EXPLORING THE IMPACT OF A VISUO-HAPTIC SIMULATION FOR THE CONCEPTUAL UNDERSTANDING OF PULLEYS

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To my mother and father.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Abstract

Randive, Shreya D. M.S., Purdue University, August 2019. Exploring the Impact of a Visuo-Haptic Simulation for the Conceptual Understanding of Pulleys. Major Professor: Bedrich Benes.

Recently, exploration to develop creative and technology-centered learning techniques have become popular. Researchers work on non-traditional tools to help students understand abstract concepts and reduce misconceptions in physics education. Studies have been performed to explore the influence computer simulations can make on learning as compared to the traditional methods. Simulations with dynamic moving images which engage visual senses have helped improve learning, while haptic channels are unexplored in comparison tactile senses are crucial in the case of embodied cognitive learning.

This thesis takes an opportunity to explore the research area of haptic technology combined with visual simulation. It tests the efficiency of the learning environment developed as a part of this thesis called the Visuo-Haptic Pulley Simulation (ViHaPS) in learning concepts of when compared to traditional learning tools. ViHaPS consists of six different scenarios and is designed to address common misconceptions of pulleys and has two different modes - minimal visual cues and added visual cues. Undergraduate students enrolled at Purdue University participated in this research. They were formed into two groups - an experimental group (ViHaPS) and control group (physical manipulatives) and were compared for learning gains.

Results indicate that ViHaPS is useful in learning concepts of pulleys; however, the results are not significant in comparison to the real experimentation with pulleys.

CHAPTER 1. INTRODUCTION

This chapter introduces the present research about identifying the efficacy of ViHaPS compared to traditional learning methods used to learn concepts of pulleys. It describes the purpose and significance of this research which led to the research questions. Finally, this chapter defines the scope and boundaries of the study.

1.1 Statement of Purpose

Students often do not have a clear understanding of scientific concepts (Driver, Guesne, & Tiberghien, 1985). Previous studies suggested that misunderstanding the fundamental concepts can affect student's understanding of succeeding advanced concepts. With the help of growing technologies, researchers have tried to enhance the traditional learning methods. Haptic is one such technology which has emerged introducing the sense of touch in the virtual world. However, in the field of educational research, haptic technology is not widely explored. The current study observes the impact of haptic technology combined with visual simulations (visuo-haptic) on undergraduate students' cognitive learning of abstract concepts of physics. The purpose of this study is to examine the students' learning by exposing them simultaneously to the visual and haptic sensory levels and comparing it to the physical setup.

1.2 Significance

Haptic technology has been used successfully in many fields such as medicine (Basdogan et al., 2004), virtual reality (Meijden & Schijven, 2009), and education (Williams, He, Franklin, & Wang, 2004). Recent studies (Magana & Balachandran, 2017a; Magana et al., 2017; Shaikh et al., 2017; Yuksel et al., 2017) have explored haptic technology by incorporating it with visual simulations, to help students improve their understanding about concepts of physics like electromagnetism and friction. Myneni et al. (2013) focused on another concept of physics, i.e., simple machines called pulleys, researchers have found out that students often have misconceptions about them. They developed a computer simulation which helped them recognize six common misconceptions that students have about pulleys, shown in Table 1.1. The simulation was successful to reduce the misconceptions among students by about 60% (Myneni et al., 2013). There has not been any study that explored the impact of visuo-haptic technology to reduce the common misconceptions of pulleys.

Table 1.1. *Misconceptions addressed by ViPS (Myneni et al., 2013).*

#	**Definition**
1	The more pulleys there are in a setup, the easier it is to pull to lift a load.
2	The longer the string in a pulley setup, the easier it is to pull to lift a load.
3	Pulling upwards is harder than pulling downwards.
4	Having more pulleys in a pulley setup reduces the amount of work.
5	Size (radius) of pulleys in a pulley setup affects the amount of work.
6	Improper understanding of force and work.

By providing a visuo-haptic simulation which would engage both visual and tactile senses, this research serves as a novel approach to tackle the misconceptions of pulleys. Also, this research can be referred to as an addition to the rapidly increasing haptic technology and a resource for other researchers to gain insight into its diverse potentialities.

1.3 Scope

The scope of this thesis includes the development of the visuo-haptic pulley simulation (ViHaPS) to examine its effectiveness in reducing the misconceptions of pulleys when compared to traditional learning methods. This simulation consists of six different scenarios with different setups of pulley-systems corresponding to four out of the six misconceptions of pulleys stated by (Myneni et al., 2013). These four misconceptions in pulleys addressed by the current research are stated in Table 1.2.

Table 1.2. *Misconceptions addressed by ViHaPS.*

#	**Definition**
1	More pulleys in a setup, easier it is to pull or lift a load.
2	Longer the rope attached to a pulley, easier it is to pull or lift a load.
3	Pulling in a upward direction is more difficult that pulling downwards.
4	Radius of pulleys in a pulley matters or it affects the force required.

Undergraduate students from the college of education at Purdue University participated in this research. Almost half of the participating students interacted with the ViHaPS - Visuo-Haptic Pulley Simulation (experimental group) and the other half interacted with the traditional learning tools/ physical manipulatives (control group). Both the groups were exposed to a similar set of various combinations of pulley systems. The equipment required for the experimental group was a laptop of the basic configuration and a haptic device (*Falcon Specifications HapticsHouse.com*, 2018). In case of the control group, the equipment (pulleys, ropes, loads) currently used in the Physics department at Purdue University in undergraduate classes as a learning tool were used. In this quasi-experimental study, pre-test and post-test scores of students were compared to find the learning gain. Along with pre-test and post-test participants took transfer test and delay test to analyze the effect of visuo-haptic simulation on transferring of learning gains and long-term retention of learning gains; respectively.

1.4 Research Questions

The current study focuses on the impact of haptic technology combined with visual simulation on remediating the misconceptions among students in the context of pulleys. Following are the research questions for this study:

1. Is visuo-haptic simulation more effective than physical manipulatives for overcoming the misconceptions of pulleys?
2. Is visuo-haptic simulation more effective than physical manipulatives for transferring the learning concepts of pulleys?
3. Is visuo-haptic simulation more effective than physical manipulatives for long-term retention of concepts of pulleys?

1.5 Assumptions

The assumptions for this study include:

- Students have taken high school "Introduction to Physics" class.
- All the participants have the similar level of understanding about the concepts in context.

1.6 Limitations

The limitations for this study include:

- Common Limitations
  - Number of participants are limited
- Haptic Simulation Limitations
  - Haptic device used for the research is Falcon Novint

  - No friction or weight for ropes and pulleys is implemented in the visuo-haptic simulation
  - Acceleration of the pulling force at the pulley is not considered when calculating the haptic force feedback

- Physical Manipulative Limitations
  - Pulleys and ropes are assumed to be weightless and frictionless
  - Acceleration of the pulling force at the pulley is not considered

1.7 Definitions

Following are the definitions for this study:

Haptic Technology Force display technology works by using mechanical actuators to apply forces to the user. By simulating the physics of the user's virtual world, we can compute these forces in real-time, and then send them to the actuators so that the user feels them. (Blattner & Dannenberg, 1992)

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

ViHaPS A Visuo-Haptic Pulley Simulation developed as a part of this thesis.

1.8 Summary

This chapter introduced this thesis and defined its scope and significance. Further, it stated its limitations, assumptions, definitions, and research questions. The current research hypothesises that the the visuo-haptic simulation - ViHaPS can help reduce the misconceptions in pulleys when compared to the the traditional methods of learning. Students from the College of Education at Purdue University participated in this research. All the participants were formed into two sections, and participants within each group were assigned one of the two treatments: ViHaPS (experimental group) and real experimentation with pulleys (control group). The experimental group was allowed to explore ViHaPS with the help of the haptic device used in this study, i.e., Falcon Novint. While the control group interacted with the physical manipulatives pulleys. Participants completed various assessments during the laboratory sessions itself. A delayed test was given to them after two weeks from the laboratory session.

The next section recognizes the gaps in the previous research in the related area and emphasizes the need for the current research.

CHAPTER 2. LITERATURE REVIEW

This literature review addresses previous work on student's conceptual understanding of physics, especially the misconceptions they have about pulleys. The following section further discusses the use of simulations in improving learning methods. The last section elaborates on haptic technology and its use in educational research.

2.1 Student's Misconception in Physics

Misconceptions can cause students to apply unscientific explanations that are inconsistent with the actual one (Hakkarainen & Ahtee, 2006). Törnkvist, Pettersson, and Tranströmer (1993) stated "The concepts of field and field lines are sources of confusion among physics students at university level" (Törnkvist et al., 1993, p.335). They did an introductory experiment on whether the reason why university students mix ideas about two closely related concepts of physics, viz. force and force field could be because they lack the complete understanding of the graphical representation of these particular concepts as well as the related concepts. According to the conclusion of their study, students attached "far too much reality" (Törnkvist et al., 1993, p.338) to the concepts in focus and often approached these concepts as "isolated entities in Euclidean space" (Törnkvist et al., 1993, p.338). They claimed that the students did not completely understand the hierarchical sequence between the concepts involved in the experiment. Törnkvist et al. (1993); Viennot (1979) further suggested that the students' confusion was seen through their representation and this confusion was partially the cause of the well-known misconceptions.

Myneni et al. (2013) described that students who complete school and get to college are supposed to have complete knowledge of the basic concepts of physics like force and energy, tend not to have the expected level of understanding. They stated that it is difficult for middle school students to learn about simple machines, especially pulleys. Moreover, teachers find it difficult to help students abstract what they understood from a hands-on exercise to general understanding of concepts of physics. Myneni et al. (2013) experimented to identify the misconceptions faced by middle school students and tried to minimize them. They developed a visual simulation for their study called Virtual Physics System (ViPS) which helped them identify misconceptions about basic concepts of pulleys (see Table 1.1). The following lists all the misconceptions marked by ViPS (Myneni et al., 2013).

Ahtee and Hakkarainen (2005) studied how students understand the concept of weight. In the study, two bodies of the same weight were hanging in a pulley in equilibrium. One body was a standard mass (metallic), and other was a bag (plastic) (see Figure 2.1). According to the results, many students built their thinking on their misconceptions. For example, the larger the object, the heavier it is or, the higher it hangs, the heavier it is. The author stated that the misconceptions are tacit in five categories - motion, position, appearance, material, and no argument or confusing data. For instance, Ahtee and Hakkarainen (2005) suggested that the correct scientific explanation against the category of “material” would be that the material of the body hanging on the pulley should not make any difference as the weights are same. The students, on the other hand, associated different properties to the material, i.e., the bag and the standard mass. Most of them said that the standard mass is heavier than the bag and the reasoning behind their choice was that the standard mass is made of metal while the bag is of plastic (Ahtee & Hakkarainen, 2005).

In a different study, Hakkarainen and Ahtee (2006) explained how they approached dealing with these misconceptions and promoting a conceptual change. They suggested that when students are exposed to clashing situations that differ

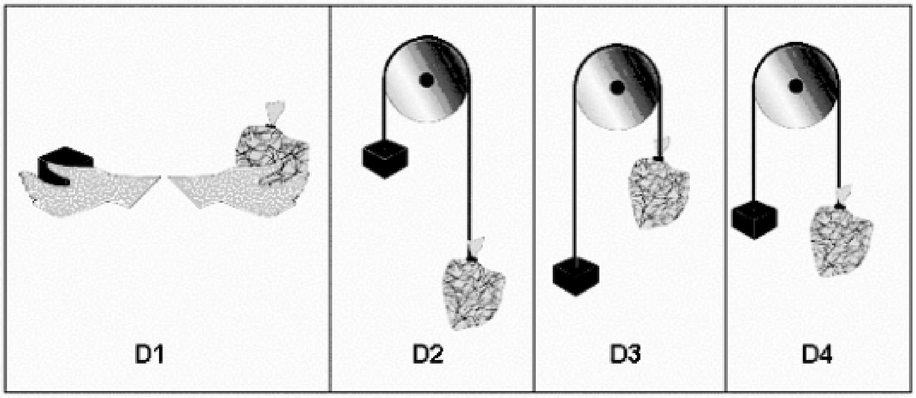


Figure 2.1. Pulley demonstration used in a study by Ahtee and Hakkarainen (2005).

with their current knowledge, cognitive conflict is invoked, which forces students to evaluate their existing conceptions in order to resolve conflict. This instructional approach can encourage conceptual change (Hakkarainen & Ahtee, 2006).

Based on this statement Ahtee and Hakkarainen (2005) introduced two more demonstrations which were the same as the previous setup (i.e., a metal standard mass and a plastic bag of same weight suspended over a pulley at equilibrium) except that the three different demonstrations were at three different positions of the pulley in balance. After these significant variations in the study, the students reasoning improved. Seventy-seven percent of the students came up to the conclusion that both the bodies must have the same weight while the total amount of the position model decreased to fifteen percent.

In order to treat these misconceptions about various concepts in physics, research suggested that the traditional method of instruction is ineffective (Jimoyiannis & Komis, 2001). Science educators like (DiSessa, 2000) argued that teaching physics concepts realistically might achieve more profound understandings than teaching the same concepts with pure mathematics. Additionally, Törnkvist et al. (1993) call for a novel educational strategy that represents the existing theoretical methods as well as considers the cognitive struggles faced by students (Törnkvist et al., 1993).

The need for innovative educational approaches that could help students to get a deeper understanding of the fundamental physical concepts motivates researchers to come up with research designs and pedagogical tools.

2.2 Simulations in Educational Research

Students face difficulties when they try to conceptualize the various phenomena of physics. Concepts are just words for students. Simulations help students to visualize these concepts. Both physical and virtual experiments are designed to achieve learning goals. With the help of physical experiments, students can develop practical laboratory skills such as setting up a piece of equipment, operating it, troubleshooting any issues that might occur and waiting for an extended period for the results and observations (Singer, Hilton, & Schweingruber, 2005). However, virtually researchers can perform experiments which may not always be feasible to perform physically. The critical quality that makes virtual experiments highly useful is that reality can be adapted (de Jong, Linn, & Zacharia, 2013; Trundle & Bell, 2010). Virtual experiments can cover many tasks in a short period (de Jong et al., 2013). Moreover, educators or educational researchers can modify the virtual experiments in a way that it would highlight the relevant concepts that they would like the students to learn and remove all the confusing details (Trundle & Bell, 2010). Virtual experiments can be efficiently performed with the help of computer simulations.

Many educators promote that visualizations, labs, experiments, and demonstrations are better ways of teaching physics to students than by mathematical formulae. It enables students to understand conceptually. Squire, Barnett, Grant, and Higginbotham (2004) stated that, learning through simulation motivates students and might also provide more natural ways to develop an inherent understanding of abstract physics concepts, and they conducted a study in a school for underserved students in which they used an electromagnetism simulation game to investigate what learning occurs. The results of their study (Squire et al., 2004), by basis of understanding, students in the experimental group performed than the control group. The mechanics of the game simulation helped students to face weaknesses in their understandings (Squire et al., 2004). They further stated that "These findings suggest that simulation computer games can be effective tools in helping students understand complex physics phenomena." (Squire et al., 2004, p.519).

Chang, Chen, Lin, and Sung (2008) indicate that computer simulations are an asset for improving student learning. Chang et al. (2008) implemented a simulation learning system and explored the differences between simulation-based learning and traditional laboratory learning. They compared high school students learning about fundamental characteristics of optical lens from two groups traditional laboratory group and simulation group. Simulation group performed significantly better than the other (Chang et al., 2008). Myneni et al. (2013) tried to identify flaws in students understanding of physical concepts, which is considered to be somewhat tricky. They achieved accurate identification of misconceptions by using a computer simulation called Virtual Physics System (ViPS). It addressed five misconceptions in pulleys which are generally expected to be identified and remedied through the curricula in physics. Myneni et al. (2013) also said that, this computer simulation was successful in correcting many of the misconceptions in pulleys.

Non-conventional methods like computer simulations have proven to be an effective way to improve learning methods inspiring researchers to come up with new and better learning technologies. Computer simulations usually engage the sense of sight and sometimes the sense of hearing. Researchers are exploring the sense of touch and trying to incorporate the same in various educational tools or learning tools. As stated by Reiner (1999), "The feel of positive and negative acceleration, the feel of push and pull, are well-exploited in physics learning." (Reiner, 1999, p.53). According to Reiner (1999) and theories of embodied cognition, tactile feedback or information helps promote the development of conceptual knowledge.

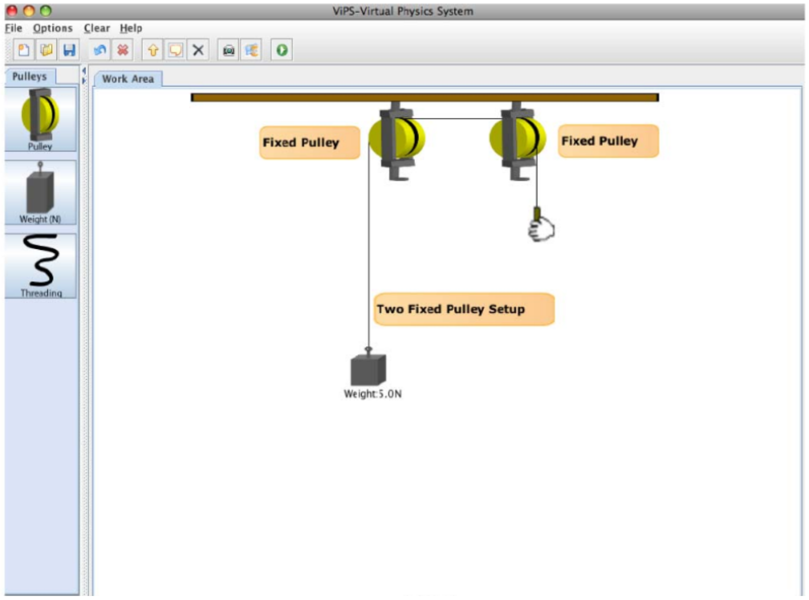


Figure 2.2. ViPS work area (Myneni et al., 2013).

2.3 Haptic Technology in Educational Research

With many studies regarding the impacts of visual senses in learning, not until recently, the human and computer interaction stopped depending solely on this sensory input (Thurfjell, McLaughlin, Mattsson, & Lammertse, 2002). Thurfjell et al. (2002) stated "Although touch is one of the most fundamental ways people interact with physical objects, the interaction with virtual objects in the computer world has until recently been restricted to the use of vision as the primary mode of receiving information" (Thurfjell et al., 2002, p.210). Haptic is imparting users with an array of devices that can perform different yet unique tasks. This evolved field is defined by various authors as a field of technology where tactile senses are used while interacting with the computer (Thurfjell et al., 2002). The technology field which focuses on the human interactions with the virtual world via the sense of touch is known as haptic (Révész, 1950). Haptic can simulate the weight, force, and hardness of an object and help the users to feel or sense the virtual objects (McLaughlin, Hespanha, & Sukhatme, 2002). It is being used successfully in the field of medicine (Basdogan et al., 2004; Escobar-Castillejos, Noguez, Neri, Magana, & Benes, 2016), virtual reality (Luciano, Banerjee, & DeFanti, 2009), and education (Magana & Balachandran, 2017b; Magana et al., 2017; Magana, Serrano, & Rebello, 2019).

Minogue, Gail Jones, Broadwell, and Oppewall (2006) argued that students learn more effectively when the learning method involves hands-on experience . Morever, Druyan (1998) stated that it is helpful when tactile sense are involved along with the sense of sight when students are learning abstract concepts. In a study, Han and Black (2011) developed an augmented haptic simulation to analyze the efficiency in presenting perceptual experiences to elementary students, and to help them build multimodal designs of the movements of gears (see Figure 2.3). Han and Black (2011) suggested through their findings that it is vital to help students makes a solid cognitive foundation with the use of a perceptual anchor such as haptic. They conclude their study as “Specifically, this study provides evidence on how emerging technologies can help students learn by providing a more embodied experience which allows students to internalize their understanding by imagining what is described in the instruction” (Han & Black, 2011, p.2289).

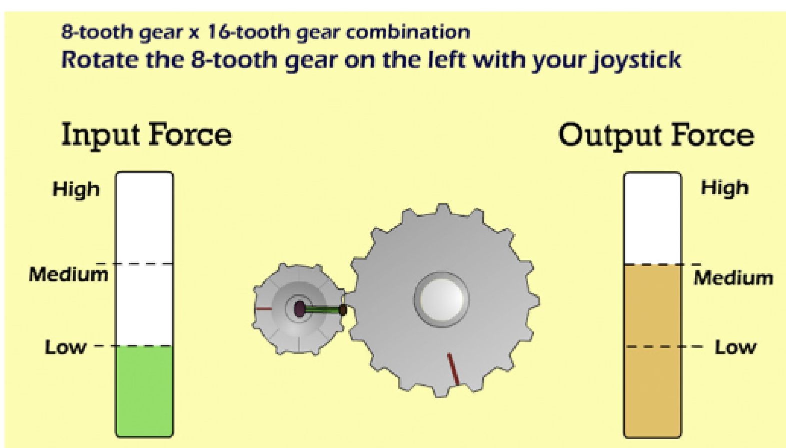


Figure 2.3. Screenshot of gear simulation by Han and Black (2011).

Haptic technology is not thoroughly explored in the field of education. Decidedly less research has been done to study the effectiveness of haptics in education (Minogue & Jones, 2009)). Researchers have paid little attention towards misconceptions in pulleys or rather pulleys. Rouinfar, Madsen, Hoang, Puntambekar, and Rebello (2012) have conducted a study to compare the development of concepts of force in a pulley among students using virtual and physical manipulatives. The results of this study indicate that the student interactions with the physical and virtual manipulatives were significantly different; however their responses to how pulleys were helpful were not significantly different. In a recent study by Neri et al. (2018), developed a haptic simulation for undergraduate students (see Figure 2.4). There were two groups in the experiment - experimental and control group (Neri et al., 2018). Experimental group used the haptic simulation along with the written materials from class while control group used only the written material. Students had to go through exercises related to classical mechanics concepts. The experimental group had to go through the haptic simulation while the control group had to go through the same set of questions but on paper. Neri et al. (2018) were careful about designing the four haptic scenarios. In their study, only two of the four scenarios were about pulleys, and they focused mainly on the mechanics of it.

The results of Neri et al. (2018)'s study indicate that students were inspired to use the haptic technology and the experimental group achieved higher learning gains in two scenarios when compared to the control group (Neri et al., 2018). It marks as a stepping stone in haptic educational research with some solid results proving significant improvement in conceptual understanding among students when compared to traditional methods. However, it does not address the misconceptions in pulleys rather it revolves around the mechanics of pulleys. In the current experimental study, the current research work aims to tackle the misconceptions in pulleys by developing a haptic simulation prototype and presenting the comparative results of its impact on the students learning.

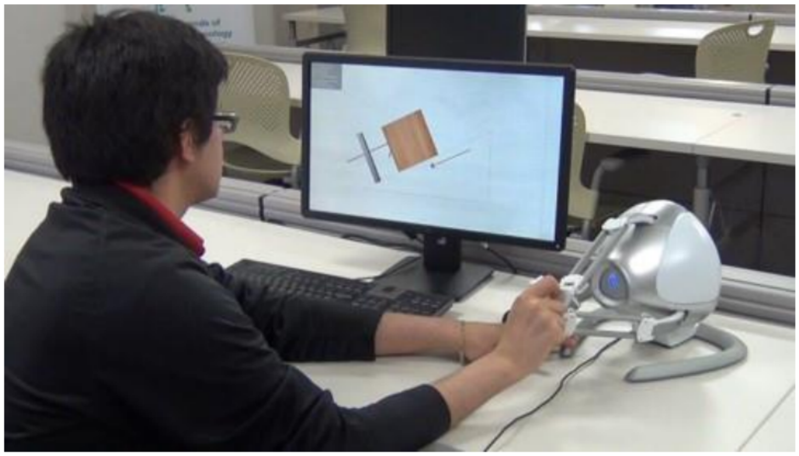


Figure 2.4. User interacting with the visuo-haptic environment (Neri et al., 2018).

Instead of the technological advances, the use of haptics in education is still widely unexplored. The reason for it is the cost of developing the technology. Moreover, the challenges associated with the level of realism that the haptic devices provide. However, just like any other rapidly growing technology these days, the cost associated with the haptic is decreasing, and applications are being developed to bring more realism to it. In the future, haptics can prove to be a revolutionary way to interact with the virtual world. There is a need for more research in the field of haptic of education.

2.4 Summary

As discussed in this chapter students often have misconceptions regarding fundamental concepts of physics. Students do not usually have a clear understanding of core concepts of physics such as simple machines, electromagnetism, and forces. Several pieces of research have used computer simulations as well as traditional methods to improve learning. Myneni et al. (2013) have used computer simulation to reduce misconceptions in pulleys. There is still not enough work done in this area, let alone with the new technology of haptic. The current research explores the efficacy of haptic technology combined with visual simulation when it comes to dealing with misconceptions in the context of pulleys compared to traditional methods such as physical manipulatives. This research would be significant to present substantial proof that using haptic for learning can create a cognitive influence.

CHAPTER 3. THEORETICAL FRAMEWORK

This chapter addresses the complications students face while understanding different concepts in general and the cognitive process of learning. It discusses how misconceptions among students can be reduced through learning. It further discusses the phenomenon of embodied cognition as the theoretical framework for this thesis.

3.1 Student's Understanding of General Concepts

According to Driver et al. (1985), students or children have specific ideas about how things work around them from a very young age. Children pick up ideas through their daily experiences and gather knowledge about a specific phenomenon. A simple example of such can be the surface temperature of a metallic object. Children usually learn through experience that a metal object would be cold or hot depending on the temperature of either the surrounding or whatever is inside that object. Another example which might require a complex reasoning structure can be "the association of one variable to another that leads some children to anticipate that 'the brighter the light bulb, the larger the shadow will be'." (Driver et al., 1985, p.4). Driver et al. (1985) also stated that students do not neutrally receive information or instruction instead they approach the lessons taught in science class with the impressions that they have already acquired in the past. These influence what they learn from new encounters which may include "observations and strategies students use to acquire new information, including reading from texts and experimentation" (Driver et al., 1985, p.4). Students building knowledge based on their preconceived information make them prone to misunderstanding foundational concepts.

Vygotskii, Hanfmann, and Vakar (1962)) suggested that, an individual can have two types of knowledge intuitive knowledge and acquired through formal instructions knowledge. The first source of knowledge described as naive knowledge or "gut" knowledge can be obtained through interaction with the surroundings. The second type of knowledge is something that students derive while listening to what the teachers are teaching and the instructions given in a classroom (Vygotskii et al., 1962)). West and Pines (1985) described that when students try to work with these two sources of knowledge, they experience cognitive growth. On the other hand, cognitive opposition happens when these two sources of knowledge conflict. Students usually may be good at taking tests and writing definitions about various phenomena. They can often demonstrate their formal understanding of complicated concepts. However, when it comes to explaining or reasoning these fundamental concepts, students face difficulties. Students may be accepting the teachings in the classroom without making the required changes in their conceptual understanding, and this might be one of the reasons why they face difficulties while defending their position (Jones, 1990).

3.2 Reducing Misconceptions among Students

Clough, Driver, and Wood-Robinson (1987) stated that misconceptions among students defy any change. To change or reduce the misconceptions among students, they must go through some irregularity or anomaly that confronts their previous knowledge. Novak (1987) believed that the misconceptions conflict with the cognitive growth of students and can be very resistant to change. Posner, Strike, Hewson, and Gertzog (1982) suggested that there are four steps to achieve conceptual change listed as follows.

- Students must experience some anomaly with their previous understanding of the concept.
- They must develop a minimum understanding of the concept.

- That concept must be plausible.
- They must find the concept as relevant and useful in various scenarios.

3.2.1 Variation Theory (Marton & Trigwell, 2000)

Marton and Trigwell (2000) talk about "variation theory" and claimed that when students/people experience variation (various aspects of a phenomenon) that is offered to them simultaneously, in turn, they discern specific features of their environment (Marton & Trigwell, 2000, p.214). Based on Marton and Trigwell (2000)'s variation theory, Hakkarainen and Ahtee (2006) suggested that "In addition to discerning features and values of features, one has to be able to discern parts within as well as wholes from their context." (Hakkarainen & Ahtee, 2006, p.214). They further summarize their state with the help of Figure 3.1.

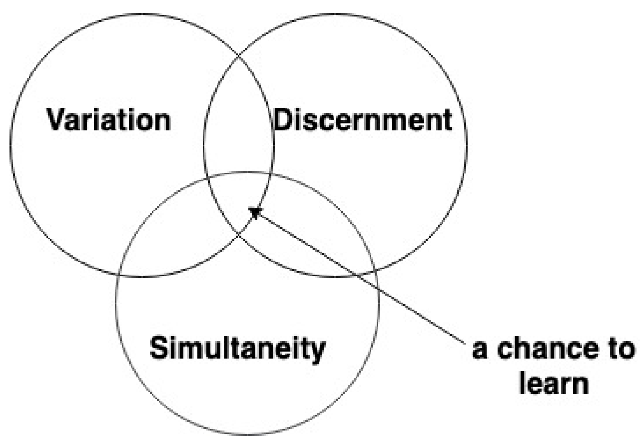


Figure 3.1. Condition of learning by variation theory (Hakkarainen & Ahtee, 2006).

Hakkarainen and Ahtee (2006) suggested that when a student has misconceptions, these ideas can be employed. Furthermore, they raise a question that what could be the best way for teachers to bring the student's misconceptions and the correct scientific explanation simultaneously to student's focal perception. They explain that bringing both the misconception and the appropriate scientific explanation of a phenomenon in awareness can help the student to realize the differences and the fact that every phenomenon has certain features that are critically defining. Moreover, they suggested that according to variation theory, students can discern the misconceptions when the features or context of the scenario where the misconception is taking place are varied (Hakkarainen & Ahtee, 2006).

Teachers usually assume that their students understand the basis of every concept taught in the classroom. However, students have a lot of different misconceptions (Hakkarainen & Ahtee, 2006). Jimoyiannis and Komis (2001) stated that in research, it is generally assumed that students have beliefs about different phenomena in physics. These intuitions are largely inferred from their day to day experience (Jimoyiannis & Komis, 2001). They further articulate misconceptions as "Such beliefs and intuitions are usually incompatible with scientific theories and knowledge; they have been referred to as misconceptions or alternative conceptions." (Jimoyiannis & Komis, 2001, p.184).

3.3 Embodied Cognition

Wilson and Foglia (2017) stated that various traits of cognition are embodied. They further assert that the features of cognition are reliant upon characteristics of the physical body of a person and plays a causal role in that person's cognitive processing. Hallman, Paley, Han, and Black (2009) stated that people acquire tacit embodied knowledge of a physical phenomenon occurs by interacting with the physical environment. Like, when people ride a bicycle, they know how to balance it even though they might not be able to justify their behavior because of the lack of explicit language. "The tacit knowledge that enables people to make judgments or predictions about certain physical phenomena is based on their bodily experiences, which are in turn based on multi-sensory modalities rather than the propositional knowledge they learned from schools" (Hallman et al., 2009, p.1).

Various attempts have been made using low (moving physical objects directly with hands (Glenberg, Gutierrez, Levin, Japuntich, & Kaschak, 2004;

Skulmowski & Rey, 2018)) and even high (use of educational animations or simulations ((Myneni et al., 2013)) technology interventions to provide perceptual experiences for abstract learning. Educational tools that make use of animations and simulations offer a chance for students to learn concepts with dynamic moving images as well as audio narration, unlike traditional methods that make use of text and static images only. Based on Paivio's dual coding theory (Paivio, 1991) and Mayer's multimedia learning theory (Mayer, 2009), studies done to examine the efficacy of such educational tools have proven to be useful in learning.

However, Minogue and Jones (2006) said that these learning tools have a limitation because they mainly rely on audio and visual senses of students and not the tactile channel. They further add that haptic channel is crucial for exploring the natural world. S Chan and Black (2006) introduced a cognitive processing model that delivers information through audio, visual and haptic channels. They further suggested to have two-way communication with hand movement where students can control the various factors like speed and direction while exploring a concept.

3.4 Summary

As discussed in this chapter, children understanding of concepts is often not correct. They experience a few phenomena while growing up and come up with an explanation for the same on their own. This explanation might not always align with the actual scientific explanation of those particular phenomena. As a result, children go to school with the same lack of proper understanding, and it becomes difficult for them to overcome these misconceptions. There is a need for techniques that would question their misconceptions and force them to think differently.

Based on the variation theory by Marton and Trigwell (2000) and the phenomena of embodied cognitive learning, the present study examines if using the haptic channel along with the visual channel helps achieve a conceptual understanding.

CHAPTER 4. LEARNING MATERIALS

Learning materials for the current research are elaborated in this chapter.

4.1 Novint Falcon

This section covers the following topics

- haptic device used in the current research - Novint Falcon, and
- its properties and general specifications.

(a) Joystick attached to arms (b) Buttons on the joystick

Figure 4.1. Novint Falcon Haptic Device.

Novint Falcon haptic device has been used by educational researchers in there studies to improve different concepts of Physics (Magana et al., 2017; Yuksel et al., 2017). The present study uses Falcon as well. Falcon is a 3D touch haptic device. Fundamentally, Falcon haptic device is a small robot. For educational purposes, force-feedback devices like Falcon are used for visuo-haptic simulations because sometimes it is difficult to visualize some of the concepts of physics, or the cost of setting up an actual setup might be higher. Falcon haptic device is used for this research considering the factor of affordability. Premium haptic devices like Omega cost higher than Falcon in comparison.

4.1.1 Specifications

Falcon Novint has force feedback capabilities approximately from two pounds to nine Newtons. It has three parallel arms that can move along three axes. It has degrees of freedom 3 - x (right-left), y (forward-backward), and z (up-down). It has a joystick-like cursor attached to these three arms and has buttons on it. The participants can use this cursor to manipulate and move around in the simulation and click the middle button whenever they wish to grab the hook attached to the pulley system to lift the load (*Falcon Specifications HapticsHouse.com*, 2018).

4.2 Visuo-Haptic Pulley Simulation (ViHaPS)

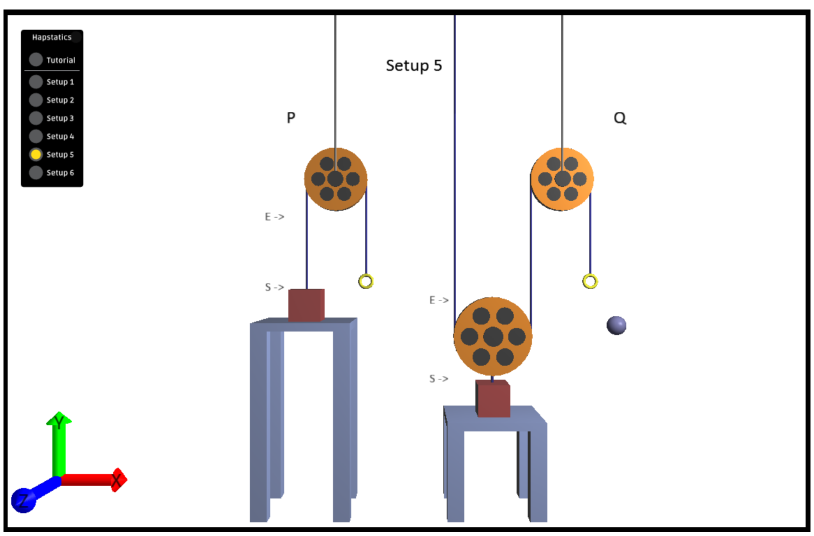
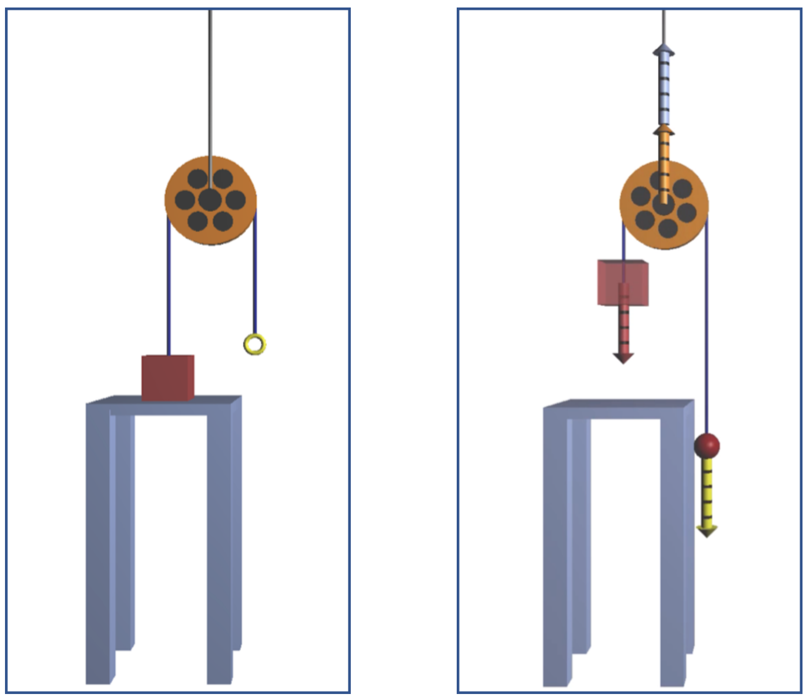


Figure 4.2. Setup 5 in ViHaPS.

Participants in the experimental group were each assigned to a random computer connected to a Novint Falcon haptic device. These computers were pre-installed with ViHaPS. It has six different setups. Each setup focuses on at least one of the common misconceptions in pulleys (see Appendix A). In addition to the six setups, there is a "Tutorial Setup" at the beginning with just a simple fixed pulley to help the participants to get familiar with the simulation and to understand how to interact with the haptic device. Participants had a worksheet which had all the instructions on how to operate the haptic device and how to proceed with the experiment (see Appendix B). Figure 4.2 shows Setup 5 from the simulation.

As seen in the Figure 4.2, each setup has two pulley systems put next to each other. Participants could move the joystick to move the cursor in the simulation. They could grab the hook attached to the pulley system by aligning the cursor with the hook and clicking the button on the joystick to get the force feedback from the haptic device.



(a) Minimal visual cues (b) Added visual cues

Figure 4.3. Sequenced approach for the experimental group.

The experimental group followed a sequenced approach. Participants interacted with ViHaPS with minimal visual cues and once they went through all the setups in the simulation, they were exposed to added visual cues (see Figure 4.3). After the participants completed the experiment and went through all the questions in the worksheet, a “special code” was entered in all the computers. This code enabled visual cues in the simulation and displayed all the forces acting on the pulley systems. Participants went through the whole worksheet again and changed their responses to the questions in the worksheet if they wanted to with a red-colored pen. The different colored pen was used to differentiate the responses of the students before and after being exposed to the visual cues in the simulation.

4.3 Physical Manipulatives

The control group was exposed to physical manipulatives. Various pulley systems were set up on different tables. The pulley systems were set up in a way so that it corresponded to the setups in ViHaPS to maintain consistency among the two learning conditions. Twenty-three participating students were randomly divided into a group of 4-5 students as the pulley systems were limited. This group went through a worksheet as well (see Appendix C).

4.4 Worksheets

Worksheets were given to the experimental group (see Appendix B) and the control group as well (Appendix C). The purpose of the worksheet was to walk the participants through the study. For each of the six pulley setups, there was a question in the worksheet which asked the participants to compare and choose one of the two pulley systems which required higher applied force to lift he attached load. Each multiple-choice question followed an open-ended question which enabled students to express their thoughts behind their answer-choice. It also consisted of questions that required students to draw the forces (free-body diagram) acting on each of the pulley systems.

The experimental group's worksheet consisted of a section in the beginning, which explained how to use the haptic device and which buttons to press to interact with the ViHaPS.

4.5 Summary

This chapter discussed the learning material used in this thesis. For the experimental group which interacts with ViHaPS, the visuo-haptic simulation itself along with the haptic device was a learning material for the participants. Similarly, for the control group, the physical manipulatives served as the learning materials. Moreover, both the groups had similar worksheets, which enabled them to think and answer questions about all the pulley setups they interacted with throughout the study.

CHAPTER 5. IMPLEMENTATION OF ViHaPS

The visuo-haptic pulley simulation was developed using an open-source set of C++ libraries called CHAI3D (Computer Haptics and Active Interface)(*CHAI3D*, 2018) and OpenGL®. It was tested on a laptop computer with Intel i7 CPU @ 2.2 GHz, 16 GB of memory, and Intel® Iris™ Graphics 540 card. Novint Falcon haptic device was used to test this simulation.

5.1 Description

The simulation has an ImGui® menu with radio buttons against all the setup names on the left-hand side. Participants can switch between different setups using the mouse or pressing "space" key on the keyboard. On pressing a sequence of keys on the keyboard or "special code", the participant can see the visual cues. Figure 5.1 shows is a screen-shot of Setup-5 with visual cues on from the simulation.

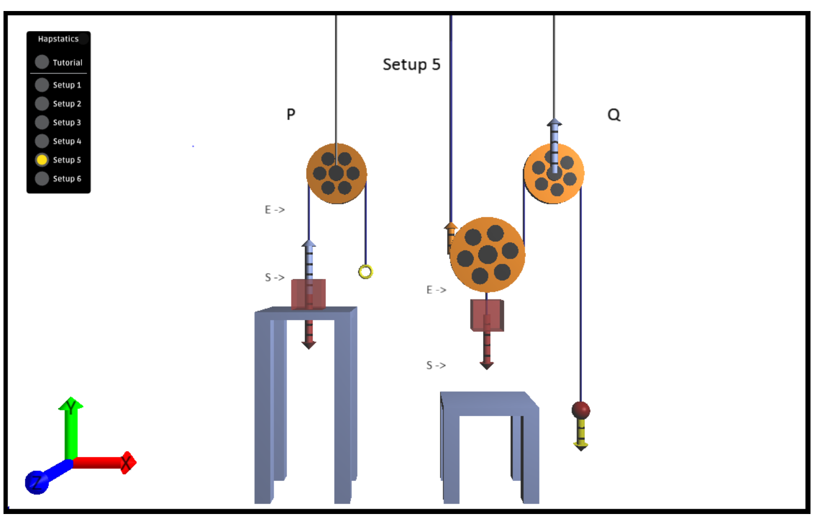


Figure 5.1. Setup 5 from ViHaPS with visual cues on.

5.2 ViHaPS Communication Model

The Falcon haptic device communicates with the visuo-haptic simulation with the help of C++ based open-source libraries called CHAI-3D, and vice versa. Once the simulation is launched, these libraries analyze haptic device's data and send it back to the simulation and vice versa. The user sends data to the simulation via keyboard and mouse like selecting the setup or entering the "special code" to turn on visual cues and receives information via the monitor of the computer. On the other hand, the user manipulates the position of the cursor by using the joystick attached to the haptic device and receives tactile feedback. Figure 5.2 shows how the visuo-haptic simulation, haptic device, and the user interacts.

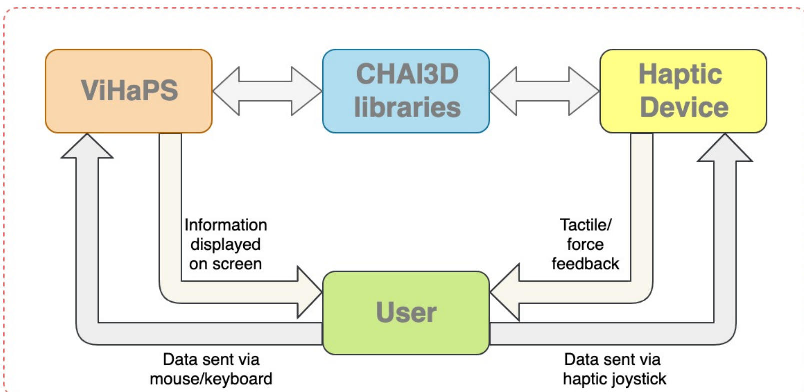


Figure 5.2. Communication between ViHaPS, user and Falcon.

Between six different setups and the Tutorial Setup in the beginning in ViHaPS (see Appendix D), there are eight different pulley systems with three different pulley sizes. Table 5.1 states all of the important dimensions and calculations associated with ViHaPS.

Table 5.1. *Dimensions and calculations for ViHaPS *values rounded off.*

	Radius	**Weight(kg)**	**Force(N)**
Regular Pulley	0.20		
Tiny Pulley	0.11		
Big Pulley	0.25		
Hook (inner)		0.01	
Hook (outer)		0.04	
Load*		0.51	
Force (single)*			5N
Force (movable)*			2.5N

CHAPTER 6. METHODOLOGY

The purpose of the current study is to explore the efficiency of a visuo-haptic simulation to improve students' understanding of concepts in the context of pulleys. This chapter covers the following areas:

- description of the research design and methodology,
- hypotheses statements,
- description for the population and sample selection,
- the procedure followed for the present study, and
- explanation for the data collection procedure and data analysis.

6.1 Research Design

Pre-test and post-test quasi-experiment design was developed for this research to explore the impact of visuo-haptic simulation on reducing the misconceptions of pulleys among students. A control group is included because this research aims to compare visuo-haptic technology to traditional methods. Students were divided into two groups - an experimental and control group and were exposed to two different learning conditions, i.e. visuo-haptic simulation and physical manipulatives, respectively. Both the groups followed a similar sequence as shown in Figure 6.1.

In addition to pre-test and post-test, a transfer test and the delayed test is included in this study to compare the two learning conditions further. While pre-test and post-test focus on simple concepts of pulleys, transfer tests includes complex concepts in comparison. The transfer test aims to identify if participants

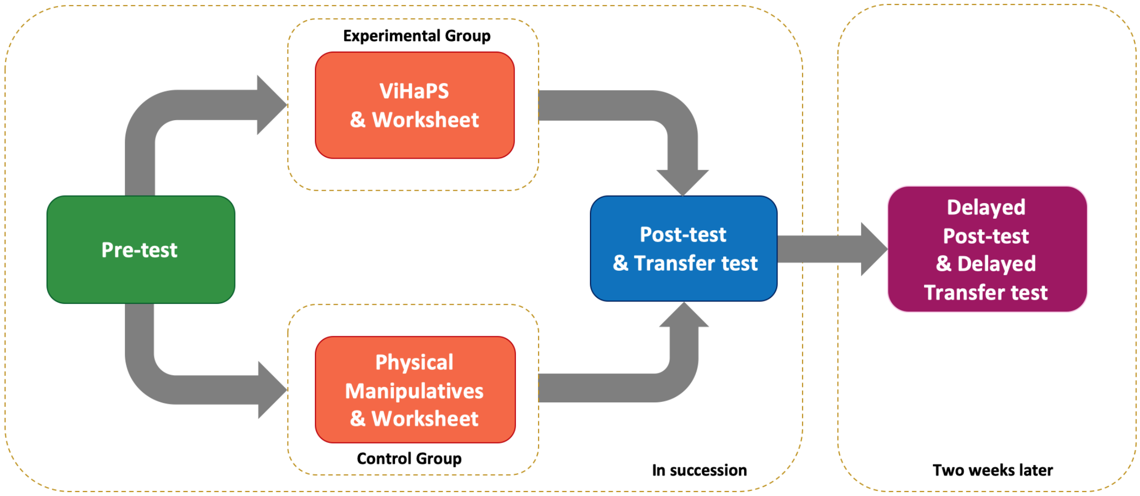


Figure 6.1. Research design for this thesis.

can transfer their learning gains in post-test to complex concepts of pulleys. Moreover, to find if they can retain these learning gains for an extended period a delayed test (taken after two weeks) is included in the research as well.

6.2 Hypotheses

The hypotheses for this study are as follows.

$H_{1\text{-}0}$: Experimental group does not show significant learning gains in posttest.

H_{α}: Students from the experimental group show significantly more learning gains in posttest than the control group.

$H_{2\text{-}0}$: Experimental group does not show significant learning gains in transferring the learning concepts.

H_{α}: Students from the experimental group show significantly more learning gains in transferring the learning concepts than the control group.

$H_{3\text{-}0}$: Experimental group does not show significant learning gains in long-term retention of concepts.

H_{α}: Students from the experimental group show significantly more learning gains in long-term retention of concepts

6.3 Participants

Undergraduate students (Sophomore/Juniors) from Purdue University enrolled in the class called "PHYS 215 - Physics for Elementary Education" participated in this study. Total number of participating students were 45. They were formed into two groups (experimental - 22 and control - 23). Both the groups followed the similar sequence of activities. The following figure depicts the general flow of the study for both groups.

6.4 Variables

The goal of the current study is to examine if ViHaPS help students learn pulley concepts better than physical manipulatives. Following are the variables for this study.

- Independent Variables
  - Control Group: Physical Manipulatives
  - Experimental Group: Visuo-Haptic Pulley Simulation (ViHaPS)
- Dependent Variables
  - Learning (concepts of pulleys) gain
  - Transferring the learning concepts gain
  - Long-term retention gain
- Moderating Variable

  - Physics classes taken in previous years

- Covariant
  - Pre-test scores

6.5 Procedures

Both experimental and control group were divided into two different sessions; morning and afternoon because the labs where the groups performed the study could only accommodate 10-15 students at a time. The pre-test/post-test and the transfer test questions were adapted from a previous study (Gire et al., 2010).

All the questions in each test were two part; objective (MCQ) and its justification. Data points for the current research were participants responses to these questions (answer choice and justification).

Following are the name of tests taken by the participants along with the corresponding number of MCQ questions followed by number of justifications:

- Pre-test (8, 7)
- Post-test (8, 7)
- Transfer test (16, 7)
- Delayed Post-test (8, 7)
- Delayed Transfer-test (16, 7)

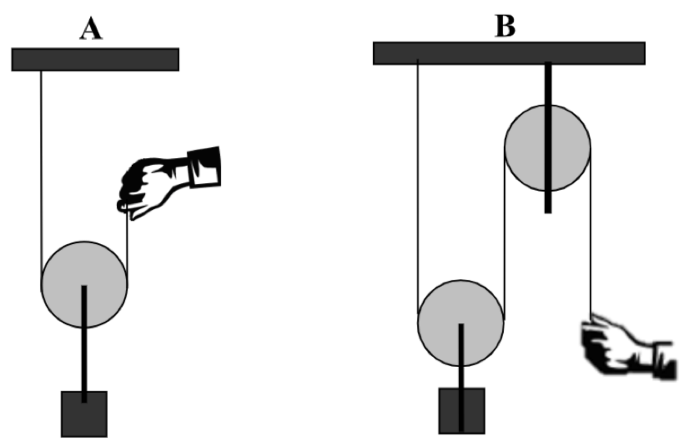
6.6 Data Collection

The data points for this thesis were pre-test, post-test, transfer test, and delayed test. These data points are described in the following sub-sections.

6.6.1 Pre-test

Before being exposed to the learning conditions both the groups took a pre-test. The pre-test questions were focused on four out of the six common misconceptions of pulleys as mentioned by Myneni et al. (2013) in their research (see Appendix E). Pre-test scores were given to the students to gauge their understanding of the concepts before they were exposed to the respective learning conditions. The test has eight multiple-choice questions, and each question required the students to justify their answer choice. After taking the pre-test, participating students were given a respective worksheet.

Which of the following pulley systems will require *less applied force* to lift the load?



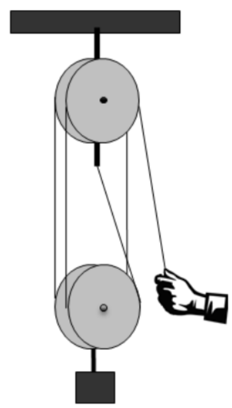
A) Pulley set-up A
B) Pulley set-up B
C) Both A and B will require the same applied force
D) Not enough information to decide

Figure 6.2. Sample pre-test question

6.6.2 Post-test + Transfer Test

After completing the respective worksheets, participants took a post-test. Post-test had the same questions as a pre-test to identify if there are any learning gains after being exposed to separate learning conditions. In addition to the pre-test questions, post-test also included seven multiple-choice transfer questions (see Appendix F), and each question required the students to justify their answer choice, just like the pre-test. These questions focused on complicated concepts of pulleys which were built upon the pre-test questions. Transfer questions were included in the post-test to recognize if participants were able to transfer their learning gains.

You are trying to lift a heavy object that weights 1,000N using a double compound pulley (see diagram below).



Using the double compound pulley set-up above:

14.1) How much applied force will it take to lift the 1,000N load?
A) 1,000N C) 250N
B) 500N D) 0N

14.2) How far would you need to pull to lift the object 20 meters?
A) 100m C) 40m
B) 80m D) 20m

Figure 6.3. Sample transfer test question

6.6.3 Delay Post-test + Delayed Transfer Test

Two weeks after the experiment, both the groups took a delayed test. The delayed test had the same questions as the post-test, i.e. pre-test questions +

transfer questions. This test contributes to identifying long-term retention of learning gains among students.

6.7 Data Analysis

After conducting the study, the participating students were assigned a pseudonym for, e.g., id22, to maintain confidentiality. This research uses (*gradescope.com*, 2018) to organize and simplify the grading process. All the data points were scanned and uploaded to (*gradescope.com*, 2018) after the names on the tests were scratched and replaced by the corresponding pseudonym.

All the participant's data was analyzed using descriptive and inferential statistics. As a part of descriptive analysis, mean scores for each test and standard deviations were calculated. All responses in each test were divided into two parts - MCQ and justifications.

- MCQ was coded as (0) incorrect, (1) correct
- Justification was coded as (0) incorrect, (0.5) partially correct, (1) correct

A rubric was designed to grade the justifications in pre-test/post-test and transfer test. Table 6.1 to Table 6.14 shows the rubric used to score the justifications. Once the data was coded, it was analyzed using inferential statistics. The performance of participants in each learning condition was compared by paired t-test. 2-sample independent t-tests were performed to check if there are any significant learning gains among the two conditions.

6.8 Summary

This chapter provided the research design and methodology used in the research. There were two groups - experimental (ViHaPS) and control (Physical Manipulative). Both the groups took a pre-test before being exposed to the respective treatments. Immediately after completing the study, participants in both groups took a post-test similar to pre-test. Along with the post-test, they took a transfer test. After two weeks, the participating students took a delayed post-test and delayed transfer test. All the assessments consisted of multiple-choice questions and open-ended questions. The next chapter talks about the results in detail.

Table 6.1. *Pre-test, Post-test, Delayed test Q1.*

Correct	**Partially Correct**	**Incorrect**	**Correct MCQ option**
two supporting strands	pulleys distribute the weight/force	lifting requires less force/or required force	A
	does not mention strands but pulleys distributing the weight	more pulleys = less force (in this case fixed pulley is only changing the direction)	
		working with gravity so pulley required less force	
		applied force with pulleys = lifting directly	
		pulley makes it easier/lesser work/greater MA	
		pulley require less applied force	

Table 6.2. *Pre-test, Post-test, Delayed test Q2.*

Correct	**Partially Correct**	**Incorrect**	**Correct MCQ option**
both have same number of supporting strands/basically same pulley system	load is of same mass/weight	only one pulley/simple system so require less force	C
		B is complex uses more force	
		pulling upward is difficult than pulling downward requires less force to pull down	
		second pulley distributes/reduces weight/work/force	
		second pulley makes it easier	
		second pulley distributes/reduces weight/work/force b/c more strands/rope	
		both are same, no reason	

Table 6.3. *Pre-test, Post-test, Delayed test Q3.*

Correct	**Partially Correct**	**Incorrect**	**Correct MCQ option option**
weight distributed across strands/more strands less force	mentions strands/idea of strands reduces the force on pulleys	more pulleys = less force/less work/easier distributes the weight	D
		bigger/wider pulleys/more surface area = less force	
		more rope = easier to pull/reduce force needed	

Table 6.4. *Pre-test, Post-test, Delayed test Q4.*

Correct	**Partially Correct**	**Incorrect**	**Correct MCQ option**
weight is distributed among 4 strands/rope	mentions strands/idea of strands	two fixed pulley make it easier = require less force	D
	more ropes = less force	pulleys are working together	
		looks easier/simple = less force	
		pulling down easier than up	
		more pulleys in a system = less force/work	
		weight distributed among pulleys = less force	
		pulling in the direction of the object requires less force	
		fixed pulley better than movable = less force required	

Table 6.5. *Pre-test, Post-test, Delayed test Q5.2 and Q5.2.*

Correct	**Partially Correct**	**Incorrect**	**Correct MCQ option**
2 strands in the movable pulley share the load and each strand has to pulled by the same distance so total distance becomes twice i.e. increases	mentions the difference between forces required in case of fixed and movable pulley	movable difficult than fix, to pull	Q5.1 A Q5.2 B
	mentions relationship between distance and force	no mention of difference between MA of fixed and movable pulley	
	movable is easier than fixed, lesser force	no mention of strands at all	

Table 6.6. *Pre-test, Post-test, Delayed test Q6.*

Correct	**Partially Correct**	**Incorrect**	**Correct MCQ option**
more string-less force	movable pulley-less force	no idea of MA	B
less applied force for movable pulley		fixed pulley-less force	
		fixed pulley easier-makes more sense	
		same system basically/same force, same MA	
		pulling down easier than up = more MA	
		movable pulley easier to pull	

Table 6.7. *Pre-test, Post-test, Delayed test Q7.*

Correct	**Partially Correct**	**Incorrect**	**Correct MCQ option**
MA is directly proportional to distance pulled (dist = height * no of strands)	mentions concepts as size/friction	distance is directly proportional to force	B
MA = Load/Force	gets relationship between distance and force correct but not the relationship between force and MA or vice versa	greater the MA, lesser the force	
distance is inversely proportional to force		MA inversely proportional to distance	
		no mention of distance pulled	
		no mention of MA	

Table 6.8. *Transfer test and Delayed transfer test Q8.*

Correct	**Partially Correct**	**Incorrect**	**Correct MCQ option**
more ropes/strands = less applied force / more MA	compound pulley uses less applied force	too many strands = less effective/more force	B
	weight is more distributed (compound pulley)	single compound pulley = double compound pulley, difference is length of strands/ropes	
	distance pulled is greater means applied force is smaller	distance pulled is proportional to the length of the strand/rope used, is proportional to force	
		compound are effective than double	
		distance pulled proportional to force applied/work	

Table 6.9. *Transfer test and Delayed transfer test Q9.*

Correct	**Partially Correct**	**Incorrect**	**Correct MCQ option**
two supporting strands		no explanation	Q9.1 A Q9.2 D
each strand pulled by 0.05m, total length is 0.1m		"that is what is showed in the figure"	

Table 6.10. *Transfer test and Delayed transfer test Q10.*

Correct	**Partially Correct**	**Incorrect**	**Correct MCQ option**
equal number of supporting strands	same MA because same setup, more pulleys	less distance to pull, more MA	C
		more pulleys = more MA/less force/easier	

Table 6.11. *Transfer test and Delayed transfer test Q11.*

Correct	**Partially Correct**	**Incorrect**	**Correct MCQ option**
strand A b/c it is distinctly attached to the load	if 11.1's explanation is correct but the rest of the sub questions are incorrect	both supporting the load equally - 6N and 6 N	Q11.1 A Q11.2 A Q11.3 A
one string, shares the weight/load/ 12N		both strands are attached to load	
		both strands are attached to load	
		force applied only on strand A	
		more force applied on A, B doing half the work of A	

Table 6.12. *Transfer test and Delayed transfer test Q12.*

Correct	**Partially Correct**	**Incorrect**	**Correct MCQ option**
both strands are directly in contact or are attached to the load	if 12.1's explanation is correct but the rest of the sub questions are incorrect	only B is supporting the load	Q12.1 C Q12.2 B Q12.3 B
	same strand so supports equally	only A is supporting the load	

Table 6.13. *Transfer test and Delayed transfer test Q13.*

Correct	**Partially Correct**	**Incorrect**	**Correct MCQ option**
all hold the load/attached to same load	if 13.1's explanation is correct but the rest of the sub questions are incorrect	only A, B support the load	Q13.1 C Q13.2 C Q13.3 C Q13.4 C
	equally supported by all the strands	C supports all the weight	
	all share the weight	position of C means it's not supporting the load at all	
		B C are sharing the weight	

Table 6.14. *Transfer test and Delayed transfer test Q14.*

Correct	**Partially Correct**	**Incorrect**	**Correct MCQ option**
each strand support the load, 1/4	each pulley shares the load, 1/4	no mention of strands, treating the pulley system as single fixed pulley	Q14.1 C Q14.2 B
force/4, b/c double compound has 4 wraps of strands	mentions the idea of force required will be less and have to pull more rope	20m distance stay the same	
		divided/multiplied by 2, considered the double compound pulley system as 2 strands	

CHAPTER 7. RESULTS AND DISCUSSION

This chapter provides the analyses and results of the pre-test, post-test, transfer test, delay post-test, and delayed transfer test for both experimental and control groups. The results are presented corresponding to research questions of the current thesis. This chapter further discusses the results in the discussion section.

7.1 Results

As the number of participants in both groups was less than thirty, Shapiro-Wilk's Normality Test was performed. Levene's test of homogeneity of variances was performed to check if both groups perform equally in the pre-test. Also to make sure that the control group does not start with an advantage a two-sample independent test was performed.

7.1.1 Post-test Learning Gains

Participant's responses were scored out of a total of two points. Both pre-test and post-test had eight questions. Descriptive statistics for pre-test and post-test for both groups are summarized in Table 7.1.

Table 7.1. *Descriptive statistics for pre-test and post-test.*

	Condition	**N**	**Mean**	**Std. Dev**
Pre-test	Experimental	22	2.82	1.82
	Control	23	3.00	1.34
Post-test	Experimental	22	4.46	2.33
	Control	23	5.04	1.37

Data was further analyzed to identify learning gains within the treatment groups using paired t-test. Table 7.2 describes the paired t-test results for pre-test and post-test for the both the conditions.

Table 7.2. *Paired t-test results for Post-test Gain (post-test score - pre-test score).*

	Condition	**Mean Gain**	**Std. Dev**	**t-value**	**p-value**
Post-test Gain	Experimental	1.68	2.97	2.61	.008
	Control	2.04	1.78	5.52	.000

Participants show significant learning gain in post-test as p-value for both groups is less than 0.05. To check if the learning gains are significant among the group, independent two-sample tests were performed. Analysis of t-test evaluation shows no significant difference between experimental and control group's mean gains ($t=-.49$, $p>.05$).

7.1.2 Transferring the Learning Gains

In the post-test, participants were introduced with few transfer questions as well. This research hypothesizes that participants in the experimental group are able to transfer their learning gains. Table 7.3 show the descriptive statistics for the two groups.

Table 7.3. *Descriptive statistics for transfer test.*

	Condition	**N**	**Mean**	**Std. Dev**
Transfer test	Experimental	22	9.64	3.27
	Control	23	9.91	4.28

Analysis of independent two-sample t-test evaluation of transfer test scores of the two treatments shows no significant difference between experimental and control group's mean gains ($t=-.24$, $p>.05$).

7.1.3 Long-term Retention of Learning Gains

Delayed test was similar to post-test and transfer test. This research hypothesizes that the participants in experimental group show significantly more learning gains for long-term retention than the control group. Table 7.4 shows the descriptive stats for delayed post-test and delayed transfer test.

Table 7.4. *Descriptive statistics for delayed post-test and delayed transfer-test.*

	Condition	**N**	**Mean**	**Std. Dev**
Delayed Post-Test	Experimental	22	3.73	1.17
	Control	23	3.85	1.51
Delayed Transfer-Test	Experimental	22	9.89	2.98
	Control	23	8.94	2.58

Paired t-test between delayed post-test and pre-test scores show significant learning gain after both the treatments. While there is no significant learning gain in case of delayed transfer test. The results of paired t-test are shown in Table 7.5.

Table 7.5. *Paired t-test results for Delayed Gain (delayed post-test score - pre-test score, and delayed transfer test score - transfer test score).*

	Condition	**Mean Gain**	**Std. Dev**	**t-value**	**p-value**
Delayed-Post Gain	Experimental	.91	1.92	2.22	.02
	Control	.85	1.72	2.39	.01
Delayed-Transfer Gain	Experimental	.25	2.94	.40	.35
	Control	-.93	5.21	-.90	.81

Further two-sample independent t-test show no significant difference in learning gains among the two learning conditions for delayed post-test ($t=.11$, $p>.05$). Moreover, the results for delayed transfer test are not significant as well ($t=.98$, $p>.05$).

7.2 Discussion

According to the results of the independent sample test, the experimental group did not perform better than the control group. While the experimental group performs significantly better in the post-test and delayed-post test, it is not significantly better when compared to the control group. To summarize, the analysis of the collected data provides a positive result for the control group over the experimental group.Split-attention effect and cognitive overload can be the likely reasons for the poor performance of participants in the experimental group.

Mayer and Moreno (2010) said that cognitive overload is a phenomenon any learning task in multimedia learning models requires the processing of information which exceeds the total processing capacity of one's cognitive system. The learning tools need to be designed in such a way that would minimize the cognitive overload. They talked about three different cognitive demands, essential processing, incidental processing, and representational holding (Mayer & Moreno, 2010). Essential processing is described as "integrating words and selecting, organizing, and integrating image" (Mayer & Moreno, 2010, p.45). The current research has two setups of pulleys in each scenario at a given time in ViHaPS, in order to compare the forces required. This might have caused cognitive overload.

As the experimental group was working with the haptic device, they experienced tactile feedback along with the visual input on the computer screen. Most of the participants were using the haptic device for the first time in their lives, so they did not have any prior knowledge. Therefore, in addition to their inexperience of the haptic device, the complexity of the visuo-haptic simulation and the novel tactile senses obtained via the haptic device may have caused a split-attention effect (Chandler & Sweller, 1992; Mayer & Moreno, 1998). Participant's attention was split between the information on the computer screen and the tactile forces provided by the haptic device.

CHAPTER 8. CONCLUSIONS AND FUTURE WORK

This chapter discusses the conclusions of the current research and its limitations. It further discusses the possible future work.

8.1 Conclusions

The data obtained in this research showed mixed results. The graph in figure 8.1 shows the normalized scores of participants in both groups. The experimental group performs better in the post-test and delayed post-test when compared to the pre-test score, and also in delayed transfer test when compared to transfer test scores. While the experimental group showed a significant learning gain in post-test

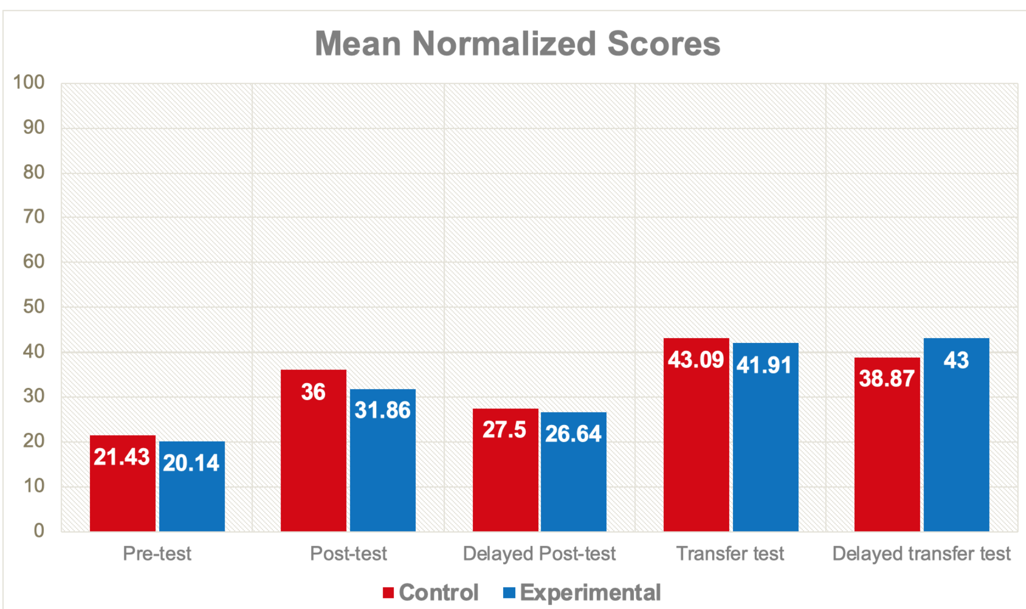


Figure 8.1. Mean normalized scores of participants.

($t=2.61$, $p<.05$) and delayed post-test ($t=2.22$, $p<.05$), the results were not significant in the long-term retention of transfer gains ($t=.4$, $p>.05$).

Similarly, the control group performs better in the post-test and delayed post-test when compared to the group's pre-test score, but the group does not perform better in delayed transfer test when compared to transfer test scores, as seen in the graph in Figure 8.1. The paired t-test results show that the control group displayed a significant learning gain in post-test ($t=5.52$, $p<.05$) and delayed post-test ($t=2.39$, $p<.05$). The group did not perform significantly different in the long-term retention of transferred gains ($t=-.9$, $p>.05$).

RQ.1 Is visuo-haptic simulation more effective than physical manipulatives for overcoming the misconceptions of pulleys?

To determine if the experimental group did better than the control group in the post-test, the post-test gains (the difference between post-test scores and pre-test scores) were compared. Following was the corresponding hypothesis:

$$\mu_{g1} = experimental\, group\, mean\, post - test\, gain$$
$$\mu_{g2} = control\, group\, mean\, post - test\, gain$$
$$H_0 : \mu_{g1} - \mu_{g2} = 0$$
$$H_A : \mu_{g1} - \mu_{g2} > 0$$

For confidence interval of 95% and $\alpha=.05$, the p-value for the two-sample independent t-test was .688, which is higher than .05. Hence, there is not enough evidence to reject the null hypothesis.

RQ.2 Is visuo-haptic simulation more effective than physical manipulatives for transferring the learning concepts of pulleys?

According to the hypothesis made by this research, the experimental group performed better than the control group in transferring the learning gains.

$$\mu_1 = experimental\, group\, mean\, transfer\, score$$
$$\mu_2 = control\, group\, mean\, transfer\, score$$
$$H_0 : \mu_1 - \mu_2 = 0$$
$$H_A : \mu_1 - \mu_2 > 0$$

The results of the two-sample independent t-test (confidence interval 95%) between the two groups gave a p-value of .596. As $p > .05$, the null hypothesis cannot be rejected. In conclusion, the experimental group did not perform significantly better than the control group.

RQ.3 Is visuo-haptic simulation more effective than physical manipulatives for long-term retention of concepts of pulleys?

To determine if the haptic group did better in long-term retention of the gains than the control, delayed post-test gain (the difference between delayed post-test and pre-test scores) and delayed transfer gain (the difference between delayed transfer test and transfer test scores) were compared.

$$\mu_{g1} = experimental\, group\, mean\, delayed\, gain$$
$$\mu_{g2} = control\, group\, mean\, delayed\, gain$$
$$H_0 : \mu_{g1} - \mu_{g2} = 0$$
$$H_A : \mu_{g1} - \mu_{g2} > 0$$

With 95% confidence, two-sample independent t-tests for delayed post-test gain gave a p-value of .455. Similarly, for the delayed transfer test, the p-value was .167. Therefore, as $p > .05$ for the delayed gains, the experimental group did not perform significantly better than the control group in long-term retention.

In conclusion, the visuo-haptic pulley simulation - ViHaPS as a learning condition is not significantly effective than the physical manipulatives for overcoming the misconceptions of pulleys.

8.2 Limitations for the Study

The current study had many limitations. As all the assessments were expected to be answered voluntarily, many participants submitted incomplete answers. These samples were coded as incorrect which in turn affected the score of the overall sample.

Students were offered credit on successful completion of this study as a motivation to participate. But, their performance in the study itself was not related to the credit they received. This might have resulted in students in failing to provide enough efforts to procure a meaningful score in the tests/assessments.

As the sample size for both the experimental and control group was limited i.e., total number of participants were less than thirty for both groups, the results of this study cannot be generalized until it is replicated with a larger sample.

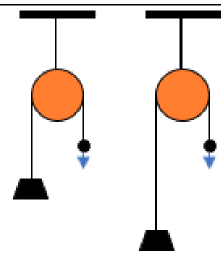
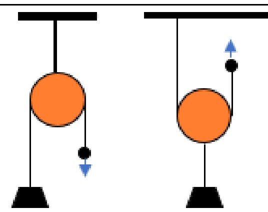
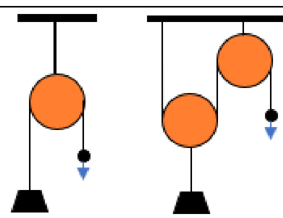
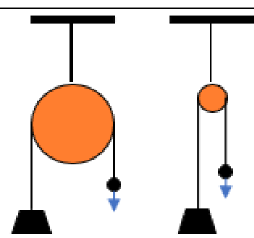
8.3 Future Work

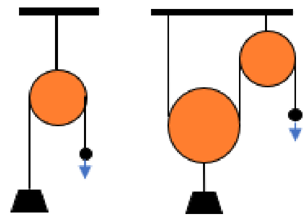
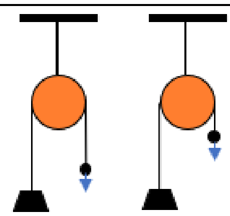
Future work includes additional research in the area of haptic and its relevance in cognitive learning. Adding complex pulley systems in the simulation ViHaPS and revising the questions in the tests/assessments and then conducting a second iteration of the study can provide more information on if visuo-haptic simulations are better than the traditional method for cognitive learning.

The current study had limited participants; the next iteration for this study can be done with a sample size of more than thirty in each group. ViHaPS has two pulley systems in each setup placed side by side; this might have caused cognitive overload. Separating each pulley systems as a different setup could probably reduce cognitive overload and could help students avoid their attention split between multiple pulley systems on the screen.

An advanced haptic device like Omega can be used along with the visuo-haptic simulation - ViHaPS to compare if the results vary from the current haptic device Falcon Novint. In the current research, how hard the load is pulled or the acceleration in the direction of the motion of the user's hand pulling the joystick to move the load was not considered. The user, no matter the acceleration experienced the same amount of force. In the future, this factor can be considered to create a more real haptic environment.

APPENDIX A. MISCONCEPTIONS ASSOCIATED WITH ViHaPs

Setup Name (Associated misconception)	**Two Pulley Systems in the Setup**	**Description of the Misconception**
Setup 1 (Misconception #2)		Longer the rope/string in a pulley setup, easier to pull the load
Setup 2 (Misconception #3)		Pulling upwards is more difficult than pulling downwards
Setup 3 (Misconception #1)		More number of pulleys in a system makes it easier to pull the load
Setup 4 (Misconception #5)		Radius of the pulley in a pulley system influences the amount of work

Setup 5 (Misconception #1 + Misconception #5)		More number of pulleys in a system makes it easier to pull the load + Radius of the pulley in a pulley system influences the amount of work
Setup 6 (Misconception #2)		Longer the rope/string in a pulley setup, easier to pull the load

APPENDIX B. WORKSHEET FOR EXPERIMENTAL GROUP

FALL 2018
PULLEY EXPERIMENTATION AND OBSERVATION

Last Name:		First Name:	Date:
Lab Section: 9 AM	2.30 PM	Laptop #	Time:
Gender: Female	Male	Prefer not to say	

Explore the Simulation:

This exercise is for you to get familiar with the simulation. After you launch the application, you will see a fixed pulley setup. The mass *M* attached to the pulley is at rest. '*S*' and '*E*' represents the start and end positions of the mass.

- '*S*' represents the position of the mass at rest
- '*E*' represents the position when the mass is lifted to the maximum height

Step 1: Using the haptic device, place the cursor on the ring at the end of the rope as shown in Fig. 1.

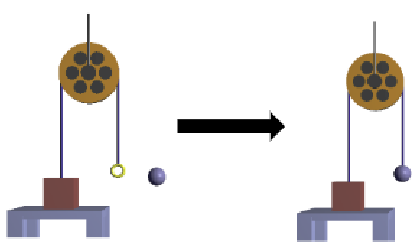


Fig. 1

Step 2: Click the middle button as shown in Fig. 2 on the haptic device to grab the hook attached to the pulley on screen.

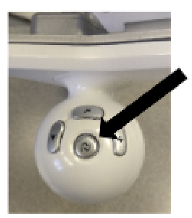


Fig. 2

Step 3: The cursor in the screen will turn red when you grab the hook as shown in Fig 3. Pull down to lift the mass.

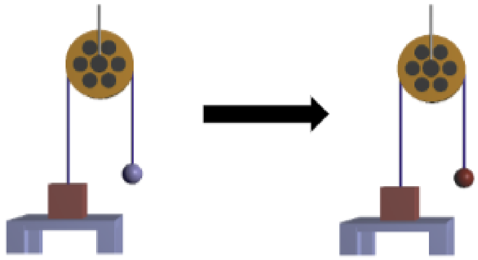
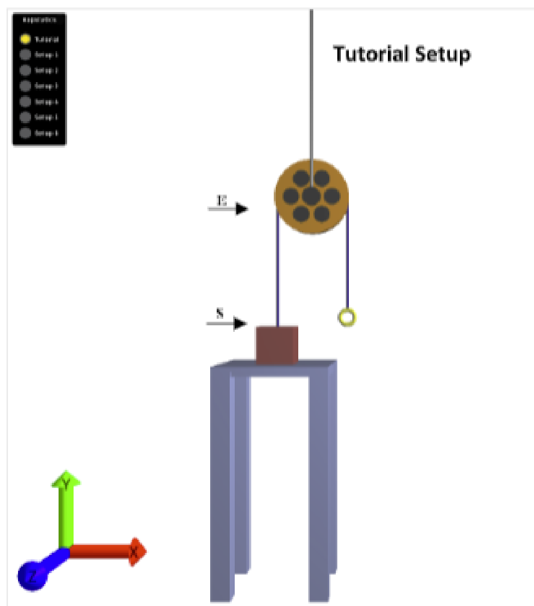


Fig. 3

Step 4: Go through all the *Setups* along with this worksheet. Answer the questions following each Setup in this worksheet based on your observations.



Tutorial Setup

Step 3: The cursor in the screen will turn red when you grab the hook as shown in Fig 3. Pull down to lift the mass.

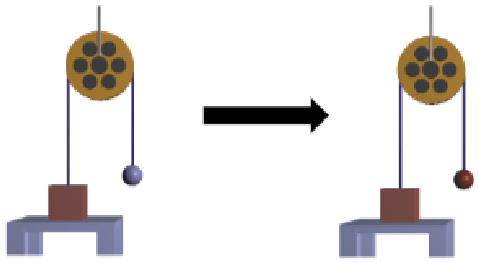
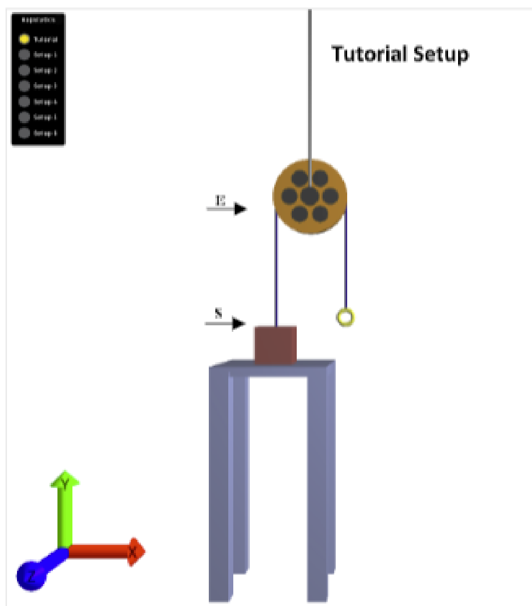


Fig. 3

Step 4: Go through all the *Setups* along with this worksheet. Answer the questions following each Setup in this worksheet based on your observations.



Tutorial Setup

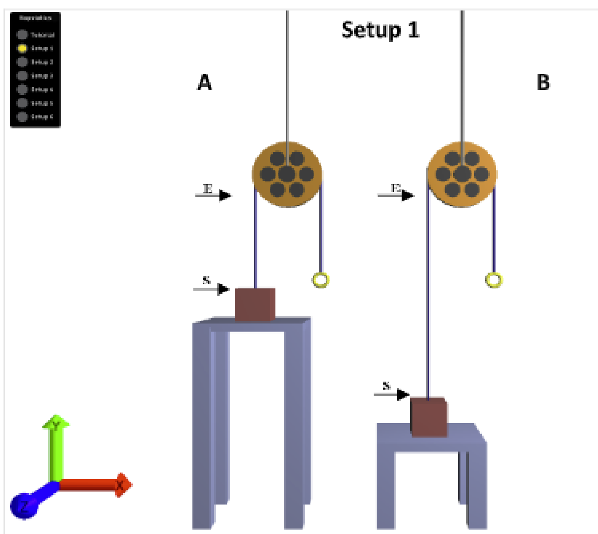
Setup 1

You are given two fixed Pulleys – *A* and *B*. Pull the rope to lift the mass attached to each pulley systems one by one and compare the forces experienced. Answer the following questions.

1. Out of the above two pulley systems, which one required a higher force to lift the mass?
   a. A
   b. B
   c. Both are equal

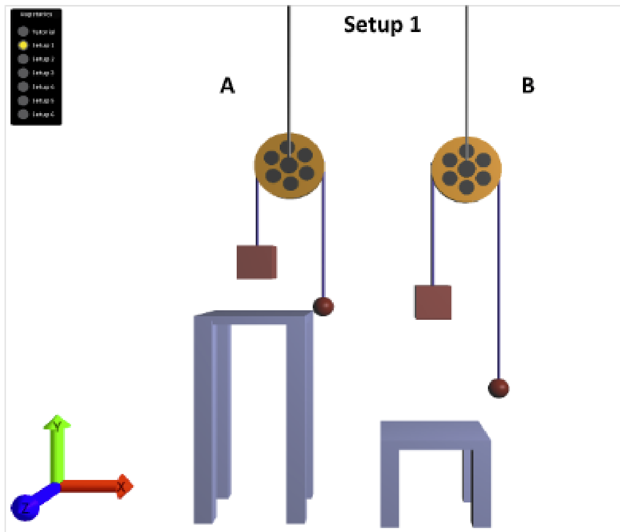
2. Please justify your answer to the previous question. You can use drawings or text to provide a complete answer.

3. Represent all the forces acting on the pulley systems (*A* and *B*) when the mass is <u>at rest</u>. You can draw on the picture bellow.



Setup 1 (Mass at Rest)

4. Represent all the forces acting on the pulley systems (A and B) when the mass is lifted. You can draw on the picture below.



Setup 1 (Mass is lifted)

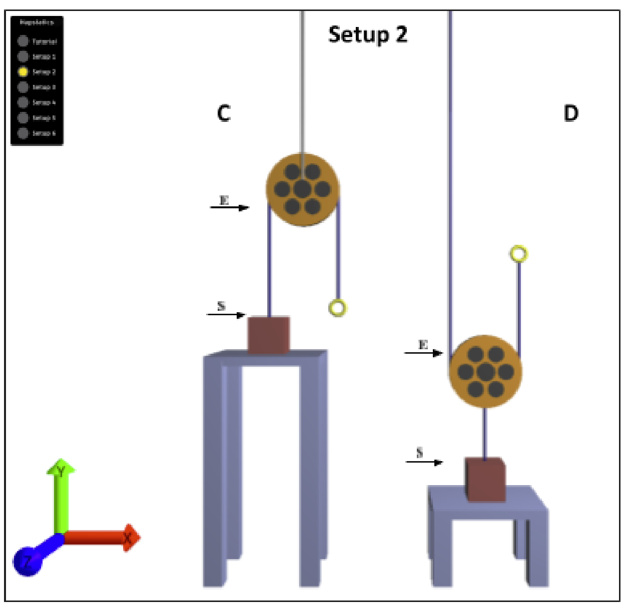
Setup 2

You are given one fixed pulley, and one movable pulley – *C* & *D*. Pull the rope to lift the mass attached to each pulley systems one by one and compare the forces experienced. Answer the following questions.

1. Out of the above two pulley systems, which one required a higher force to lift the mass?
   a. C
   b. D
   c. Both are equal

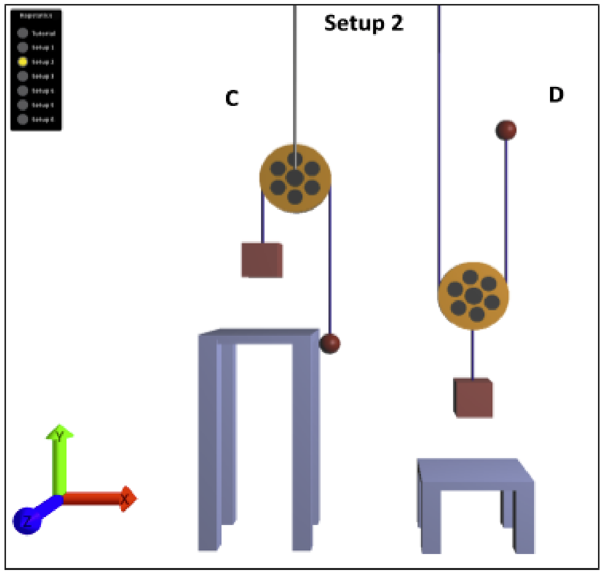
2. Please justify your answer to the previous question. You can use drawings or text to provide a complete answer.

3. Represent all the forces acting on the pulley systems (*C* and *D*) when the mass is <u>at rest</u>. You can draw on the picture below.



Setup 2 (Mass at Rest)

4. Represent all the forces acting on the pulley systems (C and D) when the mass is <u>lifted</u>. You can draw on the picture below.



Setup 2 (Mass is lifted)

at Rest)

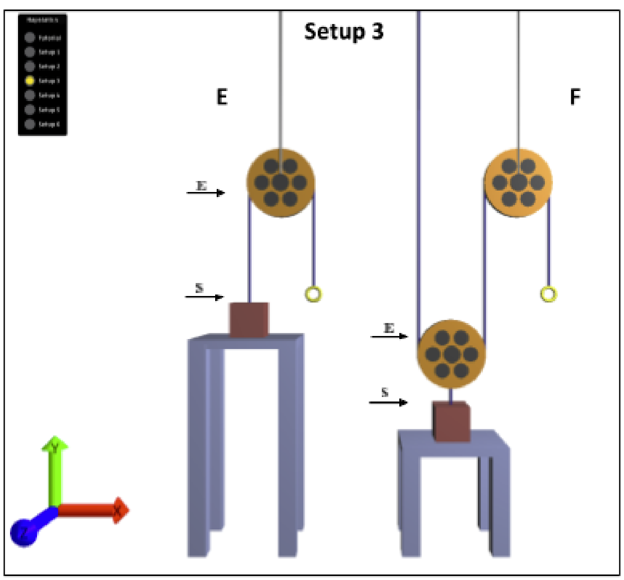
Setup 3

You are given one fixed pulley – *E* and one double pulley – *F* consisting of a fixed and a movable pulley. Pull the rope to lift the mass attached to each pulley systems one by one and compare the forces experienced. Answer the following questions.

1. Out of the above two pulley systems, which one required a higher force to lift the mass?
   a. E
   b. F
   c. Both are equal

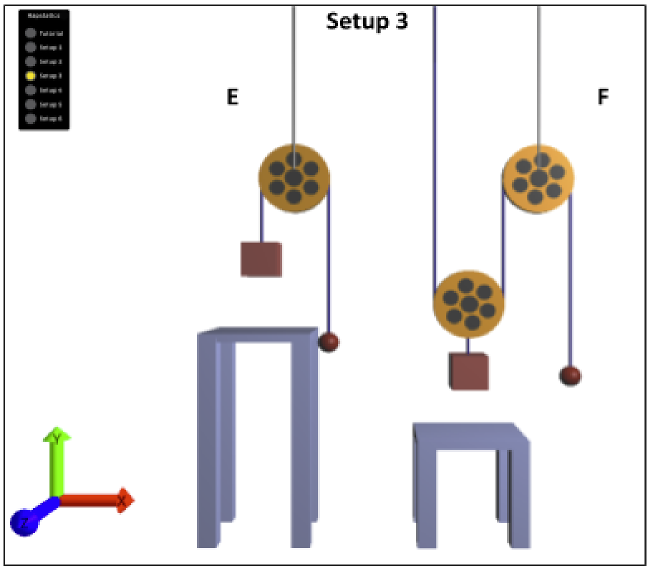
2. Please justify your answer to the previous question. You can use drawings or text to provide a complete answer.

3. Represent all the forces acting on the pulley systems (*E* and *F*) when the mass is <u>at rest</u>. You can draw on the picture below.



Setup 3 (Mass at Rest)

4. Represent all the forces on the pulley systems (*E* and *F*) when the mass is lifted. You can draw on the picture below.



Setup 3 (Mass is lifted)

at Rest)

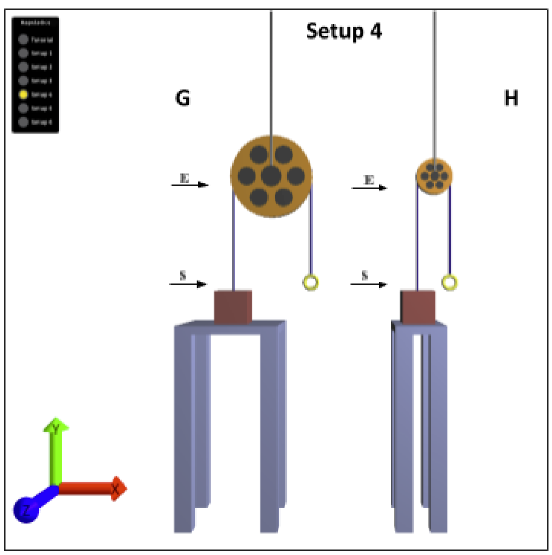
Setup 4

You are given two fixed pulleys of different sizes – *G* and *H*. Pull the rope to lift the mass attached to each pulley systems one by one and compare the forces experienced. Answer the following questions.

1. Out of the above two pulley systems, which one required a higher force to lift the mass?
   a. G
   b. H
   c. Both are equal

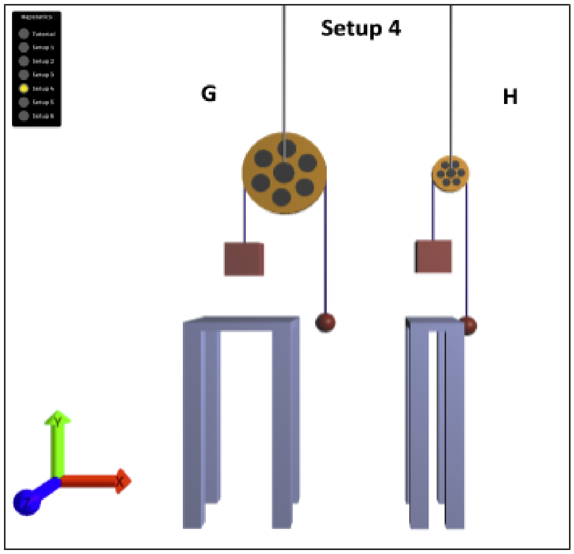
2. Please justify your answer to the previous question. You can use drawings or text to provide a complete answer.

3. Represent all the forces acting on the pulley systems (*G* and *H*) when the mass is <u>at rest</u>. You can draw on the picture below.



Setup 4 (Mass at Rest)

4. Represent all the forces acting on the pulley systems (*G* and *H*) when the mass is <u>lifted.</u> You can draw on the picture below.



Setup 4 (Mass is lifted)

at Rest)

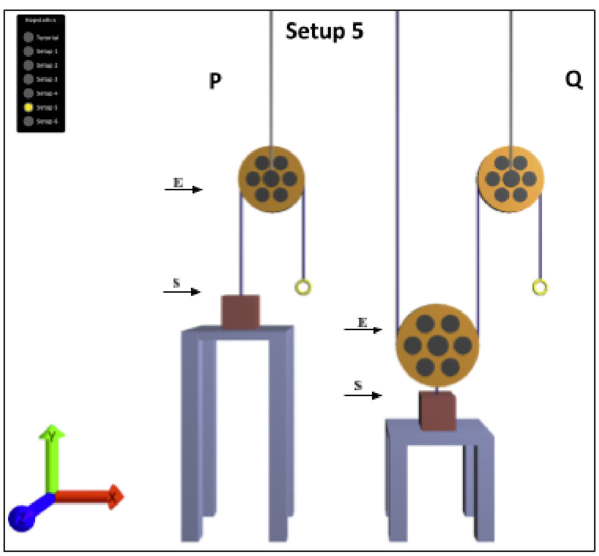
Setup 5

You are given one fixed pulley – *P* and a double pulley – *Q* consisting of a fixed and a movable pulley of different sizes. Pull the rope to lift the mass attached to each pulley systems one by one and compare the forces experienced. Answer the following questions.

1. Out of the above two pulley systems, which one required a higher force to lift the mass?
   a. P
   b. Q
   c. Both are equal

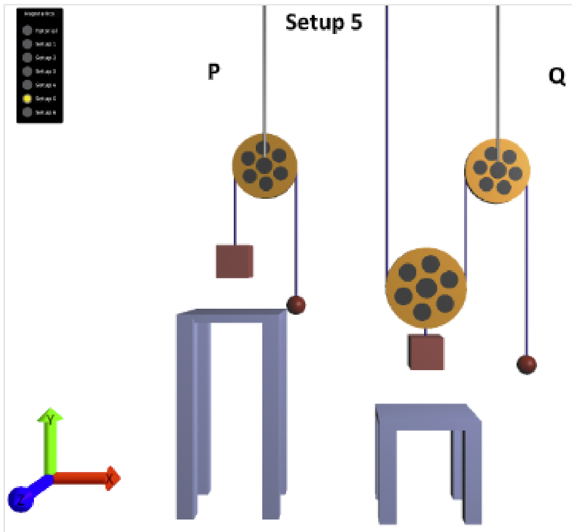
2. Please justify your answer to the previous question. You can use drawings or text to provide a complete answer.

3. Represent all the forces acting on the pulley systems (*P* and *Q*) when the mass is at rest. You can draw on the picture below.



Setup 5 (Mass at Rest)

4. Represent all the forces acting on the pulley systems (*P* and *Q*) when the mass is <u>lifted</u>. You can draw on the picture below.



Setup 5 (Mass is lifted)

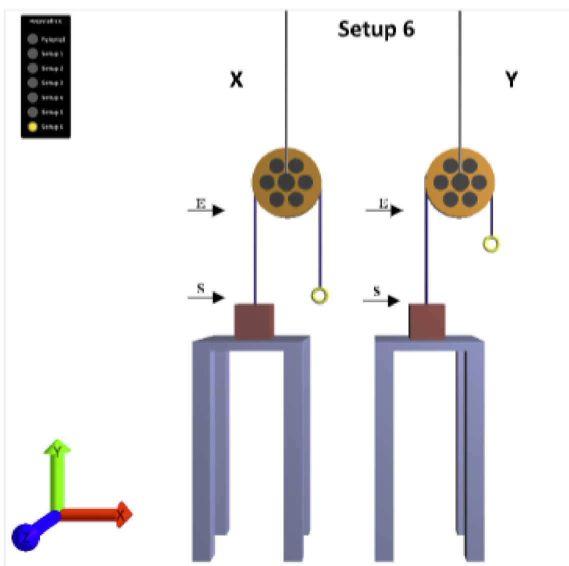
Setup 6

You are given two fixed Pulleys – *X* and *Y*. Pull the rope to lift the mass attached to each pulley systems one by one and compare the forces experienced. Answer the following questions.

1. Out of the above two pulley systems, which one required a higher force to lift the mass?
   a. X
   b. Y
   c. Both are equal

2. Please justify your answer to the previous question. You can use text or drawings to provide a complete answer.

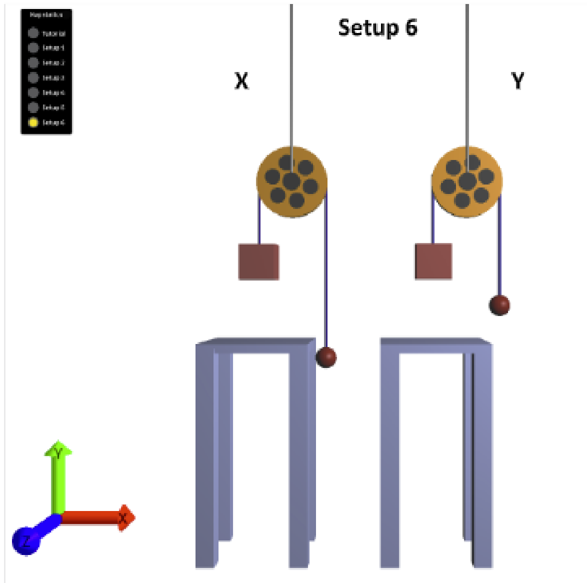
3. Represent all the forces acting on the pulley systems (*X* and *Y*) when the mass is <u>at rest</u>. You can draw on the picture below.



Setup 6 (Mass at Rest)

4. Represent all the forces acting on the pulley systems

(X and Y) when the mass is lifted. You can draw on the picture below.



Setup 6 (Mass is lifted)

APPENDIX C. WORKSHEET FOR CONTROL GROUP

FALL 2018
PULLEY EXPERIMENTATION AND OBSERVATION

Last Name:		First Name:	Date:
Lab Section: 9 AM	2.30 PM	Laptop #	Time:
Gender: Female	Male	Prefer not to say	

<u>Instructions</u>

1. You are given six different (1 to 6) pulley systems/setups.
2. Go through all the *Setups* along with this worksheet.
3. Answer the questions following each Setup based on your observations.

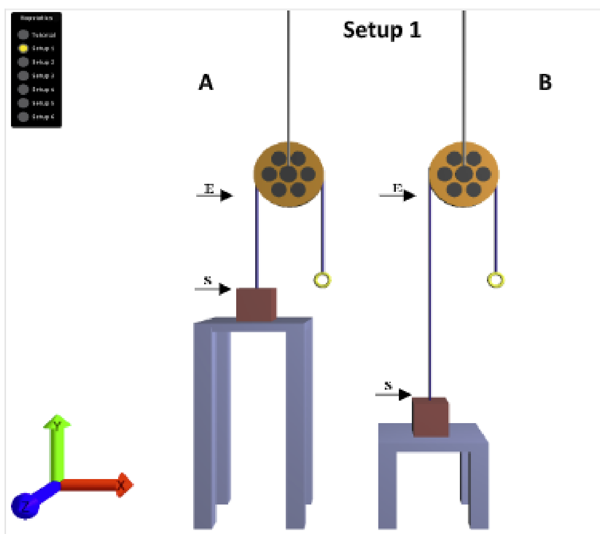
Setup 1

You are given two fixed Pulleys – *A* and *B*. Pull the rope to lift the mass attached to each pulley systems one by one and compare the forces experienced. Answer the following questions.

1. Out of the above two pulley systems, which one required a higher force to lift the mass?
   a. A
   b. B
   c. Both are equal

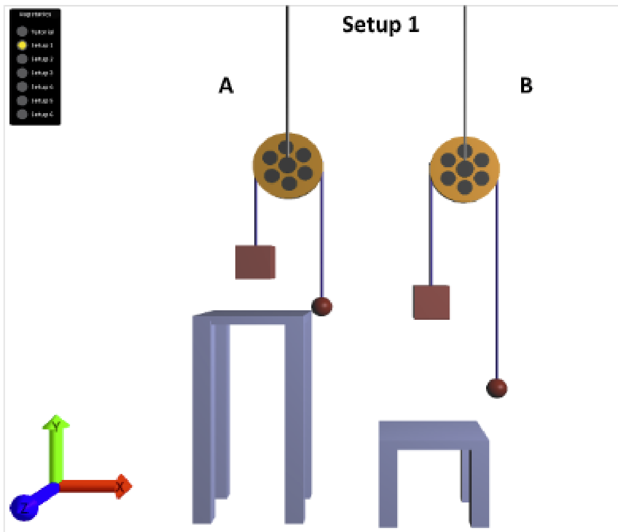
2. Please justify your answer to the previous question. You can use drawings or text to provide a complete answer.

3. Represent all the forces acting on the pulley systems (*A* and *B*) when the mass is at rest. You can draw on the picture bellow.



Setup 1 (Mass at Rest)

4. Represent all the forces acting on the pulley systems (*A* and *B*) when the mass is lifted. You can draw on the picture below.



Setup 1 (Mass is lifted)

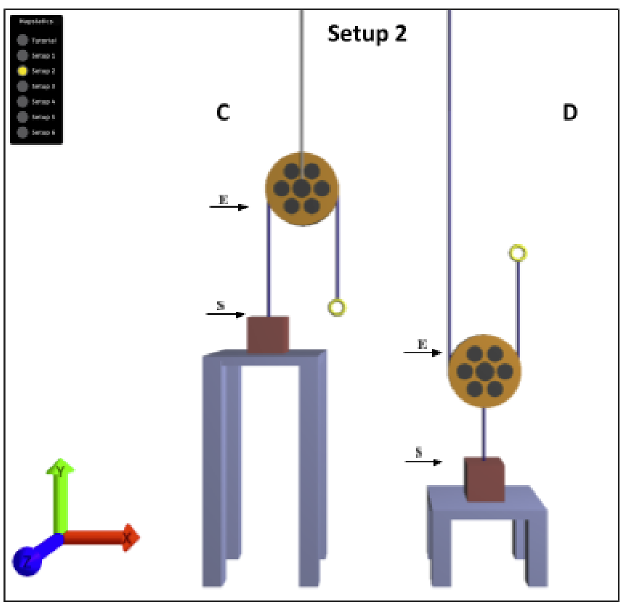
Setup 2

You are given one fixed pulley, and one movable pulley – *C* & *D*. Pull the rope to lift the mass attached to each pulley systems one by one and compare the forces experienced. Answer the following questions.

1. Out of the above two pulley systems, which one required a higher force to lift the mass?
   a. C
   b. D
   c. Both are equal

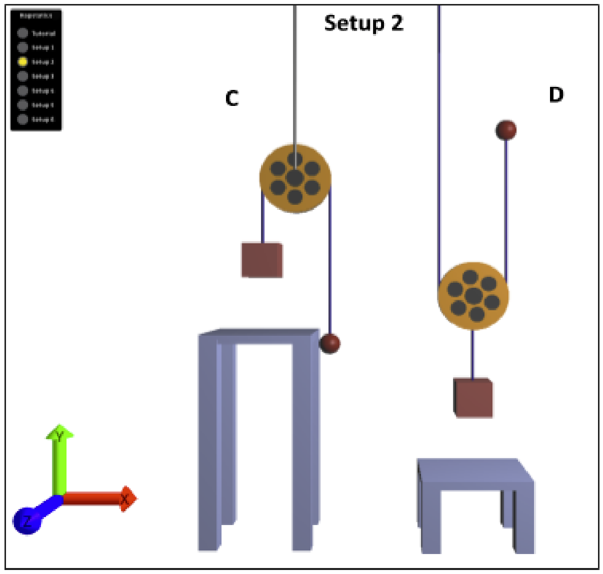
2. Please justify your answer to the previous question. You can use drawings or text to provide a complete answer.

3. Represent all the forces acting on the pulley systems (*C* and *D*) when the mass is <u>at rest</u>. You can draw on the picture below.



Setup 2 (Mass at Rest)

4. Represent all the forces acting on the pulley systems (*C* and *D*) when the mass is lifted. You can draw on the picture below.



Setup 2 (Mass is lifted)

at Rest)

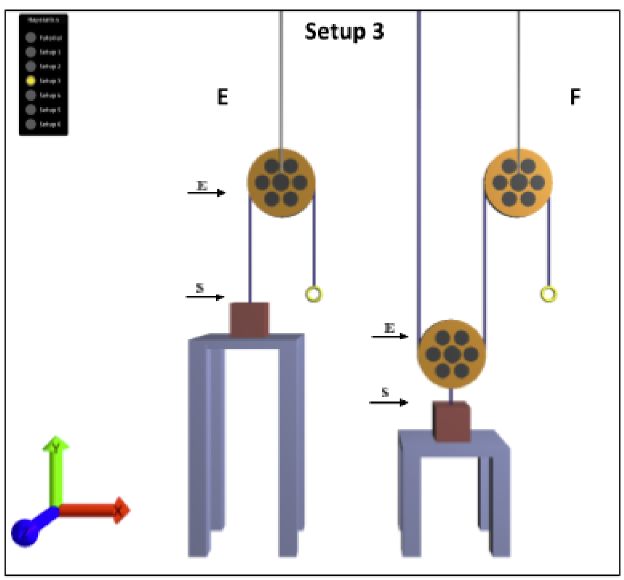
Setup 3

You are given one fixed pulley – *E* and one double pulley – *F* consisting of a fixed and a movable pulley. Pull the rope to lift the mass attached to each pulley systems one by one and compare the forces experienced. Answer the following questions.

1. Out of the above two pulley systems, which one required a higher force to lift the mass?
   a. E
   b. F
   c. Both are equal

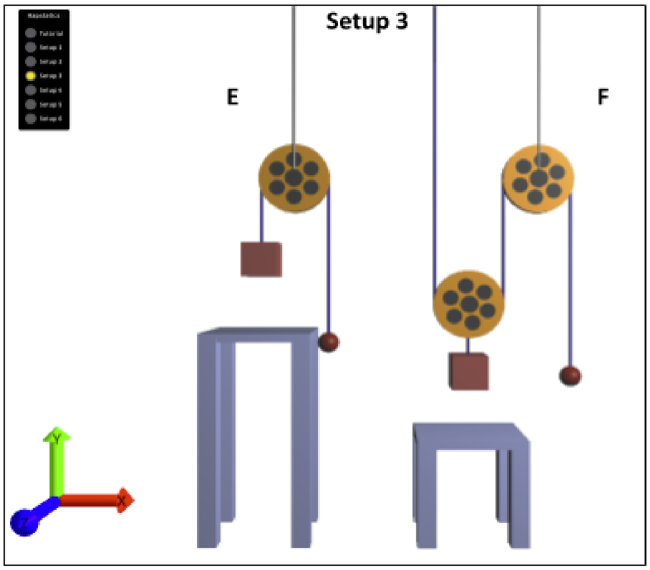
2. Please justify your answer to the previous question. You can use drawings or text to provide a complete answer.

3. Represent all the forces acting on the pulley systems (*E* and *F*) when the mass is <u>at rest</u>. You can draw on the picture below.



Setup 3 (Mass at Rest)

4. Represent all the forces on the pulley systems (*E* and *F*) when the mass is lifted. You can draw on the picture below.



Setup 3 (Mass is lifted)

at Rest)

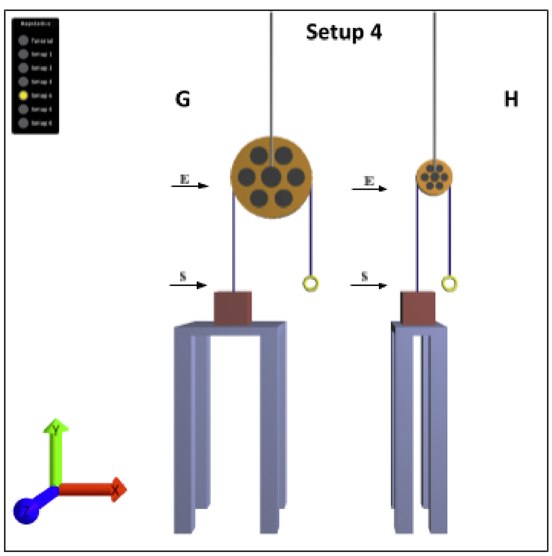
Setup 4

You are given two fixed pulleys of different sizes – *G* and *H*. Pull the rope to lift the mass attached to each pulley systems one by one and compare the forces experienced. Answer the following questions.

1. Out of the above two pulley systems, which one required a higher force to lift the mass?
   a. G
   b. H
   c. Both are equal

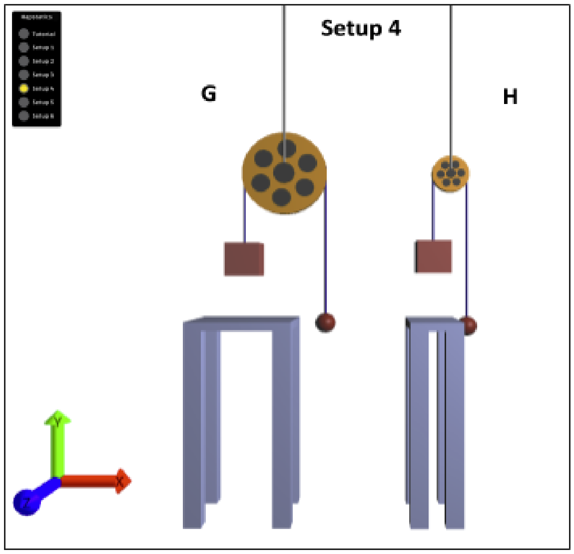
2. Please justify your answer to the previous question. You can use drawings or text to provide a complete answer.

3. Represent all the forces acting on the pulley systems (*G* and *H*) when the mass is <u>at rest</u>. You can draw on the picture below.



Setup 4 (Mass at Rest)

4. Represent all the forces acting on the pulley systems (*G* and *H*) when the mass is <u>lifted.</u> You can draw on the picture below.



Setup 4 (Mass is lifted)

at Rest)

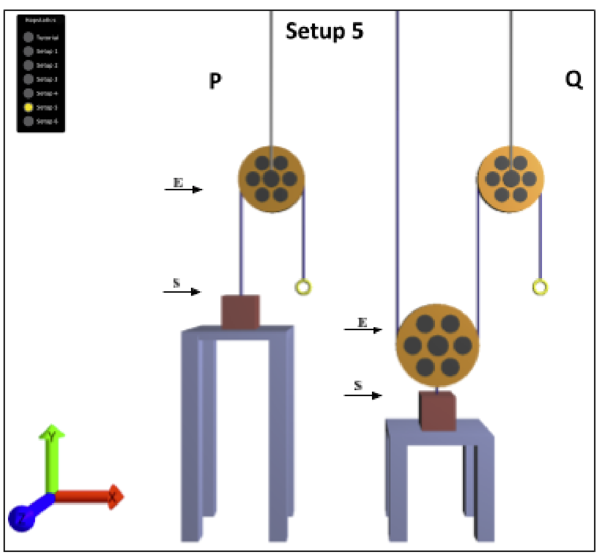
Setup 5

You are given one fixed pulley – *P* and a double pulley – *Q* consisting of a fixed and a movable pulley of different sizes. Pull the rope to lift the mass attached to each pulley systems one by one and compare the forces experienced. Answer the following questions.

1. Out of the above two pulley systems, which one required a higher force to lift the mass?
   a. P
   b. Q
   c. Both are equal

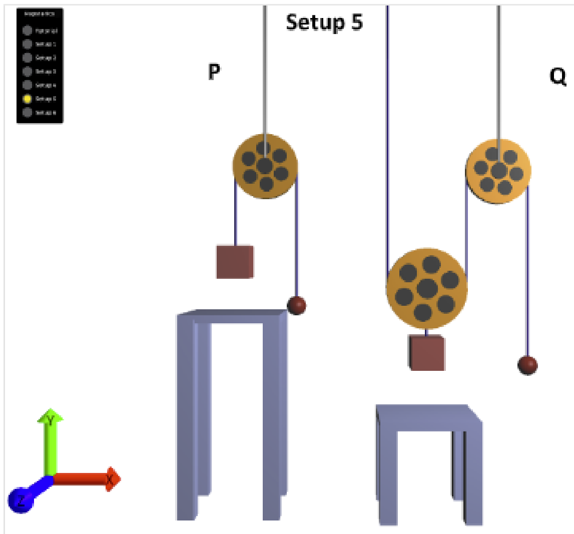
2. Please justify your answer to the previous question. You can use drawings or text to provide a complete answer.

3. Represent all the forces acting on the pulley systems (*P* and *Q*) when the mass is <u>at rest</u>. You can draw on the picture below.



Setup 5 (Mass at Rest)

4. Represent all the forces acting on the pulley systems (*P* and *Q*) when the mass is <u>lifted</u>. You can draw on the picture below.



Setup 5 (Mass is lifted)

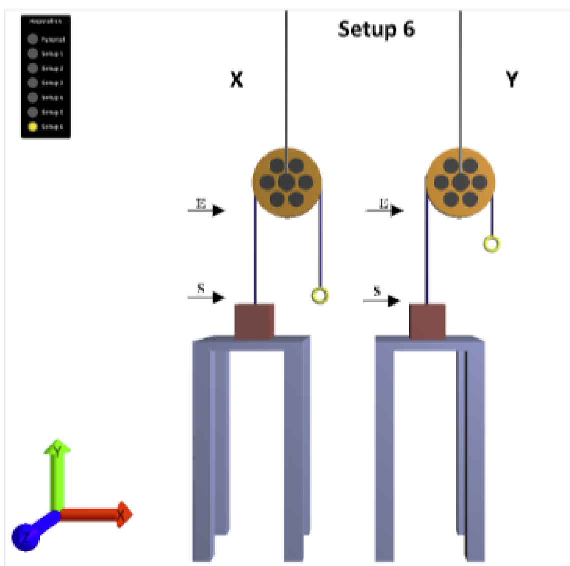
Setup 6

You are given two fixed Pulleys – *X* and *Y*. Pull the rope to lift the mass attached to each pulley systems one by one and compare the forces experienced. Answer the following questions.

1. Out of the above two pulley systems, which one required a higher force to lift the mass?
   a. X
   b. Y
   c. Both are equal

2. Please justify your answer to the previous question. You can use text or drawings to provide a complete answer.

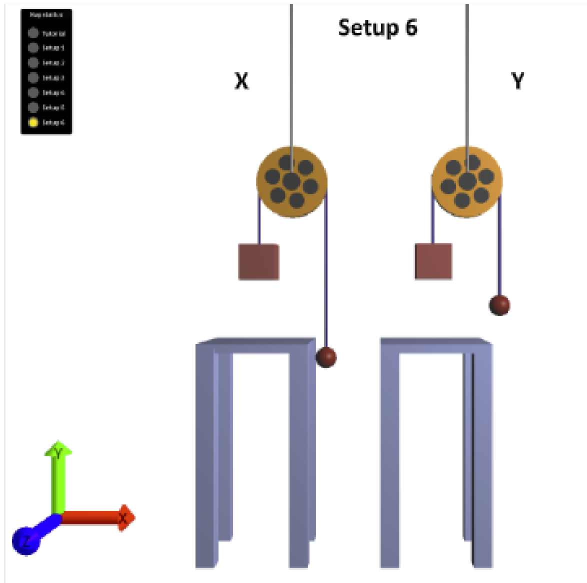
3. Represent all the forces acting on the pulley systems (*X* and *Y*) when the mass is <u>at rest</u>. You can draw on the picture below.



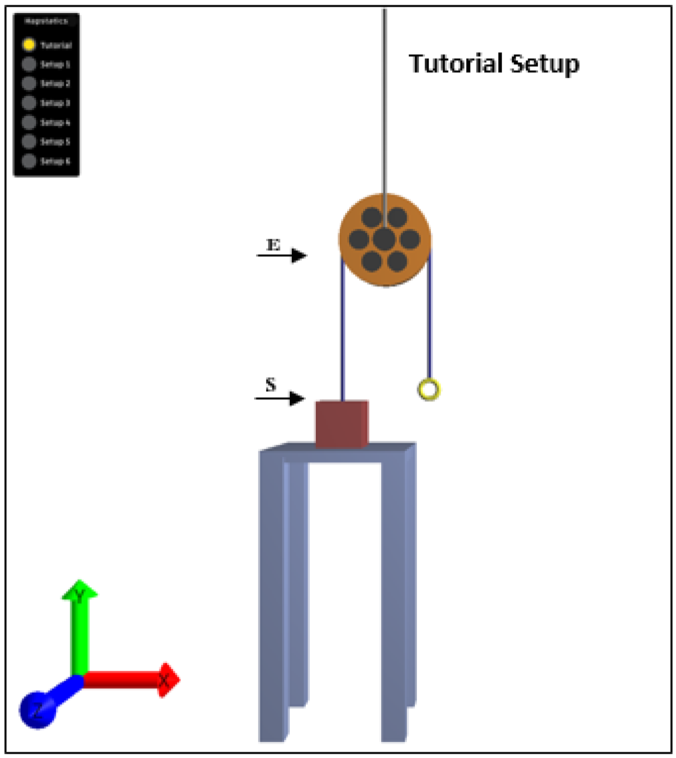
Setup 6 (Mass at Rest)

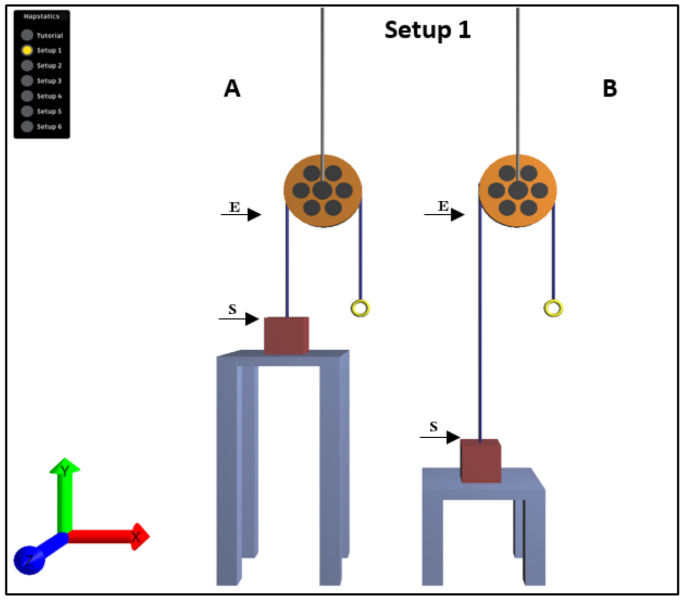
4. Represent all the forces acting on the pulley systems

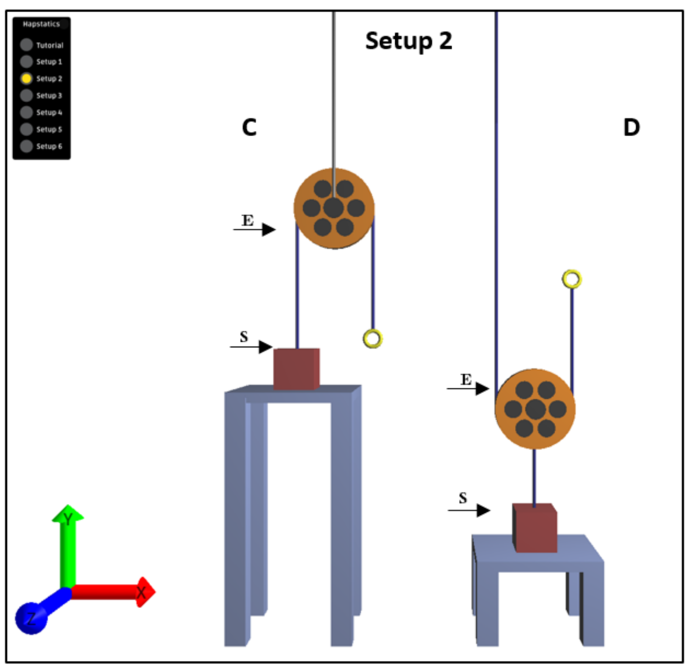
(X and Y) when the mass is lifted. You can draw on the picture below.

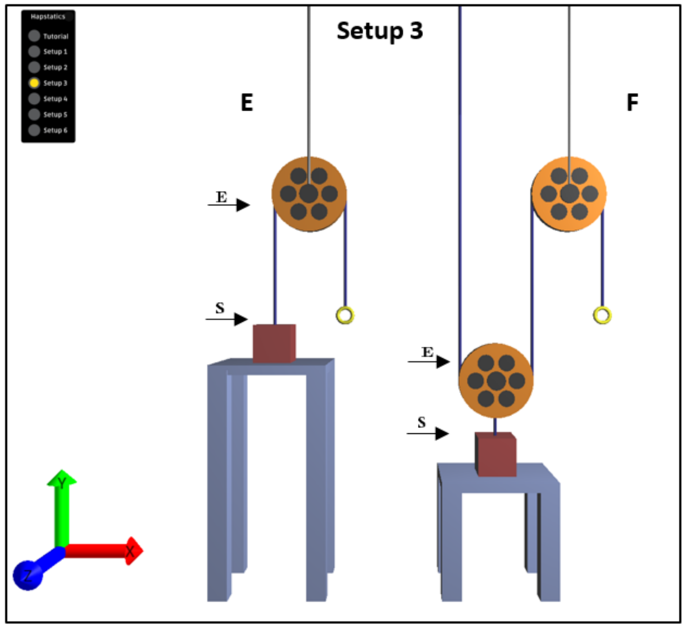


Setup 6 (Mass is lifted)


Tutorial Setup
E
S
Y
X
Z


Setup 1
A
B
E
S
E
S


Setup 2
C
D
E
S
E
S


Hapstatics
Tutorial
Setup 1
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Setup 3
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Setup 5
Setup 6
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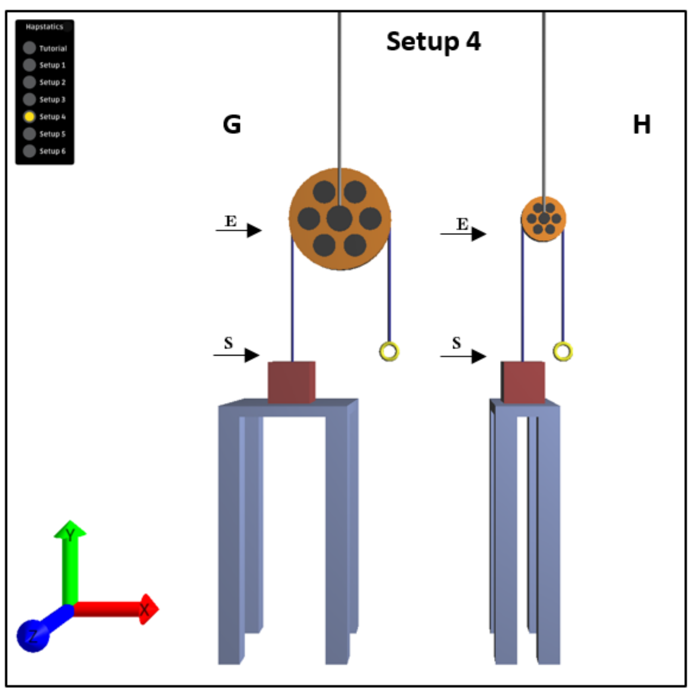
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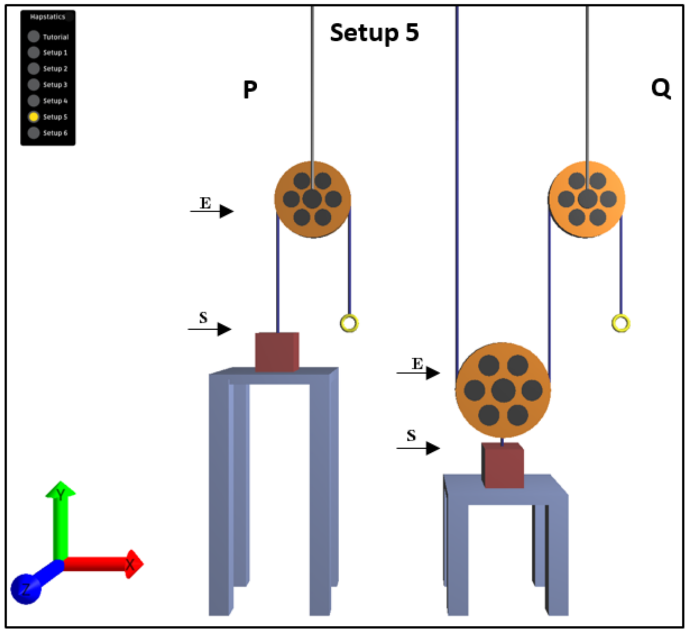

Hapstatics
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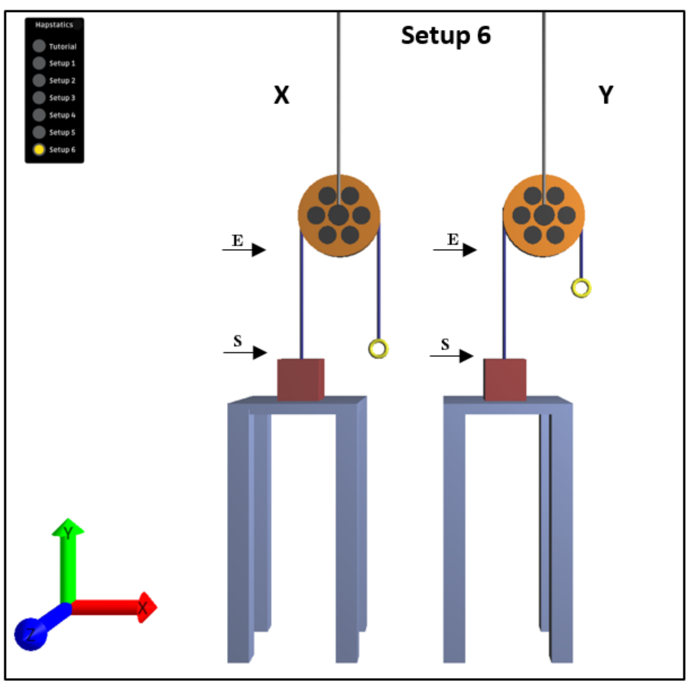

Hapstatics
Tutorial
Setup 1
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Setup 6
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X
Z

APPENDIX E. PRE-TEST & POST-TEST

FALL 2018

PULLEY PRE-TEST

Last Name:		First Name:		Date:
Lab Section: 9 AM	2.30 PM	Laptop #		Time:
Gender: Female	Male	Prefer not to say		

1.a. Please indicate your **academic major**
Elementary Education
Mechanical Engineering Technology
Engineering Technology
Other:

1.b. Please indicate your **academic level**
Freshman
Sophomore
Junior
Senior
Graduate Student

1.c. Please rate each statement below on the scale provided, by circling your choice:

I feel confident about my understanding of concepts of pulleys.	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
I know about haptic technology.	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
I know about physical measurement instruments like force scale, ruler, etc.	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

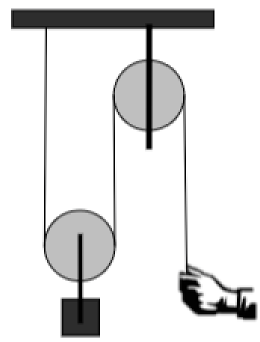
1.d. Please list any **high school physics courses** you have taken. If you have not taken any high school physics courses, please write "None".

1.e. Please list any **undergraduate physics courses** you have taken. If you have not taken any undergraduate physics courses, please write "None".

Instructions: For multiple choice questions, read carefully and choose the best answer. After each question justify your answer, please write in complete sentences and explain your ideas fully and clearly.

Important: All the situations are in an environment with ***no friction. The rope and the pulleys are weightless.***

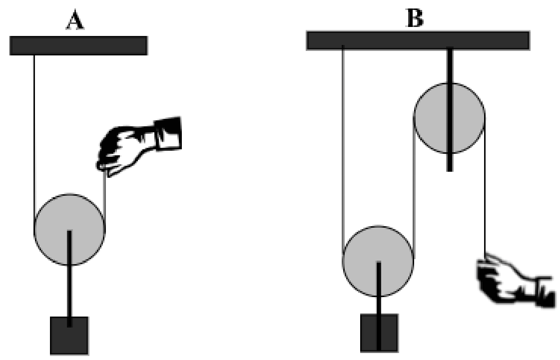
1) Which condition will require *less applied force* to lift an object to a height of 1 meter – using the pulley shown or lifting the object straight up by hand?



A) Using the pulley
B) Lifting it straight up
C) Both using the pulley or lifting it straight up require the same applied force
D) Not enough information to decide

Please justify your answer to the previous question. You can use drawings or text to provide a complete answer.

2) Which of the following pulley systems will require *less applied force* to lift the load?



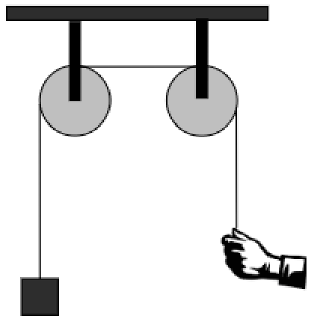
A) Pulley set-up A
B) Pulley set-up B
C) Both A and B will require the same applied force
D) Not enough information to decide

Please justify your answer to the previous question. You can use drawings or text to provide a complete answer.

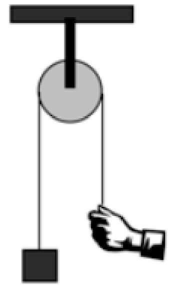
3) The easiest way to reduce the applied force using a pulley systen: is to have a system with:
A) More pulleys
B) A greater amount of rope
C) Pulleys with a wide diameter
D) More strands that support the load

Please justify your answer to the previous question. You can use drawings or text to provide a cor·plete answer.

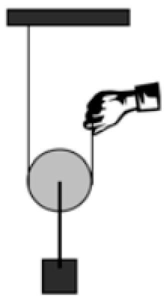
4) Which one of the following pulley systems will require the *least applied force* to lift a load to the same height?



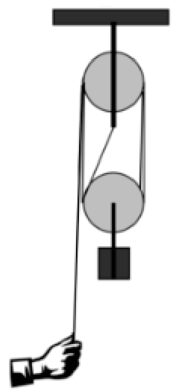
A) Two fixed pulleys



B) One Fixed pulley



C) One movable pulley



D) Double compound pulley

Please justify your answer to the previous question. You can use drawings or text to provide a complete answer.

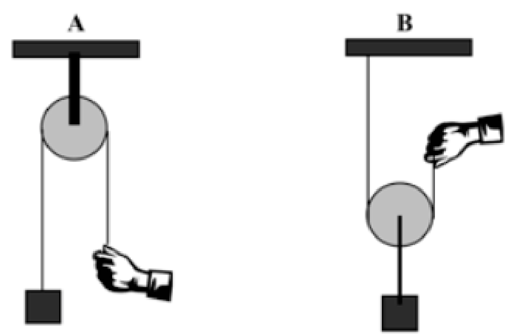
5) You used a single fixed pulley to lift a watermelon to your tree house. If you use a single movable pulley to move the same watermelon into the same tree house:

5.1) the *distance pulled* would:
A) Increase
B) Decrease
C) Stay the same
D) Not enough information to answer

5.2) the *applied force* would:
A) Increase
B) Decrease
C) Stay the same
D) Not enough information to decide

Please justify your answer to the previous question. You can use drawings or text to provide a complete answer.

6) Which one of the following pulley set-ups will give *more mechanical advantage*?



A) Pulley set-up A
B) Pulley set-up B
C) Both set-up will give you the same mechanical advantage
D) Not enough information to decide

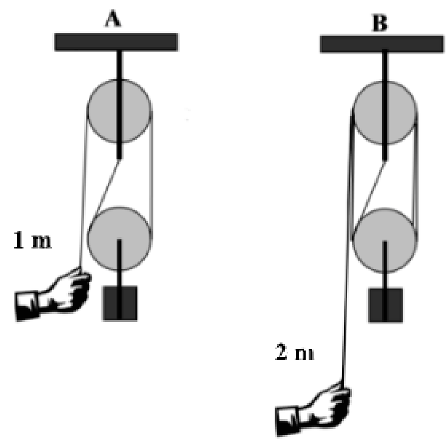
Please justify your answer to the previous question. You can use drawings or text to provide a complete answer.

7) Which of the following causal chairs r ost accurately represerts the relationships between MA, applied force, and distance pulled? (The syrr.bol " " means leads to.)
A) Greater MA less applied force and less distance pulled
B) Less MAgreater applied force and less distance pulled
C) Less MA less applied forceand greater distance pulled
D) Greater MAgreater applied forceand greater distance pulled

Please justify your answer to the previous question. You can use drawings or text to provide a cor plete answer.

APPENDIX F. TRANSFER TEST

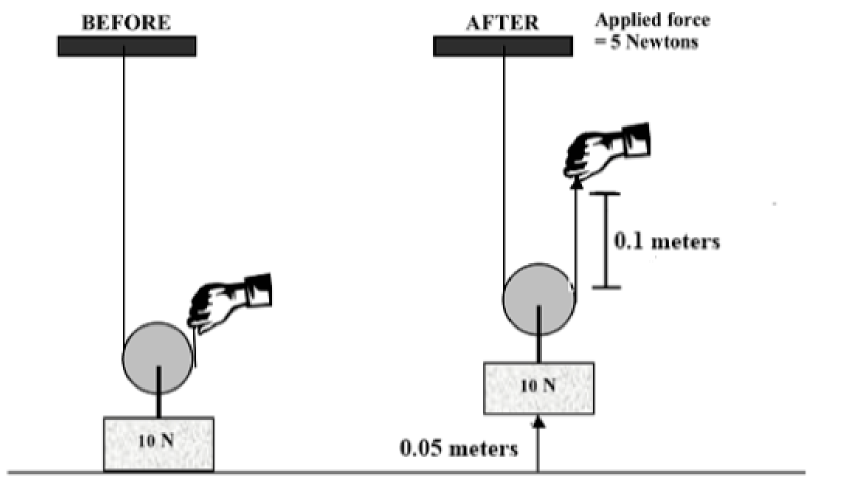
8) Lindsey lifts a load using a single compound pulley, by pulling a distance of 1m. John lifts the load to the same height using a double compound pulley by pulling a distance of 2m. Which one of them is using the *least amount of applied force* to lift the load?



A) Lindsey is using less applied force
B) John is using less applied force
C) Both are applying the same amount of force
D) Not enough information to decide

Please justify your answer to the previous question. You can use drawings or text to provide a complete answer.

9) Below is a picture of a load being lifted with the help of a pulley:

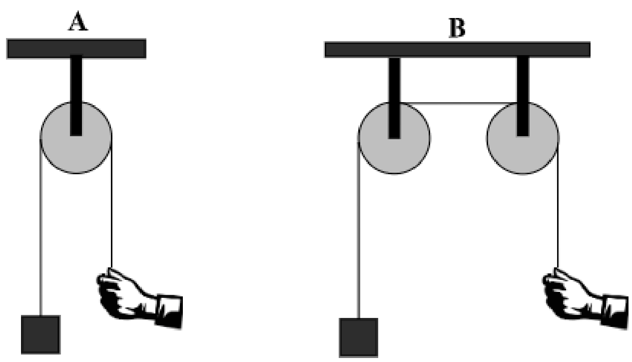


9.1) The distance the load moves is:
A) 0 .05 meters
B) 0.1 meters

9.2) The distance pulled is:
C) 0 .05 meters
D) 0.1 meters

Please justify your answer to the previous question. You can use drawings or text to provide a complete answer.

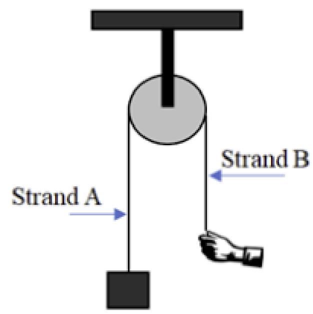
10) Which one of the following pulley set-ups will give *more mechanical advantage*?



A) Pulley set-up A
B) Pulley set-up B
C) Pulley set-up A and Pulley set-up B will give you the same mechanical advantage
D) Not erough ir.forn ation to decide

Please justify your answer to the previous question. You can use drawings or text to provide a complete answer.

11) Use the following diagram of a fixed pulley to answer the questions below:



11.1) Which of the following strands is supporting the load with lifting using this pulley?
A) Strand A only
B) Strand B only
C) Both Strands A and B are supporting the load equally
D) Strand A is supporting the load more than Strand B

If the load is 12N:

11.2) How much weight is Strand A supporting?

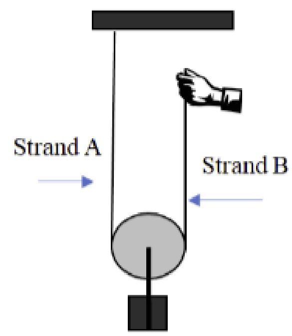
A) 12N	C) 4N
B) 6 N	D) 0N

11.3) How much weight is Strand B supporting?

A) 12N	C) 4N
B) 6N	D) 0N

Please justify your answer to the previous question. You can use drawings or text to provide a complete answer.

12) Use the following diagram of a movable pulley to answer the questions below:



12.1) Which of the following strands is supporting the load using this pulley?
A) Strand A only
B) Strand B only
C) Both Strands A and B are supporting the load equally
D) Strand A is supporting the load more than Strand B

If the load is 12N:

12.2) How much weight is Strand A supporting?

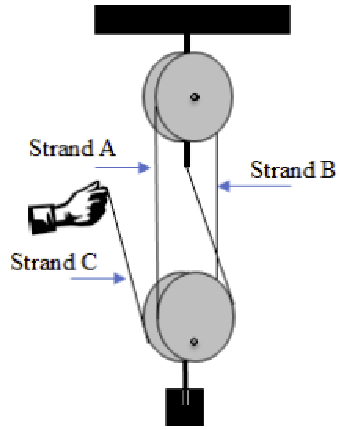
A) 12N   C) 4N
B) 6 N   D) 0N

12.3) How much weight is Strand B supporting?

A) 12N   C) 4N
B) 6N   D) 0N

Please justify your answer to the previous question. You can use drawings or text to provide a complete answer.

13) Use the following diagram of two double pulleys to answer the questions below:



13.1) Which of the following strands is supporting the load with lifting using this pulley?
A) Strands A and B only
B) Strands B and C only
C) Strands A, B, and C are supporting the load equally
D) Strands A and B are supporting the load more than Strand C

If the load is 12N:

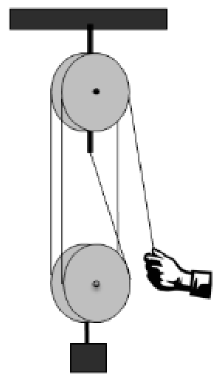
13.2) How much weight is Strand A supporting?
A) 12N C) 4N
B) 6 N D) 0N

13.3) How much weight is Strand B supporting?
A) 12N C) 4N
B) 6N D) 0N

13.4) How much weight is Strand C supporting?
A) 12N C) 4N
B) 6 N D) 0N

Please justify your answer to the previous question. You can use drawings or text to provide a complete answer.

14) You are trying to lift a heavy object that weights 1,000N using a double compound pulley (see diagram below).



Using the double compound pulley set-up above:

14.1) How much applied force will it take to lift the 1,000N load?

A) 1,000N	C) 250N
B) 500N	D) 0N

14.2) How far would you need to pull to lift the object 20 meters?

A) 100m	C) 40m
B) 80m	D) 20m

Please justify your answer to the previous question. You can use drawings or text to provide a complete answer.

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