no statistically significant difference in mean differences of test scores between these two groups, \( t(30) = -1.19, p = .24 \).

High-Prior knowledge (HP) group. To determine if there is a difference in learning outcome in the HP group, an independent sample t-test was conducted to compare the mean differences of assessment 1 and assessment 2 test scores between the group that received a descriptive lesson followed by a building task (DB), \( n = 10 \) and the group that received a narrative lesson also followed by a building task (NB), \( n = 16 \). Levene’s test for homogeneity of variances failed to detect any significant difference between the group variances, \( F(1, 24) = 2.18, p = .15 \). The results revealed no statistically significant difference in mean differences of test scores between these two groups, \( t(24) = -.20, p = .85 \).
**RQ 3.4 Is there a difference in learning outcomes between the groups that read a lesson (in either version) followed by a manipulation task with selecting of virtual objects in a game-like environment (i.e., DS vs. NS)?**

Similar to the analysis performed in RQ 2.3, to determine if there is a difference in learning outcome, an independent sample t-test was conducted to compare the mean differences of assessment 1 and assessment 2 test scores between the group that received a descriptive lesson followed by a selecting task (DS), \((n = 32)\) and the group that received a narrative lesson followed by a selecting task (NS), \((n = 31)\). Levene’s test for homogeneity of variances failed to detect a statistically significant difference between the group variances, \(F(1, 61) = 2.12, p = .11\). As shown in table 4.16 below, the results revealed no statistically significant difference in mean differences of test scores between these two groups, \(t(61) = .81, p = .42\). Table 4.16 reports the relevant means and standard deviations.

**Table 4.16**

Results of t-test and Descriptive Statistics for Mean Differences of Test Scores for DS and NS Groups

<table>
<thead>
<tr>
<th>Group</th>
<th>DS</th>
<th>NS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(M)</td>
<td>(SD)</td>
</tr>
<tr>
<td>Mean differences of test score</td>
<td>2.06</td>
<td>2.38</td>
</tr>
</tbody>
</table>

Low-Prior knowledge (LP) group. To determine if there is a difference in learning outcome in the LP group, an independent sample t-test was conducted to compare the mean differences of assessment 1 and assessment 2 test scores between the group that received a descriptive lesson followed by a selecting task (DS), \((n = 20)\) and the group that received a narrative lesson followed by a selecting task (NS), \((n = 20)\). Levene’s test
for homogeneity of variances failed to detect a statistically significant difference between
the group variances, $F(1, 38) = .52, p = .48$. The results revealed no statistically
significant difference in mean differences of test scores between these two groups, $t(38) =
1.35, p = .19$.

High-Prior knowledge (HP) group. To determine if there is a difference in
learning outcome in the HP group, an independent sample t-test was conducted to
compare the mean differences of assessment 1 and assessment 2 test scores between the
group that received a descriptive lesson followed by a selecting task (DS), $(n = 12)$ and
the group that received a narrative lesson followed by a selecting task (NS), $(n = 11)$.
Levene’s test for homogeneity of variances failed to detect a statistically significant
difference between the group variances, $F(1, 21) = 2.35, p = .14$. The results revealed no
statistically significant difference in mean differences of test scores between these two
groups, $t(21) = -.60, p = .56$.

RQ 3.5 Is there a difference in learning outcomes between the four groups
after reading a lesson and engaging in a manipulation task?

This analysis aimed to explore an interaction between providing a lesson and
engaging in a manipulation task in each experimental group (DB, NB, DS, and NS) that
includes the different type of lesson read and the type of manipulation task performed. To
examine the normality of the mean differences of assessment 1 and assessment 2 test
scores, a Shapiro-Wilk test for normality was performed. The results indicated that the
dependent variable (the mean differences of assessment 1 and assessment 2 test scores)
was normally distributed within each experimental group (DB $p = .24$, NB $p = .69$, DS $p$...
= .29, NS \( p = .46 \). In addition, Levene’s test for homogeneity of variances failed to detect any significant difference between the group variances, \( F(3, 117) = .88, p = .45 \).

A 2x2 ANOVA was conducted to examine the effect of different types of lesson and types of manipulation on the test score between the four groups. The results for the ANOVA indicated no statistically significant difference between the four groups (as well as within the sub-group between the USA and the Thailand groups).

To answer the third research question: *How does reading a lesson followed by engaging in a manipulation task affect participants’ learning outcomes as measured by post-tests?*, the results suggested that participants in these four groups performed equally well according to the measures used. This means that there was no interaction between the two factors, lesson type and types of manipulation, on participants’ learning outcomes. This concluded the analysis of the study’s third research question.

Table 4.17 below, presents all research questions and summarizes the analysis, result, and basic implications for each research question. The following chapter discusses the results presented in the current chapter, and also presents the study's conclusions, limitations, and suggestions for future research.

Table 4.17

<table>
<thead>
<tr>
<th>Research Question</th>
<th>Analysis</th>
<th>Result</th>
<th>Implication for the Research Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>RQ 1.1. Is there a difference in learning outcomes before and after reading a lesson?</td>
<td>Paired sample t-test using the mean differences of pre-intervention and assessment 1 test scores.</td>
<td>Statistically significant in favor of the LP group.</td>
<td>Having read a lesson has a positive effect on learning outcomes for participants in the LP group, but not in the HP group.</td>
</tr>
<tr>
<td>RQ 1.2. Is there a difference in learning</td>
<td>Independent sample t-test using the mean</td>
<td>Statistically significant in favor of narrative</td>
<td>Participants, specifically in the USA group and only</td>
</tr>
<tr>
<td>Research Question</td>
<td>RQ 2.1 Is there a difference in learning outcomes before and after engaging in a manipulation task in all groups?</td>
<td>Paired sample t-test using the mean differences of assessment 1 and assessment 2 test scores.</td>
<td>Statistically significant for participants in both the LP and the HP groups. However, the significant result was found only in the Thailand group.</td>
</tr>
<tr>
<td>-------------------</td>
<td>-------------------------------------------------</td>
<td>---------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------</td>
</tr>
<tr>
<td>RQ 2.2 Is there a difference in learning outcomes between the building condition lesson group (DB and NB) and the selecting condition lesson group (DS and NS) before and after engaging in a manipulation task?</td>
<td>Independent sample t-test using the mean differences of assessment 1 and assessment 2 test scores for participants in the building and selecting groups.</td>
<td>No statistically significant difference in the mean differences of test scores was found between these two groups.</td>
<td>Participants in both types of manipulation did not perform better than the other.</td>
</tr>
<tr>
<td>Research Question 3. How does reading a lesson followed by engaging in a manipulation task affect participants’ learning outcomes as measured by post-tests?</td>
<td>RQ 3.1 Is there a difference in learning outcomes between the groups that read the lesson (in either version) on physics concepts followed by a building manipulation task in a game-like environment (i.e., DB vs. NB)?</td>
<td>Independent sample t-test using the mean differences of pre-intervention and assessment 1 test scores for participants in the DB and DS groups.</td>
<td>No statistically significant difference in the mean differences of test scores was found between these two groups.</td>
</tr>
<tr>
<td>RQ 3.2 Is there a difference in learning outcomes between the descriptive lesson group (DB and DS) and the narrative lesson group (NB and NS) before and after reading a lesson?</td>
<td>Differences of pre-intervention and assessment 1 test scores for participants reading descriptive lesson vs. narrative lesson.</td>
<td>Lesson, especially the HP group. However, the significant result was found only in the USA group.</td>
<td>The ones in the HP group, who read a narrative lesson perform better than those who read a descriptive lesson.</td>
</tr>
<tr>
<td>RQ 3.3</td>
<td>Is there a difference in learning outcomes between the groups that read the lesson (in either version) on physics concepts followed by a manipulation task through building virtual objects in a game-like environment (i.e., DB vs. NB)?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Independent sample t-test using the mean differences of assessment 1 and assessment 2 test scores for participants in the DB and the NB groups.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>No statistically significant difference in the mean differences of test scores was found between these two groups.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Participants in the DB group did not perform better or worse than those in the NB group.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>RQ 3.4</th>
<th>Is there a difference in learning outcomes between the groups that read a lesson (in either version) followed by a manipulation task with selecting of virtual objects in a game-like environment (i.e., DS vs. NS)?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Independent sample t-test using the mean differences of assessment 1 and assessment 2 test scores for participants in the DS and the NS groups.</td>
</tr>
<tr>
<td></td>
<td>No statistically significant difference in the mean differences of test scores was found between these two groups.</td>
</tr>
<tr>
<td></td>
<td>Participants in the DS group did not perform better or worse than those in the NS group.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>RQ 3.5</th>
<th>Is there a difference in learning outcomes between the groups that read a narrative on physics concepts followed by a manipulation task (either building or selecting conditions) in a game-like environment (i.e., NB vs. NS)?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>sample t-test using the mean differences of pre-intervention and assessment 1 test scores for participants in the NB and NS groups.</td>
</tr>
<tr>
<td></td>
<td>significant difference in the mean differences of test scores was found between these two groups.</td>
</tr>
<tr>
<td></td>
<td>NB group did not perform better or worse than those in the NS group.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>RQ 3.4</th>
<th>Is there a difference in learning outcomes between the groups that read a lesson (in either version) followed by a manipulation task with selecting of virtual objects in a game-like environment (i.e., DS vs. NS)?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Independent sample t-test using the mean differences of assessment 1 and assessment 2 test scores for participants in the DS and the NS groups.</td>
</tr>
<tr>
<td></td>
<td>No statistically significant difference in the mean differences of test scores was found between these two groups.</td>
</tr>
<tr>
<td></td>
<td>Participants in the DS group did not perform better or worse than those in the NS group.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>RQ 3.5</th>
<th>Is there a difference in learning outcomes between the groups that read a narrative on physics concepts followed by a manipulation task (either building or selecting conditions) in a game-like environment (i.e., NB vs. NS)?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>sample t-test using the mean differences of pre-intervention and assessment 1 test scores for participants in the NB and NS groups.</td>
</tr>
<tr>
<td></td>
<td>significant difference in the mean differences of test scores was found between these two groups.</td>
</tr>
<tr>
<td></td>
<td>NB group did not perform better or worse than those in the NS group.</td>
</tr>
<tr>
<td>outcomes between the four groups after reading a lesson and engaging in a manipulation task?</td>
<td>of assessment 1 and assessment 2 test scores for all groups (DB, NB, DS, and NS)</td>
</tr>
</tbody>
</table>
V - DISCUSSION

The purpose of this study was to examine the effects of manipulation of virtual objects in a game-like environment when supplemented with a descriptive or a narrative lesson in the context of physics concepts related to force, distance, and conservation of energy. In particular, the study examined learners’ performance on a test of physics knowledge related to the study when encountered with two factors that influence learning: lesson type and type of manipulation. The research questions addressed appear below:

Research Question 1. How does receiving a lesson on physics concepts before a manipulation task affect the participants’ learning outcomes as measured by post-tests?

Research Question 1.1 Is there a difference in learning outcomes before and after reading a lesson?

Research Question 1.2 Is there a difference in learning outcomes between the descriptive lesson group (DB and DS) and the narrative lesson group (NB and NS) after reading a lesson?

Research Question 2. How do different types of manipulation (building or selecting) of virtual objects in a game-like environment affect participants’ learning outcomes as measured by post-tests?

Research Question 2.1 Is there a difference in learning outcomes after engaging in a manipulation task in across groups?
Research Question 2.2 Is there a difference in learning outcomes between the building condition lesson group (DB and NB) and the selecting condition lesson group (DS and NS) after engaging in a manipulation task?

Research Question 3. How does reading a lesson followed by engaging in a manipulation task affect participants’ learning outcomes as measured by post-tests?

Research Question 3.1 Is there a difference in learning outcomes between the groups that read a descriptive lesson on physics concepts followed by a manipulation task (either building or selecting conditions) in a game-like environment (i.e., DB vs. DS)?

Research Question 3.2 Is there a difference in learning outcomes between the groups that read a narrative lesson on physics concepts followed by a manipulation task (either building or selecting conditions) in a game-like environment (i.e., NB vs. NS)?

Research Question 3.3 Is there a difference in learning outcomes between the groups that read a lesson (in either version) on physics concepts followed by a building manipulation task in a game-like environment (i.e., DB vs. NB)?

Research Question 3.4 Is there a difference in learning outcomes between the groups that read a lesson (in either version) followed by a manipulation task with selecting of virtual objects in a game-like environment (i.e., DS vs. NS)?

Research Question 3.5 Is there a difference in learning outcomes between the four groups after reading a lesson and engaging in a manipulation task?

The study hypothesized that the supplement of a text-based pre-lesson will positively affect learners’ outcomes, especially when reading the narrative lesson. Moreover, a building condition (learners are able to build and assemble/disassemble variations of virtual objects in a game-like environment) in a manipulation task was
hypothesized to improve learning outcome after reading a lesson, as learners were able to interact more with the virtual objects. This means that learners in the building group were able to manipulate various trebuchets by assembling/disassembling virtual mechanical blocks in the game-like environment of a physics-based construction game. Learners in a selecting group, on the other hand, were not able to build and assemble/disassemble, but only allowed to interact with pre-assembled virtual objects (i.e., trebuchet) in the same environment by choosing pre-assembled trebuchet, counting the number of blocks (i.e., the length of an arm that would throw a projectile), examining a projectile’s range on each trebuchet, and observing what happens. The study also examined the impact of these factors on participants in a low-prior knowledge group (those whose pre-invention test score is lower than 50% of the possible test score) and participants in a high-prior knowledge group (those whose pre-invention test score is 50% or higher of the possible test score). In addition, the study also examined whether or not there were differences in learning outcomes across two groups of participants that were recruited from USA and Thailand.

Discussion of Research Questions

To explore these hypotheses, 126 adults participated in the study, and 121 adults completed the study's five phases. The participants had an average age of 22.73 years (SD = 5.50), were predominately female (69.84%), and were randomly assigned to one of the four experimental conditions (DB, NB, DS, and NS). All participants were asked to complete a pre-intervention survey to provide demographic information, and a pre-assessment of their prior knowledge of physics concepts in the areas of force, distance, and conservation of energy. Participants then engaged in five phases of the experiment,
consisting of reading a physics lesson, completing assessment 1, engaging in a
manipulation task, and completing assessment 2. Assessment 1 is a post-assessment that
occurred after reading the physics lesson, and assessment 2 is a post-assessment that
occurred after participants completed a manipulation task.

This chapter reviews the study’s findings, discussing them within the contexts of
the effects of descriptive and narrative lessons in learning physics concepts and learning
with virtual manipulatives, acknowledges the limitations of this study, and explores the
findings' implications for the design of interactive interventions for learning these
concepts in the future.

Discussion of Research Question 1: Lesson type

One of the main objectives of the study was to examine the effect of different
types of text-based lessons, specifically whether descriptive or narrative lessons would
enhance learning of physics concepts. Narrative has long been believed to have a central
role in learning, and story-based learning can be both engaging and effective (Mott,
McQuiggan, Lee, Lee, & Lester, 2006). Furthermore, research has shown that students
learn better from reading narrative than from reading descriptive lessons and that
narratives have a strong positive effect on reading comprehension (Fitzgerald & Spiegel,
1983).

The first research question explored the effect of reading a lesson, regardless of
type and before a manipulation task, on knowledge about the physics concepts related to
this study. Fundamentally, the first research question seeks to understand 1) the effect of
reading a lesson by examining the possible difference between pre-intervention and
assessment 1 test scores, and through sub-analyses 2) the effect of different types of
lessons by examining the possible difference between the descriptive lesson and narrative lesson group's assessment 1 test score. Moreover, an additional analysis examined these questions from the perspective of low and high prior-knowledge participants as well as the two countries from which they were recruited.

To address this research question, the study asked participants to read either a descriptive or narrative version of a lesson and then complete a post-reading assessment (assessment 1). Then the mean differences of pre-intervention and assessment 1 test scores were examined. A summary of the results and implication for each sub research question in research question 1 is shown in table 5.1, below.

Table 5.1

<table>
<thead>
<tr>
<th>Research Question</th>
<th>Result</th>
<th>Implication for the RQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>RQ 1.1 Is there a difference in learning outcomes before and after reading a lesson?</td>
<td>Statistically significant in favor of the LP group.</td>
<td>Having read a lesson has a positive effect on learning outcomes for participants in the LP group, but not the HP group</td>
</tr>
<tr>
<td>RQ 1.2 Is there a difference in learning outcomes between the descriptive lesson group (DB and DS) and the narrative lesson group (NB and NS) before and after reading a lesson?</td>
<td>Statistically significant in favor of narrative lesson, especially the HP group. However, the significant result was found only in the USA group.</td>
<td>Participants, specifically in the USA group and only the ones in the HP group, who read a narrative lesson perform better than those who read a descriptive lesson.</td>
</tr>
</tbody>
</table>

The results suggested that a lesson supplement (either descriptive or narrative lesson type) positively affected participants’ learning outcomes when it was given before assessment 1. This means that providing a lesson positively influenced learning and acquiring information on the physics concepts that were being assessed in this study. This seems intuitive, as without a lesson learning is not likely to occur. However, when the same analysis was performed to examine the mean differences of pre-intervention and
assessment 1 test scores of participants in a low-prior knowledge (LP) and a high-prior knowledge (HP) group, the results revealed that a lesson supplement positively affected participants only in the LP group. This finding seems to make logical sense, since participants in the HP group already had some background knowledge of physics concepts targeted in this study, therefore, reading a lesson pertaining to those concepts would have less of an effect on their post test score related to knowledge gained. However, when the additional analysis was conducted to examine the differences between participants in the USA and Thailand groups, the significant results were only found in the USA group. This means that participants in the Thailand group equally benefit from reading either a descriptive or a narrative type of lesson.

Furthermore, the results revealed that participants in the LP group who read a narrative lesson did not perform better or worse than those who read a descriptive lesson. On the other hand, although there was no statistically significant difference in test score when providing a lesson supplement in the HP group, the results suggested that participants in this group who read a narrative type of lesson (specifically the USA group) perform better than those who read a descriptive type of lesson. Fitzgerald and Spiegel (1983) posited that narrative text structures play an important role in individuals’ cognitive processing of text and this knowledge of narrative structure is referred to as story schema. Individuals with high prior knowledge about a topic used relevant schema that can then be used to comprehend new information (Britton & Tesser, 1982). This means that there is a difference of schema applied to understand new information between low- and high-prior knowledge participants. McDaniel, Gilles, and Einstein (1989) conducted a study to examine the combination of the type of text and reader’s
knowledge base to examine the degree to which particular reading tasks would enhance memory for the information presented by the text. The results revealed that high knowledge subjects recalled significantly more of the passage than low knowledge subjects. Therefore, appropriate prior knowledge allows the readers to better identify, extract, and retain the important ideas in a passage (McDaniel et al., 1989).

As mentioned earlier, previous work has supported the argument that the HP students are better at extracting and retaining important information than the LP students are. However, in this study the test scores did not show a statistically significant improvement pre- to post- test scores for the HP participants. This might not be surprising result as the HP participants already started with a significant amount of background knowledge in physics before the lesson was given to them. Therefore, there might have not been enough new information for the HP group to show statistically significant improvement in knowledge gain, and there may have been a ceiling effect.

In summary, narratives are an integral component in meaning making and they also provide structure for encoding experiential knowledge (Polkinghorne, 1998). Some researchers (Lunenburg & Ornstein, 2012) have argued that teaching science should involve the use of a narrative approach and not simply description because narrative teaching allows a sort of enactment of theories and concepts related to the real world. The idea of narrative explanation as a pedagogical method in teaching science draws heavily from situated learning theory. This means that science literacy and the corresponding possibility for increasing scientific knowledge are anchored on situational learning, that is, learning through experience (Barton & Hamilton, 1998; Handly, Clark, Fincham, & Sturdy, 2007). Situational learning of science subjects underscores the idea that learning
is made possible not simply through teaching materials or texts used but more importantly through situations, events, and contexts in which those materials or texts are made clear to students (Barton & Hamilton, 1998; Handley et al., 2007).

The findings of research question 1, which imply that a lesson supplement positively affected participants only in the LP group and, especially, that the narrative lesson positively affected participants in the HP group, can be contextualized within the work cited above as 1) individuals’ cognitive processing of text relies on how text is structured and, 2) that there is a difference of schema used to understand new information between low- and high-prior knowledge participants. It is also interesting to point out the different results between the USA and the Thailand groups in that participants in the USA group learned better with narrative whereas participants in the Thailand group learned equally well with either type of lesson. This could mean that participants in the Thailand group treated these two types of lesson the same, and that there was no difference between situated or contextualized narrative lessons for this group.

**Discussion of Research Question 2: Types of manipulation**

One of the common modes of interacting with computer systems is through manipulation of graphical representation of objects (Sedig et al., 2001). Manipulation as a method to control computer systems is commonly used in various application areas, including educational games.

This second research question looked at how manipulation task affects learning outcome and also how different type of manipulation of virtual objects in a game-like environment affect participants’ learning performance as measured by test score. Essentially, the second research question seeks to understand 1) the effect of engaging in
a manipulation task by examining the possible difference between assessment 1 and assessment 2 test scores, and 2) the effect of different types of manipulation by examining the possible difference between the building and selecting groups’ assessment 2 test score.

To address this research question, the study asked participants in the building group to build various trebuchets by assembling virtual mechanical blocks in a game-like environment of a physics-based construction game called Besiege. Participants who were in the selecting group, on the other hand, were only allowed to interact with pre-assembled virtual objects (i.e., trebuchet) in a game-like environment of the same physics-based construction game. This group's interactions consisted of selecting pre-assembled trebuchet, counting the number of blocks to determine the length of launch mechanisms, and examining a projectile’s range after firing each trebuchet. A summary of the results and implication for each sub research question in research question 2 is shown in table 5.2, below.
Table 5.2

A Summary of the Results and Implication for Research Question Two

<table>
<thead>
<tr>
<th>Research Question</th>
<th>Result</th>
<th>Implication for the RQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>RQ 2.1 Is there a difference in learning outcomes before and after engaging in a manipulation task in all groups?</td>
<td>Statistically significant for participants in both the LP and the HP groups. However, the significant result was found only in the Thailand group.</td>
<td>Having engaged in a manipulation task after reading a lesson has a positive effect on learning outcomes for participants in the LP and the HP groups especially for participants in the Thailand group.</td>
</tr>
<tr>
<td>RQ 2.2 Is there a difference in learning outcomes between the building condition lesson group (DB and NB) and the selecting condition lesson group (DS and NS) before and after engaging in a manipulation task?</td>
<td>No statistically significant difference in the mean differences of test scores was found between these two groups.</td>
<td>Participants in both types of manipulation did not perform better than the other.</td>
</tr>
</tbody>
</table>

The results suggested that having engaged in a manipulation task after reading the lesson (either descriptive or narrative) had a positive effect on participants’ learning outcomes. Statistically significant results were also found in low-and high-prior knowledge participants. This means that participants (regardless of their level of physics proficiency) performed better after reading either lesson and completing a manipulation task. Such findings are consistent with previous work suggesting that using manipulatives can effectively enhance students’ conceptual understanding, skills, and attitudes (Zacharia & Constantinou, 2008). The results from this study also aligned with constructivist theory, which emphasizes the importance of learners taking an active role in their own learning and actively processing and practicing the targeted information (Piaget & Inhelder, 1969). However, when the additional analysis was conducted to examine whether or not there were differences in performance across the USA and Thailand groups, statistically significant results were found only in the Thailand group. It has been known that many school subjects are taught more didactically than interactively in Asian countries (Wong, 2004). This could imply that the way that physics was taught
in school between these two countries is different and that being able to manipulate or interact with the virtual instructional materials in a concrete manner positively benefitted those students who may not have been previously exposed to this type of instruction.

In terms of the different types of manipulation, statistically significant results were not found between selecting and building groups, in low- and high-prior knowledge participants, and also not in the USA and Thailand groups. This means that participants who were in the selecting group and the building group (regardless of the type of lesson they previously received) performed equally well, and that types of manipulation did not make an impact in the learning outcomes as measured by this study's assessments.

Some educators and researchers believe that through the use of game-like environments in computer games, students can enhance their skills and competence as well as be intrinsically driven or motivated to learn (Dickey 2005). In such environments, students are able to interact with virtual materials and experience first-hand, although in a simulated environment, learning materials that are representative of the physical world. For instance, in a game-like environment, students learning physics are able to manipulate and interact with virtual objects and come to understand how similar real-world objects work outside the game environment.

While game-like environments allow for wider avenues of learning for learners, it is also possible that they limit learning capabilities. Students, for instance, can get flooded with too much information, which at times is not necessarily relevant for their learning of a specific subject. The main issues when computer games are used in teaching involve whether or not some of the information incorporated in the given game is
relevant for learning, and whether or not learners are able to distinguish between relevant and irrelevant information.

**Discussion of Research Question 3: A possible interaction between a text-based pre-lesson and a manipulation task**

This research question aimed to explore the possible interaction between providing a lesson prior to a manipulation task in each experimental group (DB, NB, DS, and NS), and addresses the different type of lesson read and the type of manipulation task. A summary of the results and implication for each sub research question in research question 3 is shown in table 5.3 below.

Table 5.3

<table>
<thead>
<tr>
<th>Research Question</th>
<th>Result</th>
<th>Implication for the RQ</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RQ 3.1</strong> Is there a difference in learning outcomes between the groups that read the descriptive lesson followed by a manipulation task (either building or selecting conditions) in a game-like environment (i.e., DB vs. DS)?</td>
<td>No statistically significant difference in the mean differences of test scores was found between these two groups.</td>
<td>Participants in the DB group did not perform better or worse than those in the DS group.</td>
</tr>
<tr>
<td><strong>RQ 3.2</strong> Is there a difference in learning outcomes between the groups that read a narrative on physics concepts followed by a manipulation task (either building or selecting conditions) in a game-like environment (i.e., NB vs. NS)?</td>
<td>No statistically significant difference in the mean differences of test scores was found between these two groups.</td>
<td>Participants in the NB group did not perform better or worse than those in the NS group.</td>
</tr>
<tr>
<td><strong>RQ 3.3</strong> Is there a difference in learning outcomes between the groups that read the lesson (in either version) on physics concepts followed by a manipulation task through building virtual objects in a game-like environment (i.e., DB vs. NB)?</td>
<td>No statistically significant difference in the mean differences of test scores was found between these two groups.</td>
<td>Participants in the DB group did not perform better or worse than those in the NB group.</td>
</tr>
<tr>
<td><strong>RQ 3.4</strong> Is there a difference in learning outcomes between the groups that read a lesson (in</td>
<td>No statistically significant difference in the mean differences of test scores was</td>
<td>Participants in the DS group did not perform better or worse than those in the NS group.</td>
</tr>
</tbody>
</table>
RQ 3.5 Is there a difference in learning outcomes between the four groups after reading a lesson prior to engaging in a manipulation task?

| | No statistically significant difference in the mean differences of test scores was found between these four groups. | No interaction between the two factors, lesson type and types of manipulation, on participants’ learning outcomes was found. |

The results suggest that participants in these four groups performed equally well according to the measures used. Significant results were not found in low- and high- prior knowledge participants as well as the two countries from which they were recruited. This means that there was no interaction between the two factors, lesson type and types of manipulation, on participants’ learning outcomes.

Although the findings from research question 3 indicate no statistical significance in the interaction between lesson type and types of manipulation, Sedig et al. (2001)’s work informs the results of this study in that learning that involves comprehension and manipulation of conceptual abstraction needs new models and techniques to address interaction, which are conducive to better learning. Moreover, they argued that since the manipulation task engages users’ attention with objects on the screen, abstract concepts must be explicit and engaging in order to fully support learning.

**Conclusion**

This study set out to examine the effects of manipulation of virtual objects in a game-like environment when supplemented with a test-based lesson on physics concepts related to force, distance, and conservation of energy. The hypotheses were that reading a narrative lesson and engaging in building virtual objects in a game-like environment
would yield positive effects in terms of learning outcomes. The study drew on the research done on using virtual manipulatives in education and theoretical support from constructivist theories of learning implying that learners form their own knowledge through meaningful interactions with the world, and that prior knowledge greatly influences the construction of new knowledge in individual learners (Barbour et al., 2009; Bruner, 1966).

From the study’s results, it seems that providing a textual pre-lesson is important for low-prior knowledge learners when it comes to learning physics concepts. Moreover, having engaged in a manipulation task also contributed to participants’ learning gain (in both low-prior knowledge and high-prior knowledge groups) as measured by the post-assessments used in this study. However, some differences in learning outcomes were found between participants from the two countries from which they were recruited: USA and Thailand. Certainly the culture and ways of teaching and learning physics were different, and that could have affected learning outcomes. Further investigation is needed to examine the factors that cause the differences, as discussed in the following section.

The results from this study help inform educational game designers who incorporate manipulatives about the role of providing pre-lessons that tie to concepts targeted by the manipulation activity, and how different kinds of manipulation in a game-like environment affect learning outcomes. The findings suggest that the role of these two factors combined requires further research. In addition, for researchers it seems reasonable to further explore the use of virtual manipulatives with different interfaces (e.g., tablets, gesture control devices) to uncover aspects of these devices that might influence learning, as interfaces directly affect how manipulation in virtual environments
can occur. Tangible interfaces, as defined by Ullmer and Ishii (2000), are environments in which digital information can be manipulated by physical form. These interfaces can provide educational benefits of physical manipulation by integrating physical and virtual representations and offering expressive activity (Marshall, 2007). Moreover, interfaces in learning applications play an important role in how students interact with the educational content, how they acquire knowledge, and what knowledge they acquire (Sedig et al., 2001).

Moreover, the results from this study can inform teachers and educators when selecting and providing instructional materials for students. Different levels of prior-knowledge and learning background certainly have an effect on learning outcomes. Hence, it is important to choose appropriate instructional materials as well as types of activity that can enhance and reinforce the understanding of newly learned concepts. Educators should also select suitable types of assessments that align with the learning activities.

**Limitations**

The results of this study must be considered in the context of a number of limitations, which are discussed below.

One limitation involves the recruitment of subjects and sites from which they were recruited. A convenience sampling of adult participants was used due to recruiting and time constraints. Although a preliminary analysis was performed to ensure that participants in the four experimental conditions were equivalent in terms of their demographic characteristics, the number of participants recruited from each site was not equal and some additional analyses were conducted that indicate differences between
participants from these two research sites (countries). Additional analyses could be conducted to find further insights about how different learning cultures and the way that physics was taught in participants' respective schools could have affected this study's results but are beyond the scope of this study. Therefore, further investigation is needed for a comparative study on the same experimental conditions between these two research sites.

A second limitation of this study is the number of participants. Although the study involved enough participants to ensure statistical power for the main analyses, increasing the number of participant in each of the subgroups (i.e., low- and high-prior knowledge groups) could yield interesting findings.

A third limitation is measurement. Test scores are not the only available measures of learning; strategies, engagement, task motivation, and topic interest during learning activities can also be an important part of learning that can be measured. There are important questions related to these areas that were beyond the scope of the current study, but are worth investigating. Furthermore, the type of measurement and assessment did not directly match the learning activities from the manipulation task. It may be appropriate to assess participants after reading a lesson with multiple-choice questions; however, these multiple-choices questions might not be a great measurement to assess participants’ knowledge after engaging in a manipulation task. Therefore, a new way of assessing the learning outcome could be used so that it aligns with the prior given learning task.

A fourth limitation realtes to the content in the assessments themselves. Although the questions in each of the three assessments are not exactly the same, the setup of the
questions (multiple choice format) as well as the images that were used is the same across all three. This could impose a testing effect on participants due to the fact that they might have been able to recall some information from the test, which may have influenced the responses. As previously discussed in the third limitation, a different way to assess the learning outcome could be introduced and used, instead of using only a multiple choice format for all parts of the assessment.

A fifth limitation is the inability to modify the game that was used in the study. Some interesting data, such as the amount of time participants spent on each exercise, how many attempts they made in the simulation, how many mistakes they made building a trebuchet (in the building condition) could be collected and yield informative results. Because Besiege is a commercial game that was not developed by the researcher, there was a limitation in terms of the capability of in-game data collection. These data could have been used to analyze how they influence the learning outcomes.

A sixth limitation lies in the amount of time that participants had to get familiar with the game-like environment used in the study. Participants were given approximately 10-15 minutes to play with the game interface and practice controlling virtual objects before diving into the exercises. Those who were not familiar with computer game interfaces and needed more time to practice might have felt frustrated and discouraged when completing the exercises.

A seventh limitation is the way the manipulation task (building versus selecting) was set up. It seemed at first that the requirements of the task in these two conditions were different; in fact there were many overlaps, from the selecting condition to the building condition. In the building condition, participants were able to do everything that
those in the selecting condition could do as well. In addition, participants in the building condition were also able to manipulate each block by assembling and disassembling it. Therefore, there may not have been clear differentiation between these two conditions to the participants and that could have influenced results.

Additionally, the amount of time for manipulation could have affected the results. Given that there was only one session for manipulation, participants had relatively little time to interact with virtual objects in the game-like environment. Adding more sessions could perhaps yield a different result. Would more interaction (i.e., adding sessions) with virtual objects alter learning outcomes? Would there be a significant difference between participants in the low- and high-prior knowledge groups when adding more sessions? These questions are worthy of exploration in a future study.

**Future Directions**

There is additional work that is suggested by the findings from this study. One of the most promising areas of research is to conduct the same study with a larger population in each site and then do a comparison of findings. Cultural differences, learning experiences, and the different ways that physics might have been taught to participants might be major influences on learning physics concepts that perhaps might emerge in a comparison study between the two sites. Some research studies have shown that students in developing countries feel differences between the culture of Western science education and their indigenous cultures (Aikenhead, 1997; Jegede, 1995). Therefore, there is a need to develop culturally sensitive curricula and teaching methods that reduce the foreignness felt by students (Aikenhead & Jegede, 1999).
Several studies have shown that different interfaces in educational software resulted in different learning outcomes (Turkay et al., 2014). For example, the use of a haptic interface was more effective than a non-haptic interface in learning physics concepts from a computer simulation (Han & Black, 2012). Another area for future work could be a study of other interfaces.

It is unknown to what extent findings from this study apply to other topics. It may seem reasonable that near-transfer topics such as work and energy, angular momentum, and projectile motion are similar enough that findings can be applied to a large extent. Therefore, these topics could be assessed and investigated in future research.

Finally, a delayed post-assessment of learning these physics concepts could be included in an iteration of the same study. Because of the time constraint in this study, the researcher was not able to measure the learning outcomes a day or a week after the experiment was conducted. Future work should take into account the delayed effect of knowledge retention when learning the physics concepts addressed in this study.

This concludes the chapter and the dissertation.
REFERENCES


APPENDICES

Appendix A

Pre-Intervention Survey

Q1 What is your name?

Q2 What is your email address?

Q3 What is your age?

Q4 What is your gender?
   ○ Male
   ○ Female

Q5 Do you identify yourself as:
   ○ White
   ○ Black or African American
   ○ American Indian or Alaska Native
   ○ Asian
   ○ Native Hawaiian or Pacific Islander
   ○ Hispanic or Latino
   ○ Mixed race
   ○ I prefer not to answer.
Q6 What is your level of education?
- Less than high school
- High school graduate
- Some college, but no degree
- 2-year college degree
- 4-year college degree
- Professional degree
- Graduate degree (Master or Doctoral)
- Other

If Less than high school Is Selected, Then Skip To Do you understand English text well?
If High school graduate Is Selected, Then Skip To Do you understand English text well?

Q7 What is/was your major in college?

Q8 Do you understand English text well?
- Yes
- No

Q9 How did you hear about this study?
- From a flyer
- From a friend/family member
- From an announcement in a class
- From online message board
- From social media sites (e.g., Facebook, Twitter)
- None of the above

The following 20 questions in the next (last) part ask about Physics. Please DON’T get discouraged if you can’t answer some of these questions, but please do your best (you can guess if you like). The study you have volunteered for will use different ways to teach this content, so we need to know your beginning knowledge of this subject.

Q1 A lever can be used to multiply__________ or change____________.
- direction, force
- power, direction
- length, force
- force, direction
Q2 What determines the class of a lever?
- Where the load and effort are with respect to the fulcrum.
- How much effort is required to lift the load.
- Whether the arms are long, medium, or short in length.
- Where the effort is doubled the weight of the load.

Q3 Two children want to balance each other on a teeter totter with the fulcrum in the middle. One weighs 20 kg and sits at one end of a teeter totter, 6 meters from the fulcrum. Where should the other child be seated if the second child weighs 40 kg?

- 1 meter away from the fulcrum
- 2 meters away from the fulcrum
- 3 meters away from the fulcrum
- 4 meters away from the fulcrum

Q4 As a load is moved farther from the fulcrum, the effort needed to lift the load ____________.
- Increases
- Decreases
- Stays the same
- Is the opposite
Q5 There are three classes of levers, first class (1), second class (2), and third class (3). They differ in the position of the Fulcrum (pivot point), Load, and Effort. In the Figure shown below, which one of these is the **first** class lever?
Q6 Please identify the fulcrum of this first class lever teeter totter.

- 1
- 2
- 3

Q7 This pair of tweezers is a third class lever. Please identify where the load and the effort are respectively.

- 2, 3
- 1, 3
- 1, 2

Q8 This nut cracker is a second class lever. Please identify where the load and the effort are respectively.

- 2, 3
- 1, 3
- 1, 2
Q9 The law of conservation of energy is a statement that
- Energy must be conserved and you are breaking a law if you waste energy.
- The supply of energy is limited so we must conserve.
- The total amount of energy is constant.
- Energy cannot be used faster than it is created.

Q10 Why were trebuchets used?

- To smash masonry walls.
- To throw projectiles over walls.
- To fight with during wars.
- All of the above.

Q11 In a trebuchet, what creates the force used to throw the payload?

- A long arm and counterweight
- Counter weight and gravity
- Counter weight and a payload
- A long arm and gravity

Q12 What happens if the counterweight is the same weight as the payload?

- The payload will travel a longer distance.
- The payload will travel a shorter distance.
- The payload will travel the same distance.
- The trebuchet will fail to launch the payload.

Q13 An object that has energy stored in it has ______ due to its position in a gravitational field.

- Potential energy
- Kinetic energy
- Chemical energy
- Mechanical energy
Q14 If an object is moving, you know it has –
- Potential energy
- Kinetic energy
- Chemical energy
- Light energy

Q15 Which of these best explains conservation of energy in a context of a trebuchet?
- The total energy in the system increases as the counterweight is being lifted to the highest point upon releasing.
- The total energy in the system decreases as the counterweight is pulled down by the gravity.
- The total energy in the system decreased as the payload is launched because potential energy is converted to kinetic energy.
- The total energy in the system stays the same.

Q16 Use this Figure for question 16 - 20

The trebuchet in the picture below is 10 meters in height and the counterweight is 15 kg. The counterweight is attached to the arm 3 meters from the fulcrum and the payload is attached to the arm 9 meters from the fulcrum. However, the throwing range of this trebuchet is too short and the rock cannot hit the target (the house). Which modifications to the trebuchet will increase its range?
- Increase the length of the counterweight arm.
- Decrease the weight of the counterweight.
- Increase the weight of the payload.
- Decrease the length of the payload arm.
Q17 Which modification of your trebuchet will most directly affect the distance of the projectile being launched?
- The size of the payload area.
- The length of the arm.
- The number of blocks needed to build the base.
- The strength of the frame structure.

Q18 Assume that you cannot increase the arm length or change the counterweight or payload to make the trebuchet throw farther. All you can do is to change where to place the fulcrum. Therefore, where should the new fulcrum be?

- The new fulcrum should be at number 1 to increase the length of payload arm.
- The new fulcrum should be at number 2 to increase the length of counterweight arm.
- The new fulcrum should be at number 3 to be as close to the payload as possible.
- None of the above answers is correct.

Q19 If the weight of the counterweight is doubled but everything else stays the same, what would happen to the projectile?
- The payload will travel a longer distance.
- The payload will travel a shorter distance.
- The payload will travel the same distance.
- The trebuchet will fail to launch the payload.

Q20 Given that you can neither increase the total arm length nor change the location of the fulcrum, how would you modify this trebuchet to increase the projectile's range most effectively?
- Increase the weight of the counterweight.
- Reduce the weight of the payload.
- Increase the weight of the counterweight and reduce the weight of the payload.
- None of the above.
Lesson: Physics in a Context of Historical Siege Machines

**Levers**

One of the simplest machines is the common lever. Even a simple log can act to magnify forces and shift objects heavier than the person holding the log.

All levers have a *Fulcrum* (turning point), *Effort* (the force provided to do the work), and the *Load* (the force we are pushing against). There are three classes of levers, **first class**, **second class**, and **third class**. They differ in the position of the fulcrum, load, and effort.

**First class lever**

This type of lever has the fulcrum placed between the effort and load. The effort motion and the resulting load motion are in opposite directions. The fulcrum reverses the direction of motion.

Examples of first class lever include: Teeter totter, and Scissors
**Second class lever**
This type of lever has the load between the effort and the fulcrum. In this type of lever, the effort motion and the resulting load motion are in the same direction. Note that the length of the effort arm goes all the way to the fulcrum and is always greater than the length of the load arm in a second class lever.
Examples of second class lever include: Nut cracker and Wheelbarrow

![Diagram of Second Class Lever]

**Third class lever**
This type of lever has the effort between the load and the fulcrum. The effort motion and the resulting load motion are in the same direction. Note that the length of the load arm goes all the way to the fulcrum and is always greater than the length of the effort arm in a third class lever.
Examples of third class lever include: Hockey stick, and Tweezers

![Diagram of Third Class Lever]

**Mechanical advantage**
When a lever takes a small input force and increases the magnitude of the output force, a mechanical advantage (MA) has been produced. For example, third class levers do not have good mechanical advantage. In fact, they have *mechanical disadvantage*. The effort is closer to the fulcrum than the load that makes the effort *greater* than the load. However, one advantage of such levers is that the distance moved by the load is greater than the distance moved by the effort.

We can find the mechanical advantage for a lever by looking at the work the lever does. The work the user inputs on the lever is equal to the work outputted by the lever, where work is a force, $F$, multiply by a displacement, $D$ (distance of fulcrum to where the force is).
\[
\text{Work} = \text{Force} \times \text{Displacement (N} \cdot \text{m)}
\]

Mechanical Advantage = \( \frac{\text{Work}_{\text{output}}}{\text{Work}_{\text{input}}} \)

For a balanced lever

\[
\text{Work}_{\text{output}} = \text{Work}_{\text{input}} \\
F_{\text{output}}D_{\text{output}} = F_{\text{input}}D_{\text{input}}
\]

Example:

I am using a can opener to open a can of peaches. The fulcrum is 1 cm from the output force and 5 cm from the input force. What is the ideal mechanical advantage of the lever I am using to open the can of peaches?

Distance from fulcrum to input force (input distance) = 5 cm
Distance from fulcrum to output force (output distance) = 1 cm

ideal mechanical advantage = 5 cm/1 cm
ideal mechanical advantage = 5

Therefore, the output force of the lever is 5 times greater than the input force.

**Catapults and Levers**

Levers are not only used in warfare. They also serve a very practical purpose in moving large masses. Archimedes, an ancient mathematician, is credited for saying “Give me a lever long enough and a place to stand, and I will move the earth.” Despite the exaggeration, levers were used throughout history to help assemble massive construction projects. It is hypothesized that levers were used in the construction of the moai on Easter Island, in raising stones at Stonehenge, and to lift stones to build the great pyramids.

A catapult is basically any kind of device such as a trebuchet or a mongonel that launches a projectile by mechanical means. Catapults vary in the type of lever used and how the effort is applied. The throwing arm of the catapult is the lever, the fulcrum is where the arm attaches to the catapult, and the load is what the catapult is throwing. Catapults normally use **first class** or **third class** levers. For all intents and purposes, second class levers would not make a good catapult.

**Examples:**

A trebuchet is a first class lever. As you can see here, the fulcrum is in the middle of the arm. The effort is applied on one end of the arm by a heavy weight, and the load is on the opposite end of the arm.
A mangonel is a third class lever. The fulcrum is at the end of the arm, where it connects to the axle. The effort is applied in the middle of the arm. The load is on the end of the arm.

The Physics of a Trebuchet
Trebuchet literally means ‘to fall over or rotate about the middle’. It is a type of catapult that is powered by a massive counterweight (CW) on one end of the arm with a sling holding a payload on the other end. The fulcrum is in the middle, and the arm rotates about the fulcrum. Historically, trebuchets were often used for defense and offense from within the walls of a city or castle.

Trebuchets have advantages over other types of catapults due to their **long range capability** and **high accuracy**. The long range throwing capability of a trebuchet results from that fact that the payload end of the beam reaches a much higher linear velocity than the counterweight end of the beam. This is the principle of **mechanical advantage**, and is what allows the payload to reach a high launch velocity. Basically, the energy created by
a heavy counterweight moving relatively slowly is traded for a light payload moving much faster. This transformation of energy is a result of the principle of **conservation of energy**.

**Conservation of energy**
The principle of conservation of energy states that the total energy of a system remains constant, and that energy can neither be created nor destroyed - it can, however, change form. In the case of a trebuchet, the energy in the system is converted from **potential energy** to **kinetic energy**. As the counterweight is raised, gravitational potential energy is being stored in the system. When the counter weight is released, gravity pulls it towards the ground, and since the arm is affixed to a fulcrum, this motion causes the arm to rotate. As the counterweight falls, its potential energy is transferred into rotational kinetic energy in the arm and the projectile. A heavier counterweight (or a counterweight raised to a higher resting height) will have more potential energy, and therefore it can deliver more kinetic energy to the projectile.

Compared to other types of catapult (e.g., ballista, mangonel, and onager), the trebuchet is the most accurate and most efficient in terms of transferring the stored energy to the projectile. Moreover, it allows a greater consistency of throws, due to the fact that if the same counterweight and height is used on each throw, it will always deliver almost the same amount of energy to the projectile.

The velocity of the projectile depends on several factors, but one major contributor is the **length of the arm**. For two arms that are rotating at the same angular velocity (completing a full circle in the same amount of time), the end of the longer arm will travel a greater distance than the end of the shorter arm in the same amount of time. Because the longer arm travels a greater distance in the same amount of time, its tip has a higher velocity, and therefore can potentially launch a projectile at a greater velocity. The optimal trebuchet design is one that launches the payload the farthest horizontal distance. This makes sense intuitively, since range is a key factor when staging an attack on an enemy. However, sometimes you just want a trebuchet that can throw in a short range and that depends on the purpose of the task.
In June 1210, Count Simon de Montfort besieged two hundred knights, priests, and citizens within the fortress of Minerve as part of his campaign throughout southwestern France to eradicate the Cathar heresy. Considered impregnable, Minerve stood atop a daunting limestone cliff 246 yards above the Cesse River in the region known as the Languedoc. De Montfort knew that with ample provisions and an internal water source, Minerve’s defenders could outlast any siege, and he had no patience.

Within days his engineers had built a towering siege engine: an oversized balance beam with a weighted bucket at one end called a trebuchet — a relatively new arrival on the European battlefield. The walls of Minerve were beyond the reach of this piece of medieval artillery, but that didn’t matter. Hurling stones weighing nearly a ton, the machine began a steady pounding of the cliff face, literally shaking the mountain beneath Minerve so vigorously that the well shaft within collapsed. In the sweltering days of summer, the defenders had no choice but surrender.

It is unclear who christened this particular war machine with the nickname Malvoisine (‘the bad neighbor’). Obviously, soldiers on both sides of Minerve’s walls gave the trebuchet ample respect. The word trebuchet comes from the Middle French verb *trebuch*, meaning ‘to tumble’ or ‘to fall over,’ which is exactly what the throwing
arm of a trebuchet does when it is released. The medieval etymology of the word (first appearing in English in the fourteenth century as ‘trepegete’) has led many historians to believe that this war engine was a medieval invention, but this ‘bad neighbor’ took up residence in the annals of military history long before that.

Stone-throwing artillery was hardly a new idea in the thirteenth century. In the ancient world, however, war engines were powered either by torsion (a wound rope, such as in the Roman onager) or tension (a drawn bow, such as in the Greek oxybeles). The trebuchet was the first war engine to employ the principles of gravity and leverage to hurl a projectile.

![Figure 2: Roman onager](image)

Renaissance and Enlightenment scholars considered this transition from the complex war machines of the ancient world to the comparatively simple design of the medieval trebuchet as proof of the superiority of classical knowledge. The trebuchet’s simplified design offers significant advantages over its more technically complex forebears.

Lacking any components capable of achieving high-energy states of elasticity, the trebuchet was not subject to the catastrophic failures that plagued earlier machines if they were not demandingly maintained. Whereas torsion and tension engines required numerous precision-made parts — such as metallic gears, locks and frames — a trebuchet could be constructed in the field almost entirely out of rough-cut lumber and using natural stones. Siege engineers, masters of adaptation, seem to have recognized a superior design when they saw it.

The earliest incarnation of this type of artillery was the traction trebuchet or perrier, a type of rotating-beam engine powered by the most readily available form of ballast imaginable: human beings. A team of haulers pulled down on a network of ropes attached
to the rear of the machine’s throwing arm to operate a traction trebuchet; an engineer stationed at the front of the throwing arm loaded ammunition into the firing cup or sling.

By the sixth century a.d., the armies of Byzantium and the Middle East were using these machines in their military campaigns. Archbishop John of Thessalonike described a battery of fifty traction trebuchets called *petrobolos* (‘city-takers’) in his eyewitness account of the siege of that Macedonian city in 597. He claimed these machines flung so many stones that ‘neither earth nor human constructions could bear the impacts.’

Yet the traction trebuchet was not without its shortcomings. As this experiment revealed, the logistics of coordinating a team of more than twelve pullers was very difficult, and the unavoidable mechanics limited the throwing arm to only a small fraction of its rotational potential.

Perhaps these limitations inspired engineers of the Near East and Mediterranean to upgrade the traction trebuchet design. They attached a weight to the short end of the throwing arm, resulting in an engine known as the hybrid trebuchet. The counterweight, possibly an iron plate forged directly to the short end of the pivoted beam, extended the range of the machines. Attaching a sling to the longer end of the beam and adding wheels that allowed the trebuchet to gain the full advantage of motion made it possible for war engines to sling a rock against a castle wall with accuracy.
Although hybrid trebuchets may have been known as early as the eighth century, documented evidence indicates this design was gaining widespread acceptance among Arab and Byzantine armies during the eleventh and twelfth centuries. In the military vernacular of the eleventh-century Islamic world, the hybrid trebuchet was called al-Ghadban, or ‘the furious one.’

In a military manual written for Saladin in 1187, Arabic engineer Murdi ibn Ali ibn Murdi al-Tarsusi depicted a hybrid trebuchet that he said had the same hurling power as a traction machine pulled by fifty men due to ‘the constant force (of gravity), whereas men differ in their pulling force.

Improved firing power was certainly the primary advantage of the hybrid trebuchet. Nevertheless, if a trebuchet powered by a small counterweight was good, then one with a large counterweight would be even better. As European engineers adopted the trebuchet and improved it in the eleventh, twelfth, and thirteenth centuries (after encountering these machines during the Crusades), this premise was taken to its logical conclusion by developing the counterpoise trebuchet.

Unlike traction and hybrid trebuchets, there was no need for human intervention in operating of the counterpoise trebuchet. These machines, powered by either stationary weights, or by hanging buckets filled with sand, rocks, or rubble from the short end of the beam, used gravity to far surpass the capacity of any crew of pullers. With no pulling team beneath the trestle, the sling could be laid in a launching trough directly under the pivot, creating a greater throwing arc. The centripetal acceleration and power of the counterpoise trebuchet could be enhanced by mounting the machine on wheels so it could move during the throw. Larger engines could sling rocks weighing a ton or more three hundred yards, hitting a castle wall with devastating force.
The counterpoise design elevated the trebuchet’s destructive power. The trebuchets could fire stones weighing between nineteen hundred and twenty-five hundred pounds. However, the improved firing capability of the counterpoise trebuchet came at a price. Such machines needed elaborate block and tackle systems to raise the heavy ballast box; they could only be fired three or four times per day, according to contemporary accounts. Nonetheless, the power of the counterpoise design gave these war machines a new role in battle. Smaller trebuchets had been relegated to the tasks of supporting troops scaling castle walls or targeting structures within a walled city; counterpoise trebuchets could actually be used against the walls themselves, thus sparking an architectural arms race that would continue well into the gunpowder age.

Not until modern times did the cannon eclipse the trebuchet. The strategist Christine de Pizan, in her book Fais d’armes et de chevalerie written for the Duke of Burgundy in 1410, explained that even an army equipped with sizable ‘gonnes – medieval hand cannon’ should still have ‘four entirely new trebuchets, completely equipped, each one with two cables and four slings to change when needed.’

Moreover, trebuchets were not limited exclusively to use outside castle walls. In 1218, while preparing for an assault on the city of Toulouse, France, Simon de Montfort, the victor at Minerve, was struck down by a rock falling from the sky — a stone fired from a trebuchet inside the city. Even the most skilled general was not immune to the wrath of a bad neighbor.
Appendix D

Assessment #1

What is your ID? __________________

Q1 What component makes up the majority of a trebuchet?
☐ Frame
☐ Arm
☐ Sling
☐ Counter weight

Q2 Why were trebuchets used?
☐ To smash masonry walls.
☐ To throw projectiles over walls.
☐ To fight with during wars.
☐ All of the above.

Q3 The law of conservation of energy is a statement that
☐ Energy must be conserved and you are breaking a law if you waste energy.
☐ The supply of energy is limited so we must conserve.
☐ The total amount of energy is constant.
☐ Energy cannot be used faster than it is created.

Q4 In a trebuchet, what creates the force used to throw the payload?
☐ A long arm and counterweight
☐ Counter weight and gravity
☐ A long arm and gravity
☐ Counter weight and a payload

Q5 What happens if the counterweight is the same weight as the payload?
☐ The payload will travel a longer distance.
☐ The payload will travel a shorter distance.
☐ The payload will travel the same distance.
☐ The trebuchet will fail to launch the payload.

Q6 If an object is moving, you know it has –
Q7 An object that has energy stored in it has ______ due to its position in a gravitational field.

- Potential energy
- Kinetic energy
- Chemical energy
- Mechanical energy

Q8 What determines the class of a lever?

- Where the load and effort are with respect to the fulcrum.
- How much effort is required to lift the load.
- Whether the arms are long, medium, or short in length.
- Where the effort is doubled the weight of the load.

Q9 A lever can be used to multiply__________ or change__________.

- direction, force
- power, direction
- length, force
- force, direction

Q10 There are three classes of levers, first class (1), second class (2), and third class (3). They differ in the position of the Fulcrum (pivot point), Load, and Effort. In the Figure shown below, which one of these is the first class lever?
Q1 As a load is moved closer to the fulcrum, the effort needed to lift the load_____________.
- Increases
- Decreases
- Stays the same
- Is the opposite

Q1 Two children want to balance each other on a teeter totter with the fulcrum in the middle. One weighs 20 kg and sits at one end of a teeter totter, 8 meters from the fulcrum. Where should the other child be seated if the second child weighs 40 kg?
- 1 meter away from the fulcrum
- 2 meters away from the fulcrum
- 3 meters away from the fulcrum
- 4 meters away from the fulcrum
Q13 This broom is a third class lever. Which one of these items is also a third class lever?

- Tweezers
- Wheelbarrow
- Nut cracker
- All of the above

Q14 This bottle opener is a second class lever. Please identify where the fulcrum and the load are respectively.

- 3, 2
- 2, 3
- 3, 1
- 2, 1

Q15 This trebuchet is a first class lever. Which one of these items is also a first class lever?

- Pliers
- Teeter totter
- Scissors
- All of the above
The trebuchet in the picture below is 10 meters in height and the counterweight is 15 kg. The counterweight is attached to the arm 3 meters from the fulcrum and the payload is attached to the arm 9 meters from the fulcrum. However, the throwing range of this trebuchet is too short and the rock cannot hit the target (the house). Which modifications to the trebuchet will increase its range?

- Decrease the weight of the counterweight.
- Decrease the length of the payload arm.
- Increase the length of the counterweight arm.
- Increase the weight of the payload.

Q17 If the weight of the counterweight is tripled but everything else stays the same, what would happen to the projectile?

- The payload will travel a longer distance.
- The payload will travel a shorter distance.
- The payload will travel the same distance.
- The trebuchet will fail to launch the payload.

Q18 Given that you can neither increase the total arm length nor change the location of the fulcrum, how would you modify this trebuchet to increase the projectile's range most effectively?

- Increase the weight of the counterweight.
- Reduce the weight of the payload.
- Increase the weight of the counterweight and reduce the weight of the payload.
- None of the above.
Q19 Assume that you cannot increase the arm length or change the counterweight or payload to make the trebuchet throw farther. All you can do is to change where to place the fulcrum. Therefore, where should the new fulcrum be?

- The new fulcrum should be at number 1 to increase the length of payload arm.
- The new fulcrum should be at number 2 to increase the length of counterweight arm.
- The new fulcrum should be at number 3 to be as close to the payload as possible.
- None of the above answers is correct.

Q20 Which of these best explains conservation of energy in a context of a trebuchet?

- The total energy in the system increases as the counterweight is being lifted to the highest point upon releasing.
- The total energy in the system decreases as the counterweight is pulled down by the gravity.
- The total energy in the system decreased as the payload is launched because potential energy is converted to kinetic energy.
- The total energy in the system stays the same.
Appendix E

Assessment #2

What is your ID? ________________

Q1 A lever can be used to multiply _______ or change _________.
   ◯ direction, force
   ◯ power, direction
   ◯ length, force
   ◯ force, direction

Q2 What determines the class of a lever?
   ◯ Where the load and effort are with respect to the fulcrum.
   ◯ How much effort is required to lift the load.
   ◯ Whether the arms are long, medium, or short in length.
   ◯ Where the effort is doubled the weight of the load.

Q3 Two children want to balance each other on a teeter totter with the fulcrum in the middle. One weighs 20 kg and sits at one end of a teeter totter, 6 meters from the fulcrum. Where should the other child be seated if the second child weighs 40 kg?
   ◯ 1 meter away from the fulcrum
   ◯ 2 meters away from the fulcrum
   ◯ 3 meters away from the fulcrum
   ◯ 4 meters away from the fulcrum

Q4 As a load is moved farther from the fulcrum, the effort needed to lift the load ____________.
   ◯ Increases
   ◯ Decreases
   ◯ Stays the same
   ◯ Is the opposite
Q5 There are three classes of levers, first class (1), second class (2), and third class (3). They differ in the position of the Fulcrum (pivot point), Load, and Effort. In the Figure shown below, which one of these is the **first** class lever?

Q6 This trebuchet is a first class lever. Which one of these items is **NOT** a first class lever?
Q7 This wheelbarrow is a second class lever. Which one of these items is also a second class lever?

- Pliers
- Tweezers
- Scissors
- None of the above

Q8 This pair of tongs is a third class lever. Which one of these items is NOT a third class lever?

- Teeter totter
- Nut cracker
- All of the above
- None of the above

Q9 The law of conservation of energy is a statement that
- Energy must be conserved and you are breaking a law if you waste energy.
- The supply of energy is limited so we must conserve.
- The total amount of energy is constant.
- Energy cannot be used faster than it is created.
Q10 Why were trebuchets used?
- To smash masonry walls.
- To throw projectiles over walls.
- To fight with during wars.
- All of the above.

Q11 In a trebuchet, what creates the force used to throw the payload?
- A long arm and counterweight
- Counterweight and gravity
- Counterweight and a payload
- A long arm and gravity

Q12 What happens if the counterweight is the same weight as the payload?
- The payload will travel a longer distance.
- The payload will travel a shorter distance.
- The payload will travel the same distance.
- The trebuchet will fail to launch the payload.

Q13 An object that has energy stored in it has ______ due to its position in a gravitational field.
- Potential energy
- Kinetic energy
- Chemical energy
- Mechanical energy

Q14 If an object is moving, you know it has –
- Potential energy
- Kinetic energy
- Chemical energy
- Light energy

Q15 What component makes up the majority of a trebuchet?
- Arm
- Sling
- Counterweight
- Frame

Q16 Which of these best explains conservation of energy in a context of a trebuchet?
The total energy in the system increases as the counterweight is being lifted to the highest point upon releasing.
The total energy in the system decreases as the counterweight is pulled down by the gravity.
The total energy in the system decreased as the payload is launched because potential energy is converted to kinetic energy.
The total energy in the system stays the same.

Q17 Use this Figure for question 17 – 20

The trebuchet in the picture below is 10 meters in height and the counterweight is 15 kg. The counterweight is attached to the arm 3 meters from the fulcrum and the payload is attached to the arm 9 meters from the fulcrum. However, the throwing range of this trebuchet is too short and the rock cannot hit the target (the house). Which modifications to the trebuchet will increase its range?
Increase the length of the counterweight arm.
Decrease the weight of the counterweight.
Increase the weight of the payload.
Decrease the length of the payload arm.
Q18 Assuming that now you cannot increase the arm length, but all you can do is to change where to place the fulcrum. Therefore, where the new fulcrum should be?

- The new fulcrum should be at number 1 to increase the length of payload arm.
- The new fulcrum should be at number 2 to increase the length of counterweight arm.
- The new fulcrum should be at number 3 to be as close to the payload as possible.
- None of the above answers is correct.

Q19 Given that you can neither increase the total arm length nor change the location of the fulcrum, how would you modify this trebuchet to increase the projectile's range most effectively?

- Increase the weight of the counterweight.
- Reduce the weight of the payload.
- Increase the weight of the counterweight and reduce the weight of the payload.
- None of the above.

Q20 If the weight of the counterweight is doubled but everything else stays the same, what would happen to the projectile?

- The payload will travel a longer distance.
- The payload will travel a shorter distance.
- The payload will travel the same distance.
- The trebuchet will fail to launch the payload.
Appendix F

Blocks List and a Controls List
Appendix G

Playbook Exercises for Building Group

Date:_______________
ID:_________________

Playbook

Besiege: A physics-based construction game about medieval engineering

In this playbook, you will find 3 exercises:
Exercise 1: Counterweight and payload arm length.
Exercise 2: Fulcrum position.
Exercise 3: Counterweight.

You will also find a reflection sheet in each exercise. The reflection sheet will help you reflect on what you observed. It is not graded.
Exercise 1: Counterweight and payload arm length

STEP 1: Start a tutorial video
- In this tutorial, I will introduce you to the game interface as well as teach you how to navigate through the game.
- You will be building your first trebuchet by following the tutorial.
- Let’s try building your first trebuchet from example 1.
- The trebuchet in example 1 has a counterweight arm length of 3 blocks and a payload arm length of 8 blocks.
- When you’re ready, click PLAY the tutorial video.

In this first exercise, you are going to build 4 trebuchets with different building specifications of arm length to examine their projectile’s range as well as to answer the question at the end.

Example: How to use a reflection sheet.

Reflection sheet

<table>
<thead>
<tr>
<th>Trebuchet</th>
<th>Where did the payload hit?</th>
<th>What modifications do you want to make?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Example 1</td>
<td>1) Mark where the payload hit.</td>
<td>1) I might need to ...</td>
</tr>
<tr>
<td><em>(3+6, cw15)</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total arm length = 11 blocks</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2) Write your thoughts about modifying the trebuchet.
STEP 2: Build trebuchet Ex1_A1
- Your trebuchet will have a counterweight arm length of 2 blocks and a payload arm length of 8 blocks.
- Start building by selecting a frame. Click on the LOAD MACHINE icon and select Frame.2+8
- When you finish building, save your machine (save as: 2+8 cw15), test it and observe what happens.

STEP 3: Fill out your reflection sheet

<table>
<thead>
<tr>
<th>Trebuchet</th>
<th>Where did the payload hit?</th>
<th>What modifications do you want to make?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ex1_A1 (2+8 cw15)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total arm length = 10 blocks</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

STEP 4: Build trebuchet Ex1_A2
- Your trebuchet will have a counterweight arm length of 5 blocks and a payload arm length of 8 blocks.
- Start building by selecting a frame. Click on the LOAD MACHINE icon and select Frame.5+8
- When you finish building, save your machine (save as: 5+8 cw15), test it and observe what happens.

STEP 5: Filling out your reflection sheet

<table>
<thead>
<tr>
<th>Trebuchet</th>
<th>Where did the payload hit?</th>
<th>What modifications do you want to make?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ex1_A2 (5+8 cw15)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total arm length = 13 blocks</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Midpoint reflection: In the 2 trebuchets you just tested, the length of payload arm is constant (8 blocks) and the counterweight is constant (15 unit in mass). The only difference is the length of the counterweight arm. What generalization can you draw from what you observed?

Answer:
STEP 6: Build trebuchet Ex1_B1
- Your trebuchet will have a counterweight arm length of 4 blocks and a payload arm length of 7 blocks.
- Start building by selecting a frame. Click on the LOAD MACHINE icon and select Frame_4+7
- When you finish building, save your machine (save as: 4+7_cw15), test it and observe what happens.

STEP 7: Filling out your reflection sheet
<table>
<thead>
<tr>
<th>Trebuchet</th>
<th>Where did the payload hit?</th>
<th>What modifications do you want to make?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ex1_B1 (4+7_cw15)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total arm length = 11 blocks</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

STEP 8: Build trebuchet Ex1_B2
- Your first trebuchet will have length of counterweight arm of 4 blocks, length of payload arm of 10 blocks.
- Start building by selecting a frame to start with. Click on LOAD MACHINE icon and select Frame_4+10
- When you finish building and already save your machine (save as: 4+10_cw15), test it and observed what happens.

STEP 9: Filling out your reflection sheet
<table>
<thead>
<tr>
<th>Trebuchet</th>
<th>Where did the payload hit?</th>
<th>What modifications do you want to make?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ex1_B2 (4+10_cw15)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total arm length = 14 blocks</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Mid-point reflection: In the 2 trebuchets you just tested, the length of counterweight arm is constant (4 blocks) and the counterweight is constant (15 unit in mass). The only difference is the length of payload arm (7 blocks and 10 blocks), What generalization can you draw from what you observed?
Answer:
Final reflection: So, does different counterweight and payload length of the arm affect the projectile's range? How so?
Answer:
Exercise 2: Fulcrum position

In this exercise, you are going to build 3 trebuchets with different points of fulcrum to examine their projectile’s range as well as to answer the question at the end.

**STEP 1: Build trebuchet Ex2_A1**
- Your trebuchet will have a counterweight arm length of 3 blocks and a payload arm length of 10 blocks.
- Start building by selecting a frame. Click on the LOAD MACHINE icon and select Frame_3+10
- When you finish building, save your machine (save as: 3+10_cw15), test it and observe what happens.

**STEP 2: Fill out your reflection sheet**

<table>
<thead>
<tr>
<th>Trebuchet</th>
<th>Where did the payload hit?</th>
<th>What modifications do you want to make?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ex2_A1 (3+10_cw15)</td>
<td>![Image of Ex2_A1]</td>
<td>![Image of Ex2_A1]</td>
</tr>
<tr>
<td>Total arm length = 13 blocks</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**STEP 3: Build trebuchet Ex2_A2**
- Your trebuchet will have a counterweight arm length of 4 blocks and a payload arm length of 9 blocks.
- Start building by selecting a frame. Click on the LOAD MACHINE icon and select Frame_4+9
- When you finish building, save your machine (save as: 4+9_cw15), test it and observe what happens.

**STEP 4: Fill out your reflection sheet**

<table>
<thead>
<tr>
<th>Trebuchet</th>
<th>Where did the payload hit?</th>
<th>What modifications do you want to make?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ex2_A2 (4+9_cw15)</td>
<td>![Image of Ex2_A2]</td>
<td>![Image of Ex2_A2]</td>
</tr>
<tr>
<td>Total arm length = 13 blocks</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
STEP 5: Build trebuchet Ex2_A3
- Your trebuchet will have a counterweight arm length of 5 blocks and a payload arm length of 8 blocks.
- Start building by selecting a frame. Click on the LOAD MACHINE icon and select Frame_5+8
- When you finish building, save your machine (save as: 5+8_cw15), test it and observe what happens.

STEP 6: Fill out your reflection sheet

<table>
<thead>
<tr>
<th>Trebuchet</th>
<th>Where did the payload hit?</th>
<th>What modifications do you want to make?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ex2_A3 (5+8_cw15)</td>
<td>![Image of payload hit]</td>
<td></td>
</tr>
<tr>
<td>Total arm length</td>
<td>13 blocks</td>
<td></td>
</tr>
</tbody>
</table>

Final reflection: Given the overall arm length constant, does changing the fulcrum position effect the projectile’s range?
How so?
Answer:
Exercise 3: Counterweight

In this last exercise, you are going to build 4 trebuchets to examine their projectile's range as well as to answer the question at the end. For this exercise, you are going to test 2 different weights: 15 unit and 20 unit.

Counterweight = 15 unit

Each ballast’s weight = 1.5 unit
There are 10 ballasts.

Total counterweight = 1.5 x 10
= 15 unit in mass

Counterweight = 20 unit

Each ballast’s weight = 2.0 unit
There are 10 ballasts.

Total counterweight = 2.0 x 10
= 20 unit in mass

To adjust the weight,

Click on each ballast to change its mass from x1.5 to x2

SHORTCUT: Once you successfully change the first ballast, click on the copy button. When you click on the second ballast, click on the paste button. Continue with the rest.
**STEP 1: Test trebuchet Ex3_A1**
- Your trebuchet will have a counterweight arm length of 3 blocks and a payload arm length of 10 blocks.
- You already built this machine from Exercise 2. Therefore, select trebuchet 3+10_cw15 from LOAD MACHINE.
- Launch it and observe what happened.

**STEP 2: Fill out your reflection sheet**

<table>
<thead>
<tr>
<th>Trebuchet</th>
<th>Where did the payload hit?</th>
<th>What modifications do you want to make?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ex3_A1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(3+10_cw15)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total arm length</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13 blocks</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**STEP 3: Adjust the weight from trebuchet Ex3_A1**
- Modify the counterweight from 15 unit to 20 unit from the trebuchet Ex3_A1 (3+10_cw15) from STEP 1.
- When you finish adjusting, save your machine (save as: 3+10_cw20), test it and observe what happens.

**STEP 4: Fill out your reflection sheet**

<table>
<thead>
<tr>
<th>Trebuchet</th>
<th>Where did the payload hit?</th>
<th>What modifications do you want to make?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ex3_A2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(3+10_cw20)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total arm length</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13 blocks</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Mid-point reflection:** In the 2 trebuchets you just tested, the length of counterweight arm and payload arm are constant (13 blocks). The only difference is the counterweight (15 unit and 20 unit).
What generalization can you draw from what you observed?

**Answer:**
**STEP 5: Test trebuchet Ex3_B1**
- Your trebuchet will have a counterweight arm length of 4 blocks and a payload arm length of 9 blocks.
- You already built this machine from Exercise 2. Therefore, select trebuchet 4+9_cw15 from LOAD MACHINE.
- Launch it and observe what happened.

**STEP 6: Fill out your reflection sheet**

<table>
<thead>
<tr>
<th>Trebuchet</th>
<th>Where did the payload hit?</th>
<th>What modifications do you want to make?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ex3_B1 (4+9_cw15)</td>
<td>![Image of trebuchet Ex3_B1]</td>
<td>![Image of payload hit]</td>
</tr>
<tr>
<td>Total arm length = 13 blocks</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**STEP 7: Adjust the weight from trebuchet Ex3_B1**
- Modify the counterweight from 15 unit to 20 unit from the trebuchet Ex3_B1 (4+9_cw15) from STEP 1.
- When you finish adjusting save your machine (save as: 4+9_cw20), test it and observe what happens.

**STEP 8: Fill out your reflection sheet**

<table>
<thead>
<tr>
<th>Trebuchet</th>
<th>Where did the payload hit?</th>
<th>What modifications do you want to make?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ex3_B2 (4+9_cw20)</td>
<td>![Image of trebuchet Ex3_B2]</td>
<td>![Image of payload hit]</td>
</tr>
<tr>
<td>Total arm length = 13 blocks</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Mid-point reflection:** In the 2 trebuchets you just tested, the length of counterweight arm and payload arm are constant. The only difference is the counterweight (15 unit and 20 unit), What generalization can you draw from what you observed?

**Answer:**
Final reflection: So, does different weight of the counterweight effect the projectile’s range? How so?
Answer:
Appendix H

Playbook Exercises for Selecting Group

Date:__________________
ID:__________________

Playbook

Besiege: A physics-based construction game about medieval engineering

In this playbook, you will find 3 exercises:
Exercise 1: Counterweight and payload arm length.
Exercise 2: Fulcrum position.
Exercise 3: Counterweight.

You will also find a reflection sheet in each exercise. The reflection sheet will help you reflect on what you observed. It is not graded.
Exercise 1: Counterweight and payload arm length

**STEP 1: Start a tutorial video**
- In this tutorial, I will introduce you to the game interface and teach you how to navigate through the game.
- You will be testing your first trebuchet by following the tutorial.
- Let’s try testing your first trebuchet from example 1.
- When you’re ready, click PLAY the tutorial video.

In this first exercise, you are going to test 4 trebuchets with different specifications of arm length to examine their projectile’s range as well as to answer the question at the end.

**Example: How to use a reflection sheet.**

![Reflection sheet image]

<table>
<thead>
<tr>
<th>Trebuchet</th>
<th>Length of counterweight arm (blocks)</th>
<th>Length of payload arm (blocks)</th>
<th>Where did the payload hit?</th>
<th>What modifications do you want to make?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Example Ex1_AB</td>
<td>3</td>
<td>8</td>
<td></td>
<td>I might need to...</td>
</tr>
<tr>
<td>Total arm length = 11 blocks</td>
<td>1) Count number of blocks and write down.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2) Write down number of total arm length (blocks).</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3) Mark where the payload hit.
4) Write your thoughts about modifying the trebuchet.
**STEP 2: Test trebuchet Ex1_A1**
- Select Ex1_A1 from LOAD MACHINE.
- Count the number of blocks of 1) counterweight arm, and 2) payload arm, and write the numbers on the reflection sheet.
- Write down the total arm length
- Launch trebuchet Ex1_A1 and observe what happened.

**STEP 3: Fill out the reflection sheet**

<table>
<thead>
<tr>
<th>Trebuchet</th>
<th>Length of counterweight arm (blocks)</th>
<th>Length of payload arm (blocks)</th>
<th>Where did the payload hit?</th>
<th>What modifications do you want to make?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ex1_A1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total arm length = ___ blocks</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**STEP 4: Test trebuchet Ex1_A2**
- Select Ex1_A2 from LOAD MACHINE.
- Count the number of blocks of 1) counterweight arm, and 2) payload arm, and write the numbers on the reflection sheet.
- Write down the total arm length
- Launch trebuchet Ex1_A2 and observe what happened.

**STEP 5: Fill out the reflection sheet**

<table>
<thead>
<tr>
<th>Trebuchet</th>
<th>Length of counterweight arm (blocks)</th>
<th>Length of payload arm (blocks)</th>
<th>Where did the payload hit?</th>
<th>What modifications do you want to make?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ex1_A2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total arm length = ___ blocks</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Mid-point reflection:** In the 2 trebuchets you just tested, the length of payload arm is constant and the counterweight is constant (15 unit in mass). The only difference is the length of the counterweight arm.

What generalization can you draw from what you observed?  
**Answer:**
**STEP 6: Test trebuchet Ex1_B1**
- Select Ex1_B1 from LOAD MACHINE.
- Count the number of blocks of 1) counterweight arm, and 2) payload arm, and write the numbers on the reflection sheet.
- Write down the total arm length.
- Launch trebuchet Ex1_B1 and observe what happened.

**STEP 7: Fill out the reflection sheet**

<table>
<thead>
<tr>
<th>Trebuchet</th>
<th>Length of counterweight arm (blocks)</th>
<th>Length of payload arm (blocks)</th>
<th>Where did the payload hit?</th>
<th>What modifications do you want to make?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ex1_B1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total arm length = ____ blocks</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**STEP 8: Test trebuchet Ex1_B2**
- Select Ex1_B2 from LOAD MACHINE.
- Count the number of blocks of 1) counterweight arm, and 2) payload arm, and write the numbers on the reflection sheet.
- Write down the total arm length.
- Launch trebuchet Ex1_B2 and observe what happened.

**STEP 9: Fill out the reflection sheet**

<table>
<thead>
<tr>
<th>Trebuchet</th>
<th>Length of counterweight arm (blocks)</th>
<th>Length of payload arm (blocks)</th>
<th>Where did the payload hit?</th>
<th>What modifications do you want to make?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ex1_B2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total arm length = ____ blocks</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Mid-point reflection:** In the 2 trebuchets you just tested, the length of counterweight arm is constant and the counterweight is constant (15 unit in mass). The only difference is the length of payload arm.

What generalization can you draw from what you observed?

**Answer:**
Final reflection: So, does different counterweight and payload length of the arm affect the projectile’s range? How so?

Answer:
Exercise 2: Fulcrum position

In this exercise, you are going to test 3 trebuchets with different points of fulcrum to examine their projectile's range.

**STEP 1: Test trebuchet Ex2_A1**
- Select Ex2_A1 from LOAD MACHINE.
- Count the number of blocks of 1) counterweight arm, and 2) payload arm, and write the numbers on the reflection sheet.
- Write down the total arm length
- Launch trebuchet Ex2_A1 and observe what happened.

**STEP 2: Fill out the reflection sheet**

<table>
<thead>
<tr>
<th>Trebuchet</th>
<th>Length of counterweight arm (blocks)</th>
<th>Length of payload arm (blocks)</th>
<th>Where did the payload hit?</th>
<th>What modifications do you want to make?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ex2_A1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total arm length = ___ blocks</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**STEP 3: Test trebuchet Ex2_A2**
- Select Ex2_A2 from LOAD MACHINE.
- Count the number of blocks of 1) counterweight arm, and 2) payload arm, and write the numbers on the reflection sheet.
- Write down the total arm length
- Launch trebuchet Ex2_A2 and observe what happened.

**STEP 4: Fill out the reflection sheet**

<table>
<thead>
<tr>
<th>Trebuchet</th>
<th>Length of counterweight arm (blocks)</th>
<th>Length of payload arm (blocks)</th>
<th>Where did the payload hit?</th>
<th>What modifications do you want to make?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ex2_A2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total arm length = ___ blocks</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
STEP 5: Test trebuchet Ex2_A3
- Select Ex2_A3 from LOAD MACHINE.
- Count the number of blocks of 1) counterweight arm, and 2) payload arm, and write the numbers on the reflection sheet.
- Write down the total arm length.
- Launch trebuchet Ex2_A3 and observe what happened.

STEP 6: Fill out the reflection sheet

<table>
<thead>
<tr>
<th>Trebuchet</th>
<th>Length of counterweight arm (blocks)</th>
<th>Length of payload arm (blocks)</th>
<th>Where did the payload hit?</th>
<th>What modifications do you want to make?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ex2_A3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total arm length = ___ blocks</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Final reflection: Given the overall arm length constant, does changing the fulcrum position effect the projectile’s range? How so?
Answer:
Exercise 3: Counterweight

In this last exercise, you are going to test 4 trebuchets to examine their projectile’s range as well as to answer the question at the end. For this exercise, you are going to test 2 different weights: 15 unit and 20 unit.

**Counterweight = 15 unit**

Each ballast’s weight = 1.5 unit
There are 10 ballasts.

Total counterweight = \(1.5 \times 10\)
= 15 unit in mass

**Counterweight = 20 unit**

Each ballast’s weight = 2.0 unit
There are 10 ballasts.

Total counterweight = \(2.0 \times 10\)
= 20 unit in mass
STEP 1: Test trebuchet Ex3_A1
- Select Ex3_A1 from LOAD MACHINE.
- Count the number of blocks of 1) counterweight arm, and 2) payload arm, and write the numbers on the reflection sheet.
- Write down the total arm length
- Launch trebuchet Ex3_A1 and observe what happened.

STEP 2: Fill out the reflection sheet

<table>
<thead>
<tr>
<th>Trebuchet</th>
<th>Length of counterweight arm (blocks)</th>
<th>Length of payload arm (blocks)</th>
<th>Where did the payload hit?</th>
<th>What modifications do you want to make?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ex3_A1</td>
<td>Counterweight = 15 unit</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total arm length = ___ blocks</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

STEP 3: Test trebuchet Ex3_A2
- Select Ex3_A2 from LOAD MACHINE.
- Count the number of blocks of 1) counterweight arm, and 2) payload arm, and write the numbers on the reflection sheet.
- Write down the total arm length
- Launch trebuchet Ex3_A2 and observe what happened.

STEP 4: Fill out the reflection sheet

<table>
<thead>
<tr>
<th>Trebuchet</th>
<th>Length of counterweight arm (blocks)</th>
<th>Length of payload arm (blocks)</th>
<th>Where did the payload hit?</th>
<th>What modifications do you want to make?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ex3_A2</td>
<td>Counterweight = 20 unit</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total arm length = ___ blocks</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Mid-point reflection: In the 2 trebuchets you just tested, the length of counterweight arm and payload arm are constant. The only difference is the counterweight (15 unit and 20 unit). What generalization can you draw from what you observed?

Answers
STEP 5: Test trebuchet Ex3_B1
- Select Ex3_B1 from LOAD MACHINE.
- Count the number of blocks of 1) counterweight arm, and 2) payload arm, and write the numbers on the reflection sheet.
- Write down the total arm length
- Launch trebuchet Ex3_B1 and observe what happened.

STEP 6: Fill out the reflection sheet

<table>
<thead>
<tr>
<th>Trebuchet</th>
<th>Length of counterweight arm (blocks)</th>
<th>Length of payload arm (blocks)</th>
<th>Where did the payload hit?</th>
<th>What modifications do you want to make?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ex3_B1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Counterweight = 15 unit Total arm length = ___ blocks</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

STEP 7: Test trebuchet Ex3_B2
- Select Ex3_B2 from LOAD MACHINE.
- Count the number of blocks of 1) counterweight arm, and 2) payload arm, and write the numbers on the reflection sheet.
- Write down the total arm length
- Launch trebuchet Ex3_B2 and observe what happened.

STEP 8: Fill out the reflection sheet

<table>
<thead>
<tr>
<th>Trebuchet</th>
<th>Length of counterweight arm (blocks)</th>
<th>Length of payload arm (blocks)</th>
<th>Where did the payload hit?</th>
<th>What modifications do you want to make?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ex3_B2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Counterweight = 20 unit Total arm length = ___ blocks</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Mid-point reflection: In the 2 trebuchets you just tested, the length of counterweight arm and payload arm are constant. The only difference is the counterweight (15 unit and 20 unit), What generalization can you draw from what you observed?

Answer: 
Final reflection: So, does different weight of the counterweight effect the projectile’s range? How so?

Answer:
Appendix I

Study Flyer

Like computer games?
See if you qualify to help in research
on learning in a game-like environment

$15
(once you qualify and complete the study)

Details
- You must be an adult between 18-60 years old (participation is voluntary.)
- See if you qualify: Take a 10-15 minute online questionnaire (do it anywhere, anytime, on your home or mobile device).
- You’ll know if you qualify right after you finish the questionnaire.
- If you qualify: Get $15 for completing the study (about 90 minutes) at Columbia University.
  You can schedule an appointment at your convenience. We work around your schedule!
- A link and a QR code to reach the online questionnaire is shown below.

TEACHERS COLLEGE, COLUMBIA UNIVERSITY
INSTITUTIONAL REVIEW BOARD
Protocol # 55-301

http://bit.ly/1SMDhSl

For more information, email: pdc2114@columbia.edu
Appendix J

Consent Forms
Informed Consent For Online Pre-Intervention Survey

**Study title:** The effects of manipulation of virtual objects in a game-like environment after being provided with a lesson on learning physics concepts.

**Principal Investigator:** Pantiphar Chantes, Teachers College, Columbia University, pdc2114@columbia.edu

This survey is part of a study designed to examine the effects of different types of manipulation in a game-like environment on learning outcomes after reading a lesson about physics concepts. Completing the survey is voluntary, and you can stop at any time by simply closing your browser. After you complete the survey, results will be combined across participants to examine average responses to the questions. No individual data will be reported and all responses are private.

This research has been approved by the Teachers College, Columbia University Institutional Review Board (IRB) under protocol number 3901. If you have any comments or concerns regarding the conduct of this research, or questions about your rights as survey participant, please contact the IRB at (212) 678-4105 or sponsoredprograms@tc.edu.

**Description of research:** If you decide to participate, you will be asked to complete a survey, which is used to determine whether you will be asked to continue onto an on-site experimental session. The pre-intervention survey will take about 10-15 minutes to complete.

If you are asked to continue in an on-site experimental session, you will be asked to sign up on Eventbrite and schedule at your earliest convenient date and time to come in for an approximately 90 minutes on-site experiment.

**Risks and Benefits:** The risks associated with the study are the normal risks associated with learning physics concepts and playing any computer game using a desktop computer. The game is non-violent and involves learning about Physics. Frustration may result during the learning task. While playing the game there is the risk that you may experience feelings of boredom, frustration, and/or fatigue. You may stop your participation at any time with no adverse effects or consequences to you, even after you begin the study.

**Payments:** You will be paid $15 upon completing the study (which includes completing a survey and participating in an on-site experimental session).

**Data Storage to Protect Confidentiality:** All of the information obtained in connection
with this study will be kept strictly confidential. The data obtained will be categorized by
an ID number. The researcher will provide you with this number at the beginning of the
study when you pass the prescreening questionnaire to participate in an on-site
experimental session. The researchers will be the only ones who can match ID numbers
with their participants, using a master list that will be kept in a secure location separate
from the data.

**How will results be used:** The results of the study will be used for educational purposes,
both in academic writing and at professional meetings. All individual data will be kept
confidential throughout.

**Participant's Right**

- I have read the informed consent. I have had ample opportunity to read about the
  purposes, procedures, risks, and benefits regarding this research study.

- My participation in this research is completely voluntary. I may refuse to
  participate or withdraw from participation at any time without jeopardy to future medical
care, employment, student status or other entitlements.

- The researcher may withdraw me from the research at his or her professional
discretion. If I do not pass the prescreening questionnaire, I will not be paid or included
  for data analysis.

- If, during the course of the study, significant new information that has been
developed becomes available which may relate to my willingness to continue my
  participation, the investigator will provide this information to me.

- If at any time I have any questions regarding the research or my participation, I
  can contact the investigator, who will answer my questions. The investigators’ email
  address is pdc2114@columbia.edu

- Any information derived from the research study that personally identifies me
  will not be voluntarily released or disclosed without my separate consent, except as
  specifically required by law.

- If at any time I have comments, or concerns regarding the conduct of the research
  or questions about my rights as a research subject, I should contact the Teachers College,
  Columbia University Institutional Review Board (IRB). The phone number for the IRB is
  (212) 678-4105. Or, I can write to the IRB at Teachers College, Columbia University,
  525 W. 120th Street, New York, NY, 10027, Box
  151.

  By signing your name and clicking the "next" button below, you hereby consent to
  participate in the study and that you are 18 years or older.
Appendix K

Consent Forms

Informed Consent For an On-Site Experimental Session (New York City Location)

Date: ___________ Time: _______________ Group: _____________ Subject ID: _____________

INFORMED CONSENT

DESCRIPTION OF THE RESEARCH: You are invited to participate in a research study on examining the effects of different types of manipulation in a game-like environment on learning outcomes after reading a lesson about physics concepts.

Upon arrival at Teachers College’s game lab you, as a participant, will be randomly placed into one of the four groups: DB, NB, DS, and NS. The details in each group are the following.

Descriptive Lesson with Building condition (DB). Participants in this group will receive a lesson regarding physics concepts. Then, participants will complete three exercises that require them to build and assemble various variations of virtual objects in a game-like environment. The exercises pertain to the physics concepts and information/content they previously received from the multimedia lesson.

Descriptive Lesson with Selecting condition (DS). Participants in this group will receive a lesson regarding physics concepts. Then, participants will complete three exercises that only allow them to interact with the given virtual objects without being able to assemble or deconstruct the components of those virtual objects. The exercises also pertain to the physics concepts and information/content they previously received from the multimedia lesson.

Narrative lesson with Building condition (NB). Participants in this group will receive a lesson in a narrative format related to the physics concepts. Then, participants will complete three exercises that require them to build and assemble various variations of virtual objects in a game-like environment.

Narrative lesson with Selecting condition (NS). Participants in this group will receive a lesson in a narrative format related to the physics concepts. Then, participants will complete three exercises that only allow them to interact with the completed version of virtual objects without being able to assemble or deconstruct the components of those virtual objects.

Participation in this research is completely voluntary. At any time, you can drop out of the study and/or refuse to answer particular questions. This decision will not impact or
jeopardize you or your family’s medical care, employment, student status, grades, or other entitlements.

**RISKS AND BENEFITS:** The risks associated with the study are the normal risks associated with learning physics concepts and playing any computer game using a desktop computer. The game is non-violent and involves learning about Physics. Frustration may result during the learning task. While playing the game there is the risk that you may experience feelings of boredom, frustration, and/or fatigue. You can stop at anytime without a penalty if you experience any discomfort.

**PAYMENT:** You will receive $15 in cash for completing the study.

**TIME INVOLVEMENT:** Your participation will take approximately 1 hr and 45 minutes.

**DATA STORAGE TO PROTECT CONFIDENTIALITY:** Any information obtained in connection with this study will be kept strictly confidential. All data collected will be password protected and kept in a locked room in locked cabinets or on a secure electronic database at TC. The cabinets will only be accessible to principal research staff directly involved with this study.

**HOW WILL RESULTS BE USED:** The results of the study will be used for educational purposes, both in academic writing and at professional meetings. All data will be kept confidential throughout.

**PARTICIPANT'S RIGHTS**

**PRINCIPAL INVESTIGATOR:** Pantiphar Chantes

**RESEARCHER TITLE:** The effects of manipulation of virtual objects in a game-like environment after being provided with a multimedia lesson on learning physics concepts

- I have read and discussed the Research Description with the researcher. I have had the opportunity to ask questions about the purposes and procedures regarding this study.
- My participation in this research is completely voluntary. I may refuse to participate or withdraw from participation at any time without jeopardy to future medical care, employment, student status or other entitlements.
- The researcher may withdraw me from the research at his/her professional discretion.
- If, during the course of the study, significant new information that has been developed becomes available which may relate to my willingness to continue to participate, the investigator will provide this information to me.
- Any information derived from the research project that personally identifies me will not be voluntarily released or disclosed without my separate consent, except as specifically required by law.
• If at any time I have any questions regarding the research or my participation, I can contact the investigator, who will answer my questions. The investigators’ email address is pdc2114@columbia.edu and the phone number is (857) 540-1228.

• If at any time I have comments, or concerns regarding the conduct of the research or questions about my rights as a research subject, I should contact the Teachers College, Columbia University Institutional Review Board (IRB). The phone number for the IRB is (212) 678-4105. Or, I can write to the IRB at Teachers College, Columbia University, 525 W. 120th Street, New York, NY, 10027, Box 151.

• I should receive a copy of the Research Description and this Participant's Rights document.

SIGNATURE OF CONSENT

If you have read this form and have decided to participate in this project, please understand that your participation is voluntary and you have the right to withdraw your consent or discontinue participation at any time without penalty. You have right to refuse to answer particular questions. Your individual privacy will be maintained in all published and written data resulting from the study.

I have read the above description and give my consent to participate in the study. My signature means that I agree to participate in this study.

Participant’s signature: ______________________________
Date: __________________

Name: ______________________________
Appendix L

Consent Forms
Informed Consent For an On-Site Experimental Session (Bangkok Location)

Date:___________ Time:___________ Group:___________ Subject ID ________

INFORMED CONSENT

DESCRIPTION OF THE RESEARCH: You are invited to participate in a research study on examining the effects of different types of manipulation in a game-like environment on learning outcomes after reading a lesson about physics concepts.

Upon arrival at School of Global Studies (SGS)’s computer lab (3rd floor, TLC) you, as a participant, will be randomly placed into one of the four groups: DB, NB, DS, and NS. The details in each group are the following.

**Descriptive Lesson with Building condition (DB).** Participants in this group will receive a lesson regarding physics concepts. Then, participants will complete three exercises that require them to build and assemble various variations of virtual objects in a game-like environment. The exercises pertain to the physics concepts and information/content they previously received from the multimedia lesson.

**Descriptive Lesson with Selecting condition (DS).** Participants in this group will receive a lesson regarding physics concepts. Then, participants will complete three exercises that only allow them to interact with the given virtual objects without being able to assemble or deconstruct the components of those virtual objects. The exercises also pertain to the physics concepts and information/content they previously received from the multimedia lesson.

**Narrative lesson with Building condition (NB).** Participants in this group will receive a lesson in a narrative format related to the physics concepts. Then, participants will complete three exercises that require them to build and assemble various variations of virtual objects in a game-like environment.

**Narrative lesson with Selecting condition (NS).** Participants in this group will receive a lesson in a narrative format related to the physics concepts. Then, participants will complete three exercises that only allow them to interact with the completed version of virtual objects without being able to assemble or deconstruct the components of those virtual objects.

Participation in this research is completely voluntary. At any time, you can drop out of the study and/or refuse to answer particular questions. This decision will not impact or
jeopardize you or your family’s medical care, employment, student status, grades, or other entitlements.

**RISKS AND BENEFITS:** The risks associated with the study are the normal risks associated with learning physics concepts and playing any computer game using a desktop computer. The game is non-violent and involves learning about Physics. Frustration may result during the learning task. While playing the game there is the risk that you may experience feelings of boredom, frustration, and/or fatigue. You can stop at anytime without a penalty if you experience any discomfort.

**PAYMENT:** You will receive 300 baht in cash for completing the study.

**TIME INVOLVEMENT:** Your participation will take approximately 1 hr and 45 minutes.

**DATA STORAGE TO PROTECT CONFIDENTIALITY:** Any information obtained in connection with this study will be kept strictly confidential. All data collected will be password protected and kept in a locked room in locked cabinets or on a secure electronic database at Teachers College, Columbia University. The cabinets will only be accessible to principal research staff directly involved with this study.

**HOW WILL RESULTS BE USED:** The results of the study will be used for educational purposes, both in academic writing and at professional meetings. All data will be kept confidential throughout.

**PARTICIPANT'S RIGHTS**

**PRINCIPAL INVESTIGATOR:** Pantiphar Chantes

**RESEARCHER TITLE:** The effects of manipulation of virtual objects in a game-like environment after being provided with a multimedia lesson on learning physics concepts

- I have read and discussed the Research Description with the researcher. I have had the opportunity to ask questions about the purposes and procedures regarding this study.
- My participation in this research is completely voluntary. I may refuse to participate or withdraw from participation at any time without jeopardy to future medical care, employment, student status or other entitlements.
- The researcher may withdraw me from the research at his/her professional discretion.
- If, during the course of the study, significant new information that has been developed becomes available which may relate to my willingness to continue to participate, the investigator will provide this information to me.
- Any information derived from the research project that personally identifies me will not be voluntarily released or disclosed without my separate consent, except as specifically required by law.
• If at any time I have any questions regarding the research or my participation, I can contact the investigator, who will answer my questions. The investigators’ email address is pdc2114@columbia.edu
• If at any time I have comments, or concerns regarding the conduct of the research or questions about my rights as a research subject, I should contact the Teachers College, Columbia University Institutional Review Board (IRB). The phone number for the IRB is (212) 678-4105. Or, I can write to the IRB at Teachers College, Columbia University, 525 W. 120th Street, New York, NY, 10027, Box 151.
• I should receive a copy of the Research Description and this Participant's Rights document.

SIGNATURE OF CONSENT

If you have read this form and have decided to participate in this project, please understand that your participation is voluntary and you have the right to withdraw your consent or discontinue participation at any time without penalty. You have right to refuse to answer particular questions. Your individual privacy will be maintained in all published and written data resulting from the study.

I have read the above description and give my consent to participate in the study. My signature means that I agree to participate in this study.

Participant’s signature: ________________________________
Date: ____________________

Name: ________________________________