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THE EFFICIENCY OF USING THREE-DIMENSIONAL MODELS TO TEACH LIFTING AND RIGGING CONCEPTS TO LEARNERS OF VARYING SPATIAL ABILITY

Matthew Atherton

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A Thesis

Presented to the

Faculty of

California State University,

San Bernardino

In Partial Fulfillment

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Master of Arts in Education:

Instructional Technology

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by

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ABSTRACT

In the literature on instructional media and its effects on learning, there is debate regarding whether a particular choice of media is essential for any given learning task. However, most studies that show conflicting results have not accounted for a differentiating learner characteristic known as spatial ability and its impact on the learner's cognitive load when visualization is required. In this study, the interaction between instructional media and the learner's spatial ability (specifically, their spatial visualization ability) was examined when the learner was required to work out a rigging problem in one of three ways: by manipulating a physical 3D model, by drawing their own visualization using paper and pencil, and by working through the problem with no additional intervention beyond the instructional video that all participants viewed. Prior to exposure to the rigging problem, each participant was given the Purdue Visualization of Rotations Test to determine a low or high spatial ability. When tested on the material after the learning task was completed, participants with high spatial ability performed higher than participants with low spatial ability, regardless of the treatment type. Some participants with low spatial ability who manipulated the 3D models scored so high, however, that they had to be marked as outliers and removed from the statistical analysis. The results of high performance by participants with high spatial visualization ability are consistent with prior research on spatial ability, and the high

performance of outliers with low spatial visualization ability suggest that further investigation beyond this pilot study is merited.

ACKNOWLEDGMENTS

I would like to thank Dr. Eun-ok Baek for her careful guidance and feedback during all stages of this thesis. Without her willingness to be my champion, this study would not have been possible.

I cannot thank Dr. Emily Wickelgren enough for her help from the very beginning of this endeavor. Her experience and advice allowed me to sidestep more than a few pitfalls into which I would have easily fallen, and her willingness to listen during my struggles to assimilate the vast body of knowledge relevant to the study was a great help and comfort.

I am deeply grateful to Dr. Barbara Sirotnik for her feedback and guidance on my statistical analysis of the data. Her willingness to spend time with me to go over all of the assumptions required for the factorial ANCOVA gave me the confidence to proceed, despite my inexperience with performing such high-level statistical work.

Lisa Bartle of the Pfau Library was also invaluable, and I benefited greatly from her guidance on the research and her advice on the very first draft of the research proposal.

DEDICATION

This thesis is dedicated to all the men and women who work tirelessly to train our people in the rigging and lifting industry so that they can leave the job site at the end of the day and return safely to their families.

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CHAPTER ONE

BACKGROUND

Introduction

With limited time, space, and funding, what is the most effective way to instruct learners in a given subject? The answer to that question must certainly depend largely on the subject: for instance, learning how to swim from reading an illustrated textbook without access to a body of water is arguably not the most effective method. While the temptation to change the media from illustrations to an animation of a swimmer might improve the learner's understanding of swimming technique, such instruction is still not teaching the learner how to swim.

Important, too, are the characteristics of the learners themselves (Bell, Tannenbaum, Ford, Noe, & Kraiger, 2017). Instructional methods that depend heavily on familiarity with a particular language are going to be largely ineffective for a learner who does not understand the language, just as a visually impaired learner will find little value in an instructional method that is largely visual. Spatial ability is a learner characteristic that relates to how individuals process visual information (Carroll, 1993, Juhel, 1991), and while it may not affect a learner's ability to read or perform calculations, it is a characteristic that is particularly relevant when learning rigging and lifting concepts via presentations of three-dimensional scenarios in the form of two-dimensional drawings. Research has provided evidence that learners with low spatial ability might have the disadvantage of a higher cognitive load when learning from a two-dimensional drawing that must be comprehended as a three-dimensional representation (Höffler & Leutner, 2011).

The environment in which the learning will be applied must also be considered. As with instructing a learner in the basic concepts of swimming, instructing a learner in the concepts of rigging and lifting anticipates the use of those fundamental skills in a demanding physical environment. In the rigging and lifting industry, even a small mistake can put a life in danger. Equipment that is defective, poorly selected, or improperly connected can mean the difference between everyone returning home safely at the end of the day or the loss of life. Even in cases where no one is injured, poor decisions resulting from inadequate training can lead to the loss of hundreds of thousands of dollars.

Learning the fundamentals of rigging is accomplished through specialized training, ranging from online training, to in-person training seminars, to individual training with an expert. The topics include the proper use and inspection of slings (the lengths of wire rope, synthetic webbing, or steel chain that connect rigging components), the load capacities of specific equipment, and the reductions of those capacities when the equipment is angularly loaded or when other conditions apply. Particularly demanding topics include a mastery of sling angles, load angle factors, and the correct calculation of sling tension based on the angle of loading.

The most effective means to master these concepts is the primary goal of this study. While the availability of a personal instructor might be of great benefit, a novice may not yet have enough concrete experience to take advantage of the presentation of abstract concepts that relate to the material being taught (Dale, 1969). Individual instruction might allow for a greater incorporation of hands-on experiences than a classroom environment or online course could offer, however, the question of whether such hands-on experiences promote learning is still up for debate.

Statement of the Problem

With such a variety of formats, a natural question is whether these existing training formats are sufficient, and if not, is it likely that the addition of different media will increase their effectiveness? There was a great debate regarding the ability for media to influence learning (Clark, 1983 & 1994, Kozma, 1991 & 1994, and Mueller, 1999), and this study attempts to contribute to that debate.

In the 1980's, Richard Clark made the assertion that learning was not influenced by the type of instructional media used for instruction (1983), and years later, in the early 90's, Robert Kozma was compelled to argue against Clark's declaration, citing that different media could enhance content in a way that allowed learners with certain characteristics to learn the material more efficiently (1991). The two researchers battled back and forth for several years, specifically addressing one another in articles that cited the results of several studies supporting their own opposing viewpoints. In these arguments they differentiated the value of instructional media (the materials used to provide instruction) from the value of instructional methods (the techniques used by instructors to impart learning). However, in the end, the argument became one of semantics, as they seemed to agree that even if no unique method or medium were particularly essential to learning, different methods of instruction (which might involve different media) could indeed improve the efficiency or effectiveness of learning in various circumstances.

The circumstance that this study attempts to address is the need to learn content that requires the comprehension of three-dimensional constructs. The specific characteristic that will be examined is the cognitive aptitude of spatial ability, which involves the processing of visual information as measured by the Purdue Visualization of Rotations Test (Guay, 1977). This concept will be discussed more fully in the following pages.

Whether it is described as media or method, the availability of relatively inexpensive 3D printers provides a new option for education and industrial training, giving learners the opportunity to interact with functional 3D models. No longer is it necessary to rely solely on two-dimensional perspective drawings to relay three-dimensional information.

Can the use of such functional 3D scale models increase learning efficiency for learners with low spatial ability who wish to master fundamental rigging concepts? Or will an even simpler solution, such as drawing the problem with paper and pencil, be just as effective? Are any of these additional interventions needed at all?

Purpose of the Project

The purpose of the project was to examine the role of spatial ability when learners were required to work out a rigging problem in one of three ways: by manipulating a physical 3D model, by drawing their own visualization using paper and pencil, and by working through the problem with no additional intervention beyond the instructional video that all participants passively viewed. If one of these methods were to emerge as more effective than the others, particularly for learners with low spatial ability, then an argument could be made for implementing such an instructional strategy on a large scale for the training of fundamental lifting and rigging concepts.

Research Questions

Given the established correlation between high spatial ability and high achievement in learning chemistry and mathematics (Stull, Hegarty, Dixon & Stieff, 2012, Wu & Shah, 2004), are the individuals who seek training in the fundamental concepts of rigging and lifting more likely to have low spatial ability or high spatial ability? It seems logical that individuals who did not experience high achievement in school subjects such as mathematics and chemistry would gravitate toward more hands-on pursuits.

Do learners with low spatial ability have higher learning outcomes when given 3D models to manipulate as opposed to simply drawing solutions with paper and pencil? Although having low spatial ability may make it more difficult to process visual information, and therefore more difficult to benefit from the use of sketching as a learning technique, perhaps an active-learning task is all that is required to achieve scores that reflect better understanding of the content.

Significance of the Project

Because the cost of failure is so high in the rigging and lifting industry, any potential improvement that allows the learner to grasp and retain the content in a safe, non-threatening environment should be explored. However, this study also has the potential to contribute to the explanation of often conflicting results that are found in studies concerning the effectiveness of the use of manipulatives and models in instruction. Perhaps the results would be less conflicting if those studies had controlled for the variable of spatial ability when learning entails visuospatial processing.

Limitations

During the development of the project, a number of limitations were noted. These limitations are presented in the next section and are expanded upon in the discussion of the findings.

The most significant limitation is the number of participants. With the experiment involving the physical manipulation of objects, a physical environment was required, making a larger pool of subjects unavailable, as might have been possible with a study conducted on-line, for instance. The course schedule at the instructional facility where the trials would take place, the willingness of the instructors to have their students participate, and the classroom size dictated the number of participants in the study.

By using classes, additional limitations to the study were also introduced. This study took advantage of a convenience sample, as is typical of many pilot studies, and therefore introduced a bias toward individuals who were motivated to enroll in continued education. The desired sample would be actual riggers who were required to know this information to complete job-related tasks.

Another significant limitation of the study is its narrow focus on training for the rigging and lifting industry. While the experiment was designed to account for different levels of spatial ability for each of the participants, all of the learning exercises and tests were designed to assess a learner's competence with rigging equipment. These findings may not apply to instruction of subjects that are less focused on physical interactions with equipment.

Additional limitations for the study will be reviewed in the discussion of the findings, as they pertain to the instruments that were used, classroom behaviors that were observed, and decisions made in the data analysis.

Definition of Terms

The following terms are defined as they apply to the project.

Spatial ability is a cognitive aptitude that consists of several different factors, two of which (spatial relations and spatial visualization) require complex sequences of mental manipulations and place a high demand on executive function (Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001).

Rigging, when used as a noun, is the equipment used in the material handling industry to connect a load to the hook of a crane, or in some cases, to the hooks of multiple cranes that will perform a coordinated lift together. When used as a verb, rigging is the process used to secure materials intended to be lifted by a crane or hoist.

Lifting is the act of picking up a load in the material handling industry, and if not done properly can lead to the loss of life or property if the lifting process fails and an uncontrolled load breaks free from its rigging.

Cognitive load is the demand that is placed on cognitive processes when a learner is attempting to comprehend a concept or learn a new task (Paas, Renkl, & Sweller, 2004).

Instructional media are defined as the materials used to provide instruction. Some examples include textbooks, models, manipulatives, audio recordings, computer graphic animations, video, and computer simulations.

Instructional methods are the techniques used by instructors to impart learning in their students. Some examples are the use of worksheets, quizzes, reading, flash cards, model-building, drawing, using manipulatives, discussion, journal-writing, and lectures.

Passive learning is learning that does not require the learner to take an active part in consuming the learning content (Chi, 2009). Examples would be watching a video or reading a textbook.

Active learning is learning that requires some type of active participation in comprehending the learning content (Chi, 2009). Examples can range from simple note-taking (consolidation of concepts into abbreviated form) to sketching diagrams or the manipulation of 3D models.

Constructive learning requires the learner to create something new that is beyond the learning materials with which they were presented (Chi, 2009).

Interactive learning is learning that occurs through collaboration with others, such as verbally interacting with an instructor or other students to discuss a concept, where all parties involved in the interaction are actively and equally contributing (Chi, 2009).

Manipulatives are physical objects that can be used to represent either abstract concepts (such as the manipulatives in mathematics to represent quantities) or more elaborate physical models used to enhance the learning process, such as the balls and sticks used in chemistry to represent molecular structures.

3D models can refer to either virtual models that are represented in three dimensions on a computer screen, or to physical models, such as those that are printed with a 3D printer. Functional 3D models are physical 3D models that can be manipulated in the same way as the objects they represent, only perhaps on a smaller scale. An example is a threaded bolt that can be screwed into another component (and later disconnected), as opposed to a model where the bolt and secondary component are fused together in a single 3D structure.

3D printing is the technology used to create a physical object through an additive process of fusing multiple layers of material. The 3D-printed model must exist as a virtual 3D model before it can be printed, so that its geometry can be separated into different printable layers.

3D animation is the technology used to create moving graphics that represent three-dimensional objects by displaying a series of images on a two-dimensional screen. The illusion of viewing the object in three dimensions is maintained through the use of perspective and shading, taking advantage of the visual cues to which the brain's visuospatial processing system is already predisposed.

CHAPTER TWO

REVIEW OF THE LITERATURE

Introduction

Chapter Two consists of a discussion of the relevant literature. Specifically, the debate of media versus method, the research on spatial ability, and research on hands-on learning.

Media vs. Method

The debate over the influence of media on learning is central to the purpose of this study.

One of the first significant attempts to create a visual metaphor for the different types of media was put forth by Edgar Dale in 1946. Dale referred it as the Cone of Experience (Dale, 1969), and without ascribing value to one type of media over another, simply expressed the continuum of media from more concrete sensory experience to more abstract experience.

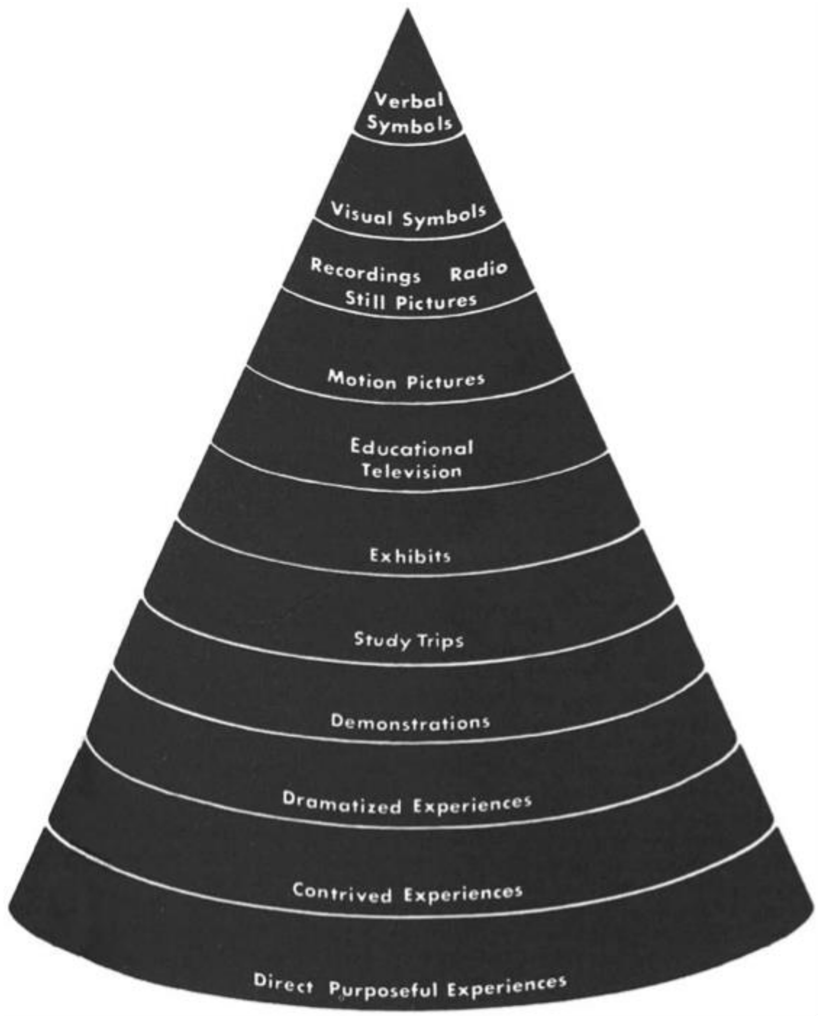

Figure 1. Edgar Dale’s Cone of Experience

Edgar Dale’s Cone of Experience, as Presented in Audiovisiual methods in teaching.3rd ed. p 107 (Dale, 1969) (earlier versions did not include television). Figure extracted from “Edgar Dale’s Pyramid of Learning in medical education: A literature review.” (Masters, 2013).

A derivation of Edgar Dale’s Cone of Experience (some would say a “corruption” of it) is the Learning Pyramid, which has been used for many years as a prescriptive tool for creating learning experiences and has often been adapted to emphasize experiential learning (Lalley & Miller, 2007). The Learning Pyramid attributes higher learning retention percentages to more concrete learning experiences, however, the specific retention percentages are not supported by research (Lalley & Miller, 2007; Masters, 2013; Subramony et al., 2015).

The Cone of Experience was never intended as a hierarchy (Dale, 1969). Instead, its conical shape was meant to convey the loss of sensory information as experience goes from the concrete to the abstract (Subramony et al., 2015). And while the numbers within the Learning Pyramid may have dubious origins, research provides support that superior learning can be achieved by more concrete experiences in certain contexts, including the simulation of a real experience (Hamilton, 2016).

Yet, in 1983 Richard Clark famously issued the proclamation that “media will never influence learning,” comparing media to delivery vehicles that have no influence on the quality of the instructional content they deliver and asserted that there is no media that is a necessary condition for learning (Clark, 1983). Clark’s opponents, including Robert Kozma, maintained that different media interact with learner and task characteristics that do, in fact, influence cognitive processes (Kozma, 1991), and asserted that the “processing capabilities of a medium can complement those of the learner; they may facilitate operations the learner is capable of performing or perform those that the learner cannot” (Kozma, 1991, p. 181-182). While Clark’s rebuttal maintained that learning gains in such instances are best characterized as a change in instructional method, (Clark, 1994), he essentially acknowledged that learning gains can indeed arise from such a shift, though he still challenged Kozma and his colleagues to provide a well-designed study that did not confound a media change with a change in method.

Whether the proposed changes in this study are characterized as changes in media or changes in method, the goal of this study is to determine if such changes can provide significant value to the learner. In this study, the operation being facilitated is the building of mental models through comprehension of two-dimensional drawings that represent three-dimensional scenarios. Any media attributes that can result in improved comprehension and learning outcomes are of interest. Such comprehension may be more difficult for learners who have low spatial ability, which will be discussed in the next section.

Spatial Ability

Spatial ability is a cognitive aptitude that consists of several different factors: spatial relations, spatial visualization, closure flexibility, closure speed, and perceptual speed (Carroll, 1993). Two of these sub-divisions, spatial relations and spatial visualization, require complex sequences of mental manipulations, and according to Miyake et al. (2001), are the two factors that place the highest demand on executive function. Spatial visualization is of particular interest when anticipating a learner's "processes of apprehending, encoding, and mentally manipulating spatial forms" (Carroll, 1993, p. 309), and is the factor that is most relevant to a learner's ability to comprehend two-dimensional representations and three-dimensional physical scenarios (Höffler & Leutner, 2011, and Hegarty, 2004).

In a study designed to examine the role of spatial visualization on learning with dynamic and non-dynamic visualizations, Höffler and Leutner (2011) found that an optimal instructional design will help "students with low spatial ability to build an effective mental representation of the learning content" (2011, p. 212). The researchers also found that providing an animation compensated for spatial-ability deficits among the participants in the learning task. Although tests for the factor of spatial relations did not show an interaction, the test used for the factor of spatial visualization did. An earlier experiment by Huk (2006) supported an opposite finding, namely, that "in the case of low spatial ability, the presence of 3D models may more easily lead to cognitive overload" (p. 402). However, Huk's study involved not passive, but interactive computer-generated 3D models designed to assist in the understanding of cell biology, and it may be that the interactivity of the learning environment created the high cognitive load, and not necessarily the 3D visualization.

Huang (2017) provided support for the use of 3D-printed models and hands-on activities with these models as a way of both improving spatial ability through hands-on learning and improving learning outcomes in tasks that involve the creation of 3D computer models. Huang proposes that, as the difficulty of a modeling task increases, the need for hands-on manipulation of 3D physical models increases, allowing the user to view the model at various angles and gain a tactile experience of it. While learners with high spatial ability may not benefit greatly from the use of the models, learners with low spatial ability should be given teaching aids that focus on practical operation, especially when the difficulty of the task is high (Huang, 2017).

Hands-On Learning

Much as Edgar Dale identified a continuum for different types of media from the concrete to the abstract, Michelene Chi provides a framework that differentiates learning activities along a continuum from passive to interactive. Chi (2009 & 2014) offers support for the assertion that active learning activities are more effective than passive learning activities, that constructive learning activities are more effective than active ones, and that interactive learning experiences are even more effective than constructive learning activities.

Passive learning is learning that does not require the learner to take an active part in consuming the learning content (Chi, 2009). Watching a video, reading a textbook, or listening to a lecture without taking notes would all fall into this category.

Active learning is learning that requires some type of active participation in comprehending the learning content (Chi, 2009). Simple note-taking is an example of active learning, as is drawing a diagram or manipulating a 3D model in service to the consolidation of the concepts to which the learner has been exposed.

Constructive learning requires the learner to create something new that is beyond the learning materials with which they were presented (Chi, 2009). A certain level of content mastery is required in order to participate in this level of learning and is often not available to learners who are just being introduced to that content.

Interactive learning is learning that occurs through collaboration with others, such as verbally interacting with an instructor or other students to discuss a concept, where all parties involved in the interaction are actively and equally contributing (Chi, 2009). Unequal interaction is not considered true collaboration and is otherwise categorized as active learning for the dominant member of the interaction and passive learning for the non-dominant members.

Each study included in Chi's research used different measures for learning outcomes. In the comparison between active learning and passive learning, for instance, learners who had a chance to practice tying knots while watching an instructional video were able to learn how to tie knots more quickly than learners who watched the same video but did not have the opportunity to practice (Chi, 2009). Learners who could rotate objects in a virtual environment learned the structure of those objects better than students who only observed the objects (Chi, 2009). This active approach is also well-documented in the subject of chemistry, where physical manipulatives are often used to model molecular structures, (Gross, Erkal, Lockwood, Chen, & Spence, 2014, Stull, Hegarty, Dixon & Stieff, 2012, and Wu & Shah, 2004). Some of these unique hands-on learning activities are possible only with the use of 3D-printing, creating functional physical structures that demonstrate bond rotational barriers and allow for consideration of degrees of freedom (Gross et al., 2014).

Chi's theory is compatible with cognitive load theory in that the effectiveness of the learning activity is dependent on the cognitive demand placed on the learner (Paas, Renkl, & Sweller, 2004). By making the distinction between "intrinsic," "extraneous," and "germane," cognitive load, Pass, Renkl, and Sweller (2004), indicate that removal of "extraneous" cognitive load will result in better learning outcomes. This improvement is accomplished by allowing the learner to devote more cognitive processing toward schema construction (the categorization of elements of information) and the schema automation (the eventual unconscious processing) that will result from those processes. An argument is also made for reducing the number of interacting elements (the "intrinsic" type of cognitive load), however, this process normally manifests as a reduction in the complexity of a learning task (Paas et al., 2014), which may actually reduce the effectiveness of the lesson.

Summary

If cognitive load theory provides any guidance, it is that the removal of "extraneous" cognitive load will result in better learning outcomes. If the cognitive processes required for translation of 2D diagrams into visualizations of 3D environments are considered "extraneous," then it is natural that we would expect learners with low spatial ability to encounter less cognitive load when involved in learning activities that provide 3-dimensional ready-made visualizations or physical models.

Research in the realm of hands-on learning provides evidence for the age-old wisdom that is often attributed to Ben Franklin (some say incorrectly so): "Tell me and I will forget; Teach me and I may remember; Involve me and I will learn."

By providing direct comparisons between two active-learning interventions that may vary in their cognitive load based on the user's spatial ability, this study hopes to replicate the findings of the research reviewed, while also contributing to the body of research surrounding the use of 3D-printed models for instruction.

CHAPTER THREE

METHODOLOGY

Introduction

The purpose of this study was to gain some insight to the effectiveness of using 3D models in an instructional setting, but to do so in a way that would take into account the learner characteristic of spatial ability. To achieve this goal, an experimental instructional intervention was designed. The results of this experiment could be used to examine the correlation between spatial visualization ability test scores and final test scores, under three different conditions: a control group that would complete practice exercises without any additional resources, a group that would manipulate 3D models to work out their solutions to the practice exercises, and a group that would use pencil and paper to draw their solutions.

Population Served

In this study I conducted a quasi-experimental design using a sample of 82 students attending the classes at an OSHA Training Institute.

All participants were students in the

“OSHA Standards for the Construction Industry” course which was chosen for the interest the participants were presumed to have in the construction industry, and for the frequency with which the class was offered during the year. Ages of the subjects ranged from 19 years old to 68 years old (mean

39.8), contained a mix of males and females, and the self-reported length of time of rigging experience ranged from 0 months to 15 years.

The students of this course were chosen for the study because of the greater likelihood that they would have rigging experience, or at least some familiarity with rigging equipment, as opposed to freshman students enrolled in an introductory psychology course, for instance. Because there were no entrance requirements for the course, it was also believed the subjects would have a wider range of scores on the spatial ability test, given the established correlation between high spatial ability and high achievement in learning chemistry and mathematics (Stull, Hegarty, Dixon & Stieff, 2012, Wu & Shah, 2004). As this study hoped to provide insight on the performance of students with both low and high spatial ability, it was important to gather data from subjects with as wide a variety of spatial abilities as possible.

The trials contributing to the data set that was analyzed took place between May 8th, 2019 and October 26th, 2019. On May 8th, the trial for the drawing group was conducted from 3:00 PM to 4:15 PM. On August 21st, the trial for the control group was conducted from 3:00 PM to 4:15 PM, and on October 26th the trial for the 3D models group was conducted from 3:00 PM to 4:15 PM.

Instruments

Several instruments were obtained or created to carry out the experiment. These instruments are provided in their entirety in Appendices D - N. The first instrument was the Purdue Visualizations of Rotations test, designed to obtain a score between 0 and 20 as a measure of the subject's spatial ability (see Appendix E). This 20-question test which is designed to take ten minutes is a modified version of the original 30-question test that was designed to take 20 minutes. The modified test was developed by Dr. George Bodner and Dr. Roland Guay (1997) and permission to use the test was granted in the publication of their 1997 article in *The Chemical Educator*, suggesting that it could be used "as a research instrument for work on students' abilities to use multiple representations or to probe alternative modes whereby students solve problems" (Bodner & Guay, 1997, p. 13).

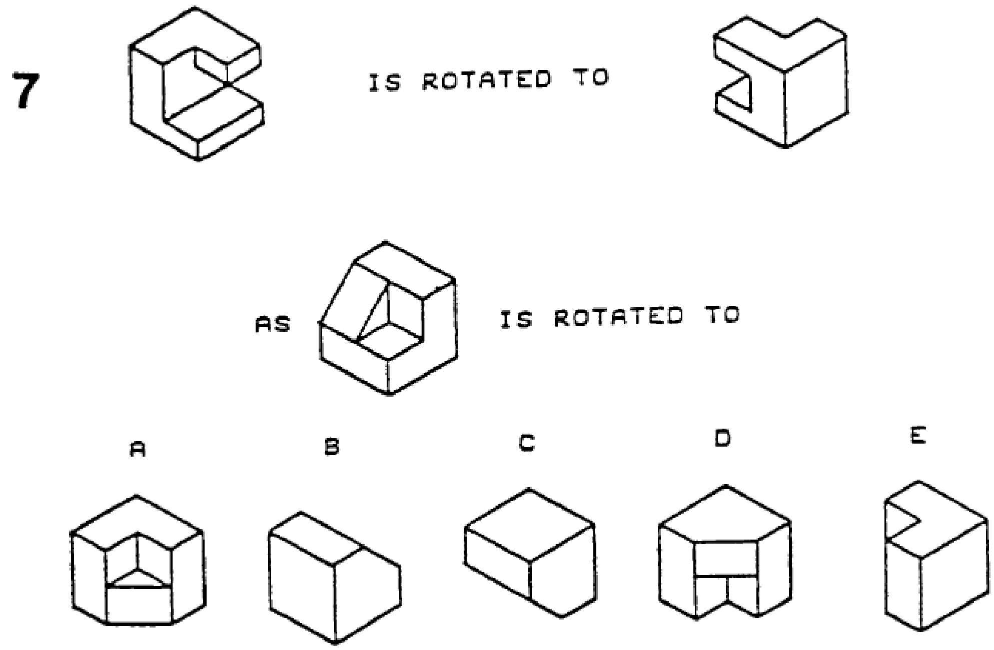

Figure 2. Example of Purdue Visualizations of Rotations Test

The 7th question from the 20-question Purdue Visualizations of Rotations Test (Bodner & Guay 1997)

Bodner and Guay provide arguments for both the reliability and validity of the test, based on its high correlation with the Shepard–Metzler tests (for validity), and the means and standard deviations of multiple uses of the test in different contexts (for reliability). The Shepard–Metzler rotations test, taken from their 1971 study, consists of two-dimensional representations of three-dimensional cubes and is widely recognized as a valid test of spatial visualization ability (Bodner & Guay, 1997).

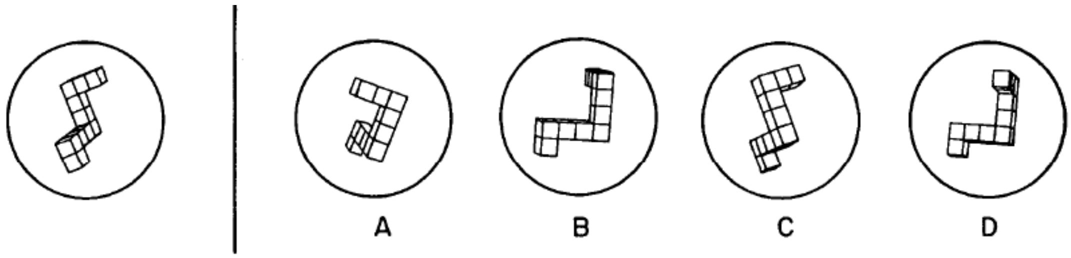

Figure 3. Example of Shepard–Metzler Rotations Test

An item from the Shepard–Metzler rotations test that was adapted for group testing (Bodner & Guay 1997)

The researcher created an answer sheet for the Purdue Visualizations of Rotations Test that would allow the test booklets to be re-used. To avoid participants marking their choices incorrectly on the answer sheet, a visual cue of the 3D figure corresponding to the numbered problem in the booklet was provided for each number (see Appendix D). The full contents of the test booklet provided to participants is reproduced in Appendix E, and the answer key is provided in Appendix F.

The other instruments used in the experiment were designed specifically for this experiment, and as such, cannot claim the pedigree of validity and reliability of the Purdue Visualizations of Rotations Test. The first of these instruments created by the researcher, the rigging pretest, asks the user to answer several rigging questions involving mechanical advantage to gauge the subject's familiarity with the subject matter. Consisting of only 7 questions, this instrument generated a pretest score between 0 and 7, and also asked for demographic data of age, gender, and months of rigging experience. This pretest is included in Appendix G with the answer key provided in Appendix H.

Additional instruments for the study were created for the three practice exercises, consisting of multiple questions, and corresponding feedback sheets containing the correct answers were created as well. Through the use of testing, these instruments were designed to reinforce the knowledge conveyed through the instructional videos but were not scored. The feedback sheets contained the correct answers in text form as well as graphical form, showing the correct rigging configurations. Some feedback sheets were designed for the subject to place stickers on them to become familiar with the materials and procedures that would be used for the final assessment.

Math worksheets were developed to ensure that the control group had a consistent experience with those of the treatment group, with respect to the time spent on the practice exercises. These sheets were also never scored. The practice exercises, feedback sheets, and math worksheets for the control group can be found in Appendix I. The practice exercises and feedback sheets for the drawing group can be found in Appendix J, and the practice exercises and feedback sheets for the 3D models group can be found in Appendix K.

The last of these instruments created by the researcher was the final assessment. It consisted of 10 questions and one rigging design challenge with a maximum score of 20. Seven of the questions were analogous to the pretest questions, and two other conceptual questions were added. The design challenge required each participant to solve a given rigging problem, select the appropriate equipment, and indicate the correct sling and hardware orientations. It was here that all subjects were to place their stickers and connect the elements of their design by drawing a few lines to represent the wire rope. An instructional sheet that explained how to complete the design challenge was provided to each subject as part of the instrument. The sticker sheets provided to participants can be found in Appendix L. The final test is included in Appendix M, and the answer key to the final test is included in Appendix N.

Data Collection

The experiment was designed with two independent variables. The first independent variable was the treatment type. All of the members of the class participating in the experiment would experience only one treatment, either the use of drawings, the use of 3D models, or neither when completing three practice exercises. The second independent variable was spatial ability, and the instrument to measure this variable had a range between 0 and 20, although this score would later be categorized as either “low” or “high”. There was one dependent variable, the final assessment score, which had a range of

0 to 20. Two covariates were included in the design: the rigging pretest score (with values ranging between 0 to 8) and the months of rigging experience (ranging from 0 to 180).

By using a factorial experimental design that resulted in a 2 x 3 matrix, the data for all six groups could later be analyzed to look for relationships between final score and treatment type, final score and spatial ability, and any interaction effects. It is important to note that, because subjects were assigned to different treatment groups based on the class in which they were enrolled, and not randomly, the design must be considered quasi-experimental, hence, the “N” instead of the “R” in the design notation (see Figure 4).

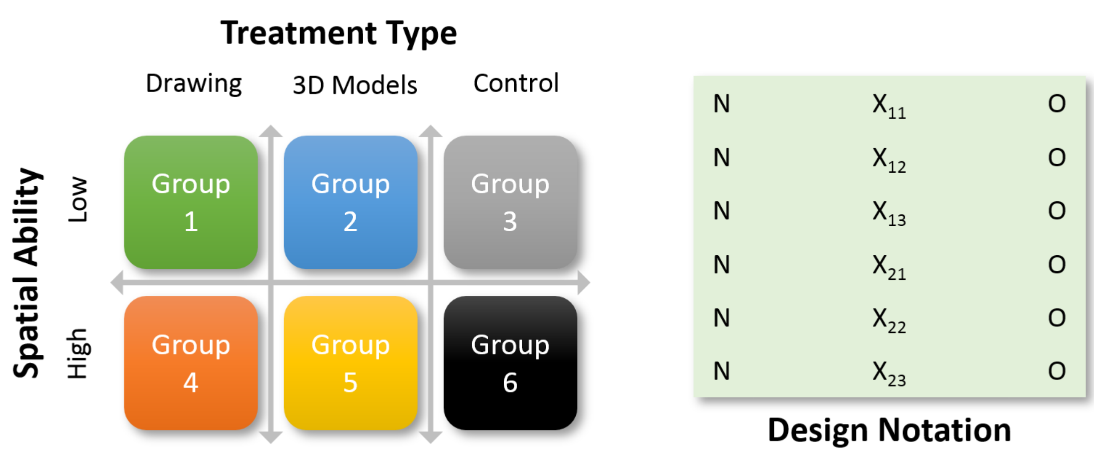

Figure 4. 2 x 3 Factorial Quasi-Experimental Design

All experimental trials took place in the state of California over a period of 6 months. Upon arrival at the testing location, each participant was seated at a table and provided with two copies of a consent form – one for them to keep, and one for them to indicate their email address, sign, and hand in to the researcher. Each consent form was individually labeled, indicating the participant's test subject number. The researcher then introduced the study and collected the signed copies of the consent forms.

All participants in a given class were assigned to either the control group or to one of the two treatment groups. All data was collected via written tests. For the control group, extra sheets with math problems for the participants to fill out were provided. For the drawing group, extra sheets for drawing were provided, as were several pencils and pencil sharpeners. For the 3D models group, an articulating arm, representing a crane's hook, was mounted to the table for each participant prior to their arrival. For this group, three small containers for each participant were also provided, one for each practice exercise, with each one containing a set of 3D functional models.

When the start time for the study arrived, each participant was given the abbreviated 20-question Purdue Spatial Visualization of Rotations Test. After this test was collected, 10 minutes later, each participant was then given 5 minutes to complete the 8-question written rigging knowledge pretest. The participants were also instructed to provide demographic data (age, years in the rigging industry, etc.) on the last page of the pretest.

After the pretests were completed, the participants were asked to watch the first instructional video with a running time of 4 minutes and 41 seconds. After the video finished playing, each participant was prompted to turn over their first practice exercise sheet and answer a series of questions based on the content that was just presented. Participants in the drawing group were prompted to use the paper and pencils to draw the rigging scenario during the 6-minute answer period and then answer the questions. Participants in the 3D models group were prompted to use the 3D models to simulate the rigging scenario and then answer the questions during the 6-minute answer period. Participants in the control group were asked to answer the questions and then to complete as many math problems as they could in the time remaining for the 6-minute answer period.

After the 6-minute answer period, the researcher passed out a feedback sheet, providing the correct answers to the practice exercise problems. The participants were given 2 minutes to review the feedback sheet. The researcher then started the second instructional video with a running time of 4 minutes and 23 seconds. After the video finished playing, each participant was prompted to turn over their second practice exercise sheet and to answer another series of questions based on the content that had just been presented. The same materials and procedures were used by the participants for the second practice exercise as for the first.

After the 6-minute answer period, the researcher passed out a feedback sheet with the correct answers to the second guided practice exercise, as well as a sticker sheet with stickers that represented rigging components of different capacities. The feedback sheet prompted each participant to take a given sticker from the sticker sheet and apply it to a given location on the feedback sheet as practice for the final test, which would make heavy use of the stickers.

After 2 minutes to review the second feedback sheet and apply the sticker, the researcher showed the third and final instructional video with a running time of 3 minutes and 17 seconds. After the video finished playing, each participant was prompted to turn over their third practice exercise sheet and asked to answer another series of questions based on the content that had just been presented. The same materials and procedures were used by the participants for the third practice exercise as for the first and second.

After the 6-minute answer period, the researcher passed out a feedback sheet with the correct answers to the third practice exercise. The feedback sheet again prompted each participant to take a given sticker from the sticker sheet and apply it to a given location on the feedback sheet.

After 2 minutes to review the third feedback sheet and apply the sticker, the researcher passed out the final assessment which included ten written questions and a design challenge. Seven of the ten written questions corresponded to seven of the questions on the rigging pretest. In the design challenge, each participant was instructed to review the selection of the remaining stickers and apply the correct stickers in the correct orientation to the rigging scenario illustration. All participants were given 15 minutes to complete the final assessment.

Hypotheses

The null hypothesis is as follows:

H_0: The combination of a rigging student's spatial ability and the type of training method received has no effect on the student's final assessment score.

The alternative hypotheses for the three treatment types (drawing, 3D models, and the control group) are as follows:

H_1: The rigging students that train with 3D models perform better on the final assessment than students in the drawing and control groups.

H_2: The rigging students that train with drawings perform better on the final assessment than students in the control group.

H_3: When averaged across all three groups, rigging students categorized as having high spatial ability perform better on the final assessment than rigging students categorized as having low spatial ability.

H_4: When instructed with 3D models, rigging students categorized as having low spatial ability perform better on the final assessment than rigging students in the control group who are also categorized as having low spatial ability.

H_5: When instructed with 3D models, rigging students categorized as having high spatial ability will not perform better on the final assessment than rigging students instructed through the use of drawings who are also categorized as having high spatial ability.

Thus, it is hypothesized that there will be two main effects (one for each independent variable: the type of treatment and a learner's spatial ability) and an interaction effect where the effectiveness of the training method will be dependent on spatial ability. It is hypothesized that the use of 3D models will result in a higher score for those with low spatial ability, but the training method will be less critical for participants with high spatial ability.

Data Analysis

The results were analyzed using analysis of covariance (ANCOVA) in SPSS, with the covariate of the rigging pretest score. Of the original sample of 82, the months of rigging experience was also highly correlated with the final assessment score, and this factor was considered as a covariate. However, four outliers were identified and removed from the study before performing the factorial ANCOVA, and this weakened the correlation but did not remove it entirely. Two outliers had scores that were much higher than the other scores in both their treatment group (3D models) and their spatial ability group (low spatial ability). The third outlier scored a zero on the final assessment and a zero on the Visualizations of Rotations test and did not appear to have been engaged in the study. A fourth outlier with a very high final assessment score, this one from the drawing group, was identified as a high leverage point during the ANCOVA, having high spatial ability and a great deal of rigging experience. Once that participant was removed from the study, the months of rigging experience were no longer correlated with the final assessment score. The rigging pretest, however, remained correlated, and a two-way ANCOVA was conducted in SPSS on the remaining sample of 78 subjects to examine the effects of treatment and spatial ability on final test score, after controlling for pretest score.

Assumptions Satisfied for the Ancova

There was no evidence of a lack of linearity between the pretest score and post-intervention final test score for each intervention group, as assessed by visual inspection of a scatterplot. There was a significant Pearson Correlation between the pretest score and the final test score, $p = 0.05$.

There was homogeneity of regression slopes as determined by a comparison between the two-way ANCOVA model with and without interaction terms, $F(5, 66) = 1.180$, $p = .329$.

There was homoscedasticity overall, but with slight indications of heteroscedasticity within two of the group combinations of the two independent variables, as assessed by visual inspection of the studentized residuals plotted against the predicted values for each group. There was homogeneity of variances, as assessed by Levene's test of homogeneity of variance (p = .063). After removal of the four outliers previously mentioned, there were no outliers in the data, as assessed by no cases with studentized residuals greater than ±3 standard deviations. There were no leverage or influential points, as assessed by leverage values and Cook's distance, respectively. For five of the six cells, studentized residuals were normally distributed, as assessed by Shapiro-Wilk's test ($p > .05$). One cell, the Control group with High Spatial Ability, was not normally distributed.

Summary

By including a rigging knowledge pretest and a spatial orientation evaluation, the opportunities for analysis of the data broaden considerably. Spatial ability is important because it can provide a baseline for the student's ability to interpret and learn from 3D drawings used as visual aids, as suggested by Huang & Lin (2017). The rigging knowledge pretest allows for the reduction of extraneous variables, such as prior rigging knowledge, that might otherwise skew the results (for example, participants with a vast knowledge of rigging would likely achieve a higher score on the posttest, regardless of the intervention).

CHAPTER FOUR

RESULTS AND DISCUSSION

Introduction

Included in Chapter Four is a presentation of the results of completing the study, organized by the hypotheses. The limitations of the study, as well as its implications, are also discussed in the same manner.

Presentation of the Findings

H_0: The Combination of a Rigging Student's Spatial Ability and the Type of Training Method Received Has No Effect on the Student's Final Assessment Score

Means, adjusted means, standard deviations and standard errors are presented in Table 1. There was not a statistically significant two-way interaction between spatial visualization ability and treatment on the final test score, whilst controlling for pretest score, $F(2, 71) = 1.603$, $p = .208$, partial $\eta^2 = .043$. Therefore, the null hypothesis cannot be rejected. An analysis of the main effects for spatial visualization ability and treatment was performed to see if the results gave any support to the alternative hypotheses.

Table 1. Means, Adjusted Means, Standard Deviations and Standard Errors for Final Test Score for the Six Intervention Groups

	Intervention Group					
	Low Spatial Ability			High Spatial Ability		
Final Score	Control	Drawing	3D Models	Control	Drawing	3D Models
M	3.539	3.667	3.385	4.882	7.222	5.273
(SD)	(1.506)	(2.469)	(1.609)	(2.058)	(3.073)	(3.319)
M_{adj}	3.608	3.797	3.509	4.763	7.208	5.062
(SE)	(0.651)	(0.613)	(0.657)	(0.576)	(0.780)	(0.725)

Note. Final test score measure on a scale of 1 to 20.

H_1: The Rigging Students that Train with 3D Models Perform Better on the Final Assessment Than Students in the Drawing and Control Groups

There was no statistically significant main effect of treatment, $F(2, 71) = 2.317$, $p < .106$, partial $\eta^2 = .061$. In fact, although not statistically significant, the trend in the data shows the drawing group outperformed both the 3D models group and the control group on the final assessment when averaged across both groups of spatial ability.

H_2: The Rigging Students That Train with Drawings Perform Better on the Final Assessment Than Students in the Control Group

As discussed above, while a trend was observed with the students that trained with the drawing performed better than the students in the control group, there was not a statistically significant difference in adjusted marginal mean final test score for any of the treatments.

H_3: When Averaged Across All Three Groups, Rigging Students Categorized as Having High Spatial Ability Perform Better on the Final Assessment Than Rigging Students Categorized as Having Low Spatial Ability

The main effect of spatial visualization ability showed a statistically significant difference in adjusted marginal mean final test score for those with high spatial ability (>10 on a 20-point scale) versus those who had low spatial ability (<= 10), 95% CI [0.903, 3.176], $p = .001$. The histogram of the results, shown in Figure 5, clearly illustrates this statistically significant finding.

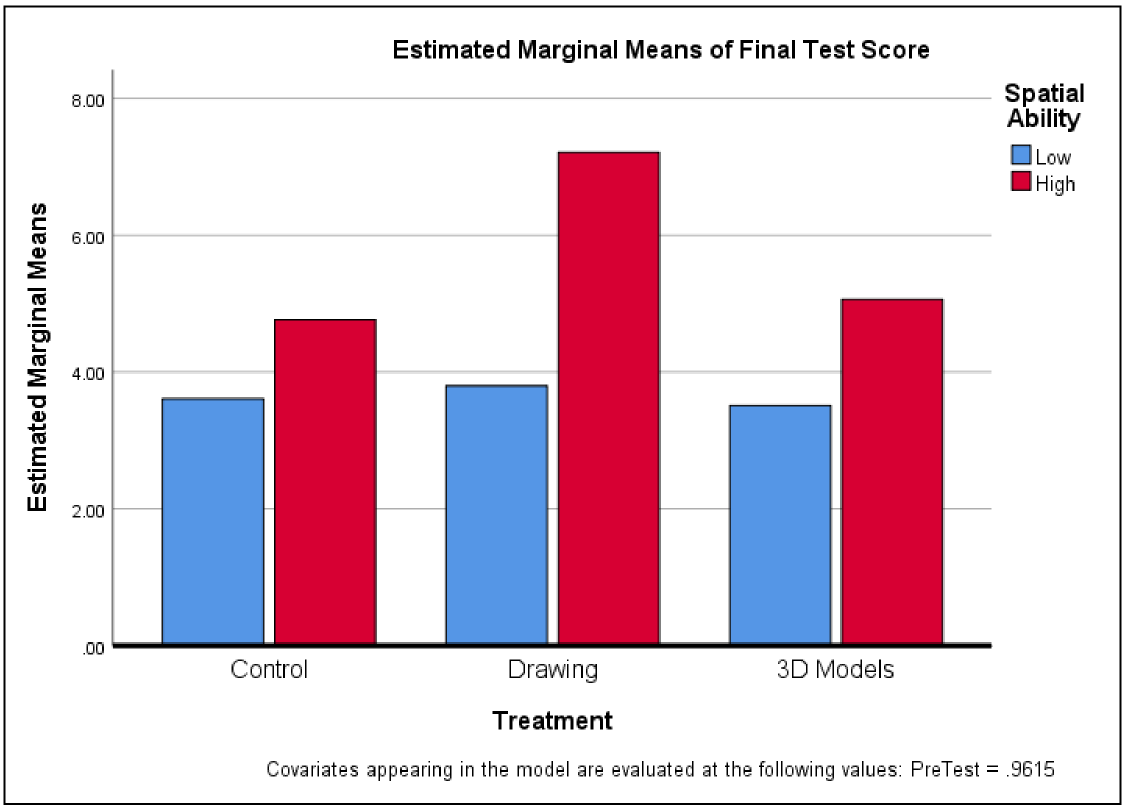

Figure 5. A Histogram Representing the Final Test Results Based on Treatment Type and Spatial Ability.

H_4: When Instructed with 3D Models, Rigging Students Categorized as Having Low Spatial Ability Perform Better on the Final Assessment than Rigging Students in the Control Group Who Are Also Categorized as Having Low Spatial Ability

Though not statistically significant, as can be seen in the numbers in Table 1 and in the graphic in Figure 5, rather than an upward trend, a downward trend was observed between the final score of participants with low spatial ability when the performance of the 3D models treatment group was compared to that of the control group.

H_5: When Instructed with 3D Models, Rigging Students Categorized as Having High Spatial Ability Will Not Perform Better on the Final Assessment Than Rigging Students Instructed Through the Use of Drawings Who Are Also Categorized as Having High Spatial Ability

While the difference is not statistically significant, the trend observed in the data supports this hypothesis. This trend is obvious in the histogram presented in Figure 5, with the high spatial ability participants who trained using drawings scoring the highest of all groups of participants.

Discussion of the Findings

Limitations

In addressing the results of the study, it is constructive to discuss the results within the context of the study's limitations. There were several limitations in the study's design that were noted earlier, such as the number of participants and the bias that arises from the convenience sample. However, additional limitations arise when considering the instruments that were used to obtain the study's results, as well as the observations that were made during the collection of the data, and even with the way the data was analyzed.

To begin, although the Purdue Visualizations of Rotations Test has considerable arguments for its validity and reliability (Bodner & Guay, 1997), there were no measures of reliability or validity for the final assessment, which was developed by the researcher. The use of the stickers for the rigging design challenge, or the wording of the questions may have created some confusion for the participants, interfering with the measurement of their acquired knowledge. In addition, the final assessment may have introduced a bias favoring the drawing group. As it was a written test, those participants in the drawing group may have been better primed for the rigging design portion of the exam due to their heavily visual interaction with the practice exercises. This also leads to yet another limitation with regard to the final assessment. Bias may have been introduced simply by virtue of the final assessment being in written form, rather than by evaluating a subject's performance with life-size rigging equipment.

Although there was a normal distribution of scores for the Spatial Visualizations of Rotations test within each of the three groups, spatial ability was a pseudo-experimental variable because it was not entirely within the control of the researcher. It was also observed by the researcher that some subjects were even looking at the answers of other subjects adjacent to them, and in two cases, the researcher noted verbal communication between participants during the Visualizations of the Rotations test. Despite instructions to not collaborate with others, the classroom environment may have introduced additional error via this ability for subjects to communicate during the study.

As their performance in the study yielded neither a grade nor any other incentive related to their performance, there is also no way to say that each of the participants were equally as motivated to try their best on the Visualizations of Rotations Test, pay attention to the videos, or learn the material.

It was also noted by the researcher that some subjects were observed to be distracted by the 3D models in front of them during the time the instructional videos were being played. Without the first instructional event of gaining attention no learning can take place (Gagne, 1985), and this distraction may have interfered with the subjects' ability to absorb the instructional content. The other groups were not presented with this distraction, and this should be noted as a limitation to the study.

The study was conducted over a compressed time frame and used only video instruction. It may be that different results would have been found in an instructional setting that allows for multiple interactions with both the content and the learning resources (such as the 3D models). Having a human instructor that could answer questions and provide interactive assistance with the learning resources and the content might also result in very different findings.

Another limitation related to the compressed timeframe was how long each subject had to review the feedback sheets. As these sheets were physically passed out to subjects in the classroom after each exercise was complete, not everyone received the same amount of time to review the feedback sheets, and this may also have introduced error into the results.

An additional limitation was introduced by the decision of how to categorize spatial ability during the data analysis. The division between “Low” spatial ability and “High” spatial ability was made at the halfway point with regard to the maximum value of the test (0 to 10 was considered “Low,” 11 to 20 was considered “High”). It should be noted that an initial analysis of the data using values of “Low,” “Medium,” and “High” spatial ability yielded different results: that a statistically significant interaction effect between treatment type and spatial ability existed. However, the cell sizes in this design violated the homogeneity of variances assumption of the ANCOVA, and the 3x3 matrix analysis was discarded in favor of the analysis presented here, a 3x2 design with large enough cell sizes to satisfy the assumption of homogeneity of variances. Still, the decision of how to analyze the data, and the sensitivity of the data to this categorization should be noted as a limitation to the findings.

Another significant limitation to the study pertains to the use of a factorial ANCOVA for analysis. To perform an ANCOVA, several assumptions must be met, and though the data set used for the ANCOVA all met those assumptions, certain data points had to be removed from the data set to meet these assumptions. On the point of motivation, it was an easy decision to remove the participant who scored a zero on the spatial ability test as well as a zero on the final assessment. However, three other outliers had to be removed – and two of them scored extremely well on the final assessment yet scored low on the spatial ability test. And two of the three were in the 3D models treatment group – one with 15 years of rigging experience (who scored the highest on the final test of all participants) and one who had no rigging experience. These outliers, participants 34 and 40, can be seen in both Figure 6 and Figure 7.

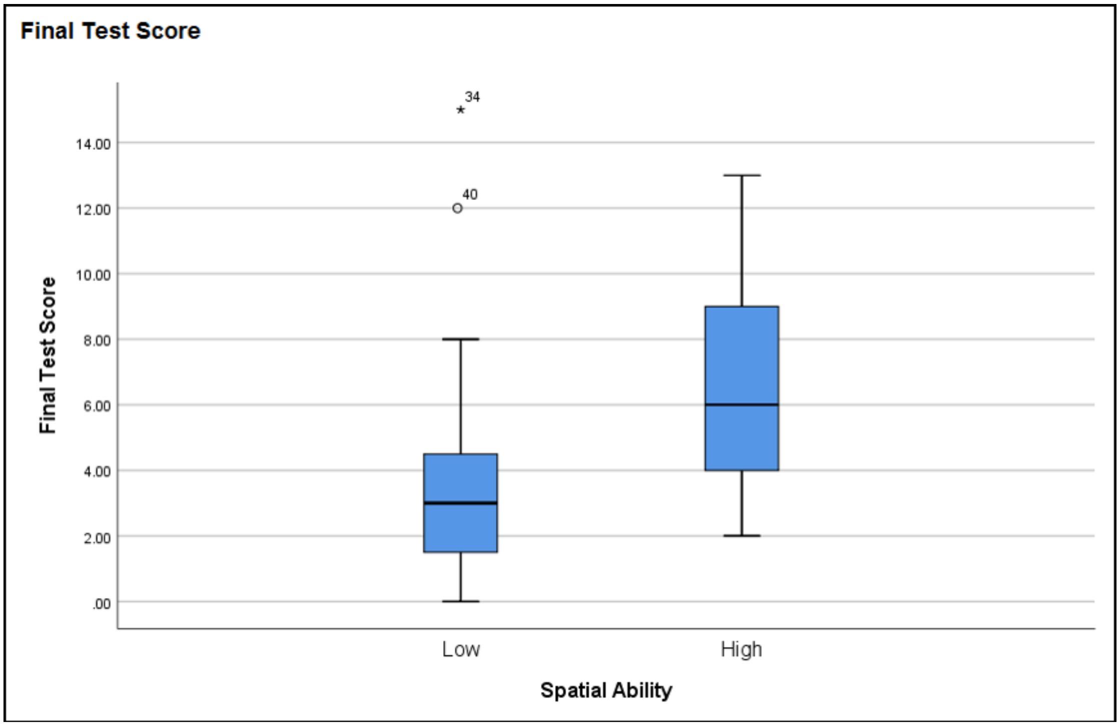

Figure 6. A Boxplot Showing the Outliers Based on Spatial Ability in the Original Data Set

These outliers had to be removed because they scored too high on the final assessment.

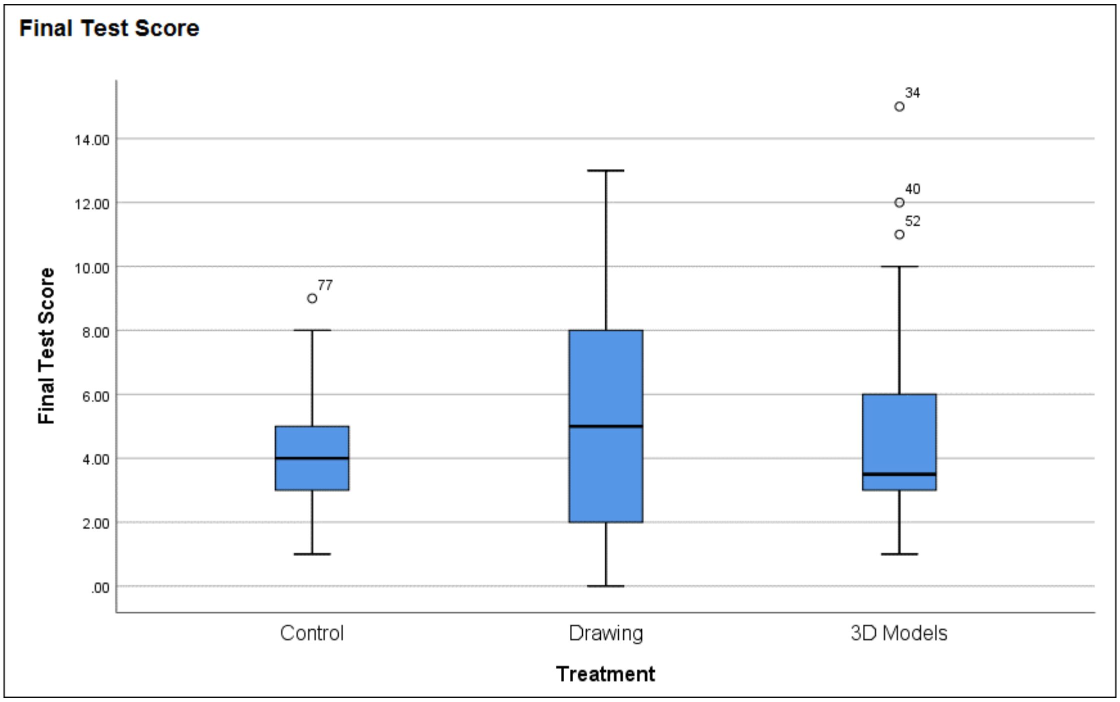

Figure 7. A Boxplot Showing the Outliers Based on Treatment Type in the Original Data Set

Two of these outliers had to be removed because they scored too high on the final assessment

A third high-scoring outlier in the drawing group who also scored high for spatial ability had to be removed because its presence created a leverage point, violating one of the assumptions of the ANCOVA. While the removal of this data point doesn't seem to have gone against the trend that can be seen in the results histogram in Figure 5, the removal of the outliers from the 3D drawing group tells a different story, as discussed in the following Hypotheses sections.

H_0: The Combination of a Rigging Student's Spatial Ability and the Type of Training Method Received Has No Effect on the Student's Final Assessment Score

Given the limitations of the study, it is perhaps not surprising that the data did not support rejecting the null hypothesis. But it should be emphasized that the lack of support to reject the null hypothesis assumes that low scores on the spatial visualization test are solely the consequence of low spatial ability, and not low motivation. This deserves mention because two participants (participant 34 and participant 40) scored low on the spatial visualization test but scored so high on the final test that they had to be considered outliers and removed from the study.

These two participants with low spatial ability were members of the 3D models group and represented the highest and third highest scores of any participants in the study.

These outliers were not included in the ANCOVA, but they are not errors in the data to be discarded. Rather, without these outliers, the merit for further study would not be as strong. Instead, their presence should encourage additional inquiry.

H_1: The Rigging Students that Train with 3D Models Perform Better on the Final Assessment Than Students in the Drawing and Control Groups

Aside from the outliers that excelled using the 3D models, there may be several valid explanations for why participants using the 3D models did not perform any better on the final assessment than participants using drawings or the participants in the control group.

An argument could be made that the participants were new to these models, and that this novelty increased cognitive load rather than reducing it. In fact, since both low spatial-ability participants and high-spatial ability participants suffered in their performance (though not by a statistically significant degree) when using the 3D models, the degree of challenge may have been greatly increased for those participants, giving them less time to focus on their written answers during their practice exercises. Or, the models may have served as a distraction from the video lessons, as was directly observed by the researcher twice during the study.

Regardless of why the results were inconclusive, the results of this study are consistent with existing research that sometimes supports and sometimes rejects the assertion that the type of learning intervention is not a significant factor in performance outcomes, just as Richard Clark asserted in 1983. A 2013 meta-analysis of 55 studies involving manipulatives to learn mathematics lead researchers to conclude that “evidence supporting the efficacy of concrete math manipulatives is inconsistent” (Carbonneau et. al., 2013, p. 380) due to varying levels of instructional guidance, different manipulatives, and varying ages and other characteristics of learners.

These varying learner characteristics may be what made it possible for the outliers and some learners to perform better than others on the final assessment when using the 3D models. Perhaps those with more hands-on rigging experience had a more intuitive grasp of how the models were supposed to work because they had dealt with the real versions of the equipment in some form or fashion. Others may have drawn upon model-making experience, or even playing with LEGOs as a child or with their own children. To seek a generalization of how 3D models could enhance instruction for everyone may be just as flawed as the notion of "learning styles" or the mythical Learning Pyramid that is now the subject of academic excoriation (Masters, 2019). But that does not mean there is no student or topic that can benefit from such interventions; it just may be that these interventions only improve learning outcomes when certain learner characteristics are present, or perhaps absent.

H_2: The Rigging Students That Train with Drawings Perform Better on the Final Assessment Than Students in the Control Group

Setting aside the 3D models, the trend in the results seems to suggest that higher learning outcomes might be achieved if learners use diagramming, however, it should be noted that this trend only appears for participants with high spatial ability. This makes sense, as participants with low spatial ability are particularly challenged by graphical media, so it would not be expected that they would perform any better than the control group, as was seen in the trend here (though not to a statistically significant degree). This trend is in contrast to the framework Michelene Chi suggests (2009 & 2014), that active learning activities are more effective than passive learning activities. However, those with high spatial ability were likely able to make use of the drawing treatment because of their innate spatial ability, and this is supported by Chi's framework (2009 & 2014), and by Gobert's study that suggests the drawing of diagrams results in increased learning outcomes over writing or just reading (1999).

This study's results were not able to show a statistically significant difference in the effectiveness of the drawing treatment based on spatial ability. However, if results of further study were found to be consistent with the observed trend, it could help teachers understand why drawing diagrams just might not work for all students, even though it is an "active" learning activity.

H_3: When Averaged Across All Three Groups, Rigging Students Categorized as Having High Spatial Ability Perform Better on the Final Assessment Than Rigging Students Categorized as Having Low Spatial Ability

This finding (the only one in this study that is statistically significant) is consistent with prior research that suggests spatial visualization ability and academic achievement are positively correlated (Stull, Hegarty, Dixon & Stieff, 2012, Wu & Shah, 2004). While the final assessment has its limitations, the fact that the learning outcomes for all high spatial ability participants were higher across all treatment groups may indicate a sufficient level of reliability of the final assessment as a measurement of learning outcomes. However, this consistency cannot support that it is a valid test of increased knowledge on mechanical advantage (yet, it is assumed to be a valid test for the purpose of this study).

H_4: When Instructed with 3D Models, Rigging Students Categorized as Having Low Spatial Ability Perform Better on the Final Assessment Than Rigging Students in the Control Group Who Are Also Categorized as Having Low Spatial Ability

As discussed earlier, support for this alternative hypothesis was only observed in the outliers that had to be discarded from the ANCOVA, as shown in Figures 5 and 6. These outliers, participants who tested low for spatial ability yet were among the top-scoring individuals for the final assessment, give support to the notion that in these two cases the low spatial ability scores were not reflective of a lack of motivation. So, the question becomes, why did they score so high? In one case, the extensive rigging experience could explain the high score, but that participant's pretest score was no higher than those of other participants – so clearly that participant didn't know the material beforehand.

The other outlier had no rigging experience at all and scored almost just as high. Could the treatment type, the use of 3D models, been a significant aid in comprehending the instructional material for these individuals? The story of the outliers is not conveyed in the results of the ANCOVA, yet it is not beyond reason that a different story might be told with a larger number of participants, or with participants who are as motivated to learn as these outliers, despite their spatial processing handicaps.

Taken together, these two participants seem to support this hypothesis, but on the whole, the low spatial ability participants performed poorly regardless of the treatment to which they were exposed. This poor performance is consistent with the findings of Huk (2006) where the use of 3D models by learners with low spatial ability was thought to lead to cognitive overload.

H_5: When Instructed with 3D Models, Rigging Students Categorized as Having High Spatial Ability Will Not Perform Better on the Final Assessment Than Rigging Students Instructed Through the Use of Drawings Who Are Also Categorized as Having High Spatial Ability

This hypothesis is supported by the data as there was no significant difference between treatment types at all. However, the trend of the data seems to suggest that high spatial ability participants who used 3D models did not perform as well as high spatial ability participants who used the diagrams during the practice exercises. This may be another indicator that the unfamiliar 3D models increased the cognitive load or that their novelty provided a distraction to the learning process. The fifth highest score that was achieved, participant 52, had high spatial ability and was in the 3D model group (shown in Figure 7). Because high spatial ability participants scored higher overall, participant 52 was not considered an outlier for the 3D model group. While outside the norm for the 3D model group participants that were retained in the study, participant 52 performed well on the final assessment despite the distraction or novelty the 3D models provided. This is where the months of rigging experience might help to account for such high performance. Even though the correlation for rigging experience fell away during the ANCOVA, the data collected is still valid. Participant 52 reported that they had 0 months of rigging experience, so it may be that this relatively high score (the fifth highest of 82 participants) was indeed due to the use of 3D models. Participant 52 scored very high on the Visualizations of Rotations test with a score of 17 out of 20. Three individuals in the control group also scored a 17 on the Visualizations of Rotations test and reported 0 months of Rigging Experience, but their final test scores were 5, 4, and 2. Participant 52, without any additional rigging experience, certainly did better than three members of the control group who achieved the same high score on the Visualizations of Rotations test. Though not captured in the ANCOVA, such an observation might justify further study with a higher number of subjects and a narrower focus.

Summary

Given the significant number of limitations associated with the study, from participant motivation to data analysis, ascribing meaning to the results will be challenging. While the researcher took every effort to ensure that the study was conducted in a consistent manner across all trials, that the data was collected in a consistent and methodical way, and that the data was analyzed prudently, any conclusions and recommendations will need to be made based on assumptions that the data is a reflection of reality. And while the findings of this study are consistent with the literature, it would be an error to declare with certainty that this study supports even its statistically significant finding in a general sense: that spatial ability, as a learner characteristic, impacts learning outcomes. Instead, it can only be said that the category of the score of a participant's spatial ability test, as measured by the instrument that was used in this study, was highly correlated to the score of the final assessment that was used in this study. Beyond that, little more of substance can be said.

And while any data set can be cherry-picked to suggest there might be support for one or more assertions, without a large enough data set, there is only so much that an exploratory study like this can assert. However, if the purpose of this study is to spark further inquiry, then the data collected, including the outliers, have some interesting implications. If some of the existing studies were to be conducted again but included a measure of the spatial ability of the participants, more might be revealed. The learner characteristic of spatial ability might be able to explain why the previously inconclusive results were so inconsistent. In this study, however, the results of the ANCOVA could not reject the null hypothesis that there is no interaction effect between spatial ability and treatment type for the given sample.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

Introduction

Included in Chapter Five is a presentation of the conclusions gleamed as a result of completing the study. Further, the recommendations extracted from the project are presented. Lastly, the Chapter concludes with a summary.

Conclusions

The main research question this study attempted to answer was, “Do learners with low spatial ability have higher learning outcomes when given 3D models to manipulate as opposed to simply drawing solutions with paper and pencil?” Within the very limited scope of this study, the findings indicate that the answer is “no.” While the threats to the reliability and validity of this study’s results keep this answer from being anything close to definitive, there are several conclusions that can be drawn, which follow.

1. Those who score higher on a spatial ability test are likely to score higher on a final test, regardless of the treatment type.
2. Additional learning interventions may not result in higher learning outcomes for a wide array of students, but that should not be misread as a reason to avoid their use. All people learn differently, and while Richard Clark may have been right, that “media will never influence learning," it would be a difficult task,

indeed, to prove this, simply due to the individual nature, motivations, and background of each learner. For some students, just witnessing their instructor trying something new may result in an uptick in engagement or effort that results in higher learning outcomes. For others, something new might cause anxiety or distraction that interferes with their ability to process new material. But this also does not mean it should be avoided, for even learning how to overcome anxiety and work competently despite distraction is a form of growth that students may need in their field of study and in their lives.

Recommendations

The recommendations resulting from the project follow.

1. This study focused on individual performance, but a future study could focus on how teams of two or more individuals use 3D models to collaborate and solve problems. Using constructive and interactive learning models may be best for learning more advanced concepts and can provide a way for learners to create novel solutions and understand the merits or problems with those novel solutions. When it comes to the collaborative learning model, learners working together on a 3D model allow for greater opportunities for interaction and participation than two people working on a drawing together.

2. The use of a convenience sample created inherent limitations in the study that could perhaps be overcome by engaging a more focused set of participants, perhaps individually. Although such a study would take much longer to complete, other limitations that this study presented might also be overcome. Individuals could be randomly assigned their treatment type after taking the spatial ability test, but before exposure to the instructional material. The method for testing an individual's comprehension of the material and its application on the job site could also be tested with real equipment, if participants were engaged individually.
3. A future study that does not have to occur in such a compressed time frame might also yield very different results. The unfamiliarity with both the 3D models and the new material could be mitigated over a longer study, and the outliers provide support for the notion that engaging with 3D models could enhance learning outcomes given the right background or aptitude for hands-on learning.
4. The researcher made an attempt to test retention of the material, but with such low scores on the final assessment and with very low participation in the retention test, this part of the study was excluded from analysis. However, with a larger pool of

participants, and under different conditions (such as a longer study), the inclusion of 3D models, with their complemental tactile nature, may provide more "hooks" into the memories of such learning experiences. Perhaps this retention of information, and the ability to access it via the conduit of interaction, will yet provide support for the old adage, "involve me and I will learn."

5. It might be informative to repeat some of the previous studies that involve manipulatives and, controlling for motivation, measure the spatial visualization ability of the participants. Perhaps some pattern of spatial ability as a learner characteristic might then emerge to identify which learners can benefit most from the use of manipulatives.

The contribution of this study to the body of existing research is further support that those with low spatial ability may face learning deficits for which there is no easy remedy. This study also gives further evidence that regardless of what treatment type may be used for an intervention, learner characteristics cannot be ignored. Instead, learner characteristics such as spatial ability may even have the potential to clarify why conflicting outcomes were achieved for a given learning event.

Summary

Chapter Five reviewed the conclusions extracted from the project. Lastly, the recommendations derived from the project were presented. Studies such as this one are important for us to conduct as we push the boundaries of knowledge in how we acquire knowledge. In the rigging and lifting industry, a life can be lost because of training that just “didn’t stick” in the minds of the attendees. Perhaps they were required to attend a class, signed the sheet that showed they were there, but they just were not engaged and could not give the instructor the attention that was required. Being a human being is to be unique, and though we all have different characteristics that make us who we are, we also have many things in common. For the subset of learners who are considered to have low motivation or cannot overcome distraction, it is questionable that any learning intervention will be able to improve learning outcomes. But for learners who genuinely have a spatial processing challenge, who are motivated to learn but have chosen the field of rigging and lifting specifically because it is a “hands-on” industry, for these learners, I believe we owe it to them to provide learning interventions that allow them to overcome their challenges and grasp the concepts that could ultimately save a life.

APPENDIX A

CSUSB INSTITUTIONAL REVIEW BOARD APPROVAL LETTER

February 27, 2019

CSUSB INSTITUTIONAL REVIEW BOARD
Administrative/Exempt Review Determination
Status: Determined Exempt
IRB-FY2019-146

Mr. Matthew Atherton and Prof. Eun-Ok Baek
Department of Educational Leadership & Technology
California State University, San Bernardino
5500 University Parkway
San Bernardino, California 92407

Dear Mr. Atherton and Prof. Baek:

Your application to use human subjects, titled "THE EFFICIENCY OF USING 3D MODELS TO TEACH LIFTING AND RIGGING CONCEPTS TO LEARNERS OF VARYING SPATIAL ABILITY" has been reviewed and approved by the Chair of the Institutional Review Board (IRB) of California State University, San Bernardino has determined that your application meets the requirements for exemption from IRB review Federal requirements under 45 CFR 46. As the researcher under the exempt category you do not have to follow the requirements under 45 CFR 46 which requires annual renewal and documentation of written informed consent which are not required for the exempt category. However, exempt status still requires you to attain consent from participants before conducting your research as needed. Please ensure your CITI Human Subjects Training is kept up-to-date and current throughout the study.

The CSUSB IRB has not evaluated your proposal for scientific merit, except to weigh the risk to the human participants and the aspects of the proposal related to potential risk and benefit. This approval notice does not replace any departmental or additional approvals which may be required.

Your responsibilities as the researcher/investigator reporting to the IRB Committee the following three requirements highlighted below. Please note failure of the investigator to notify the IRB of the below requirements may result in disciplinary action.

- Submit a protocol modification (change) form if any changes (no matter how minor) are proposed in your study for review and approval by the IRB before implemented in your study to ensure the risk level to participants has not increased,
- If any unanticipated/adverse events are experienced by subjects during your research, and
- Submit a study closure through the Cayuse IRB submission system when your study has ended.

The protocol modification, adverse/unanticipated event, and closure forms are located in the Cayuse IRB System. If you have any questions regarding the IRB decision, please contact Michael Gillespie, the Research Compliance Officer. Mr. Michael Gillespie can be reached by phone at (909) 537-7588, by fax at (909) 537-7028, or by email at mgillesp@csusb.edu. Please include your application approval identification number (listed at the top) in all correspondence.

If you have any questions regarding the IRB decision, please contact Michael Gillespie, the Research Compliance Officer. Mr. Michael Gillespie can be reached by phone at (909) 537-7588, by fax at (909) 537-7028, or by email at mgillesp@csusb.edu. Please include your application approval identification number (listed at the top) in all correspondence.

Best of luck with your research.

Sincerely,

Donna Garcia

Donna Garcia, Ph.D., IRB Chair
CSUSB Institutional Review Board

DG/MG

APPENDIX B

CSUDH INSTITUTIONAL REVIEW BOARD APPROVAL LETTER

CSUDH Institutional Review Board

for the Protection of Human Subjects in Research

Date:	**March 15, 2019**
To:	**Dr. Hamoud Salhi, Mathew Atherton, Dr. Eun-OK Baek, Dr. Enrique Murillo, Jr.** **CC: File**
From:	**Judith Aguirre, Research Compliance Officer** **CSUDH Institutional Review Board (IRB)**
Subject:	**#19-124 – "The Efficiency of Using 3D Models to Teach Lifting and Rigging Concepts to Learners of Varying Spatial Ability"** **March 15, 2019 through March 14, 2020**

The IRB at California State University, Dominguez Hills is pleased to inform you that it has reviewed your project and will rely on the approval of California State University, San Bernardino.

Your study is approved for one year beyond which time you must seek approval for a continuation of your study. Procedural changes or amendments must be reported to the IRB and no changes may be made without IRB approval except to eliminate apparent immediate hazards. Please notify the Office of Graduate Studies and Research (a) if there are any adverse events that result from your study, and (b) when your study is completed.

If you have any questions, you may contact the Office of Graduate Studies and Research at (310) 243-2136.

Thank you.

Subject recruitment and data collection may not be initiated prior to formal written approval from the IRB Human Subjects Committee

APPENDIX C

INSTITUTIONAL REVIEW BOARD INFORMED CONSENT FORM

CALIFORNIA STATE UNIVERSITY
SAN BERNARDINO

College of Education
Department of Educational Leadership and Technology

INFORMED CONSENT

The study in which you are being asked to participate is designed to investigate the effectiveness of different forms of instruction when teaching rigging and lifting concepts. This study is being conducted by Matthew Atherton under the supervision of Dr. Eun-Ok Baek, Professor and Coordinator of the Instructional Technology Program at California State University, San Bernardino. This study has been approved by the Institutional Review Board, California State University, San Bernardino.

PURPOSE: The objective of the study is to see if your ability to visualize three-dimensional objects will impact your success when solving rigging problems. The study will have three different testing environments, one of which you will be exposed to: working with physical 3D models, drawing your own visualization of the rigging scenarios using paper and pencil, or working through the problems without drawing them or using 3D models. If one of these methods is found to be more effective than the others, especially for learners that have a harder time visualizing three-dimensional objects, then that method could be used to help trainers when teaching lifting and rigging concepts.

DESCRIPTION: Your class and two others will be used to gather the data for the study. You will first be given 20 questions that will help the researcher understand how well you visualize three-dimensional objects when the objects are rotated. You will then be given a pre-test to determine how much you already know about what the lesson will cover. (You are not expected to know any of the correct answers as this is what the lesson is all about. But if you already know the material and you score high on the final test, the research needs to take your prior knowledge into account.) You'll then be shown a ten-minute video and given a practice problem.

Depending on which class you are in, you may be asked to work with the 3D models, use pen and paper to draw the rigging scenarios, or neither. After you finish the problem, you'll receive a feedback sheet so that you can see the correct answers.

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5500 UNIVERSITY PARKWAY, SAN BERNARDINO, CA 92407-2393

A 5-minute video will then be shown to you and you will be given a second practice problem, using the same tools (or neither of them). You'll get another feedback sheet for that problem. The last instructional video will also have a practice problem, and you will be asked to complete it like you did the first two, receiving feedback after it, as well. You'll then be given a test over the material that was covered and asked to write down your thoughts on how helpful the extra tools were (or weren't). Two weeks from today, you will be asked to go online and take another test that will be like the one you take today. The reason for that test is to see how well you remember what was covered today.

PARTICIPATION: Your participation in this project is distinct from the OSHA Training Institute Education Center coursework required for evaluation for a grade in the course and is completely voluntary. You do not have to answer any questions you do not wish to answer and can freely withdraw from participation at any time. You can decide to not answer any questions associated with this study even if you have signed this letter of consent. Your decision to not participate in this study's activities will have no penalty of any kind. Specifically, it will have no effect on your grade for this course. We will ask all students in the course if you would like to voluntarily participate in the study activities for which you may decline. Only students who agree to participate at those times will be included.

CONFIDENTIAL: You will write your name on a paper sign-in sheet and receive a test subject number. This sheet will remain in the possession of the Director of the OSHA Training Institute Education Center. This will be the only record that matches you to your subject number. The Director will use this sheet to provide your test subject number to you as a reminder when sending out the follow-up message for you to take the online test in two weeks. After the email has been sent, the Director of the program will be asked to shred the sign-in document. All results of the study will be reported in aggregate and no individual test subject number will be discussed in the results of the study, protecting your identity and the identity of all participants.

DURATION: The study will take approximately 1 hour and 30 minutes for the instruction, practice problems, feedback, the initial test, and the open-ended questions. An additional 15 minutes will be required two weeks after the initial assessment for the test on how well the instruction is remembered.

RISKS: There is a risk of a confidentiality breach. Participants may reveal personal, sensitive, or identifiable information when responding to open-ended questions in the narrative portion of the study. Participants may become fatigued or frustrated due to the length or assessment components of the study.

To minimize these risks, data will be stored securely according to campus policy. Identifiable information will be stored separately from other study data and participant identities will be masked in publication. Participants will be informed about all aspects of the study during consent and have the option to skip or withdraw from any activities that make them upset or uncomfortable. Personal, sensitive, or identifiable information will be removed from the research record. Participants will be informed of the approximate length of study activities during the consent process and will be offered the opportunity to take breaks during the study activities if needed.

BENEFITS: Because the subject matter of the study is not typically discussed in the regular OSHA 510 course, you can expect the benefit of the skills and experience associated with the additional instruction.

PHOTOGRAPH: I understand and agree to allow my pictures to be used as part of this research. I understand that pictures of the classroom sessions will be taken of me participating in the study. Initials___.

CONTACT: For answers to pertinent questions about the research and research subjects' rights, and in the event of a research-related injury, please contact Dr. Eun-Ok Baek, Professor and Coordinator of the Instructional Technology Program at California State University, San Bernardino. The physical address is: 5500 University Parkway, Department of Educational Leadership and Technology, California State University, San Bernardino, CA 92407. The email address is EBaek@csusb.edu and the telephone number is (909) 537-5454.

RESULTS: Results of the study can be digitally obtained, once completed and uploaded, at https://scholarworks.lib.csusb.edu/etd/ by searching for the study entitled "THE EFFICIENCY OF USING 3D MODELS TO TEACH LIFTING AND RIGGING CONCEPTS TO LEARNERS OF VARYING SPATIAL ABILITY"

CONFIRMATION STATEMENT:

I understand that I must be 18 years of age or older to participate in your study, have read and understand the consent document and agree to participate in your study.

SIGNATURE:

Signature: ____________________________ Date: ________

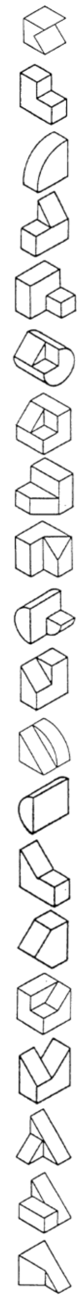
APPENDIX D

PURDUE VISUALIZATIONS OF ROTATIONS TEST ANSWER SHEET

Visualizations of Rotations Test

Subject #:

1)	A	B	C	D	E
2)	A	B	C	D	E
3)	A	B	C	D	E
4)	A	B	C	D	E
5)	A	B	C	D	E
6)	A	B	C	D	E
7)	A	B	C	D	E
8)	A	B	C	D	E
9)	A	B	C	D	E
10)	A	B	C	D	E
11)	A	B	C	D	E
12)	A	B	C	D	E
13)	A	B	C	D	E
14)	A	B	C	D	E
15)	A	B	C	D	E
16)	A	B	C	D	E
17)	A	B	C	D	E
18)	A	B	C	D	E
19)	A	B	C	D	E
20)	A	B	C	D	E



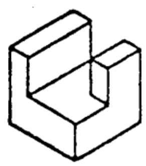
Created by Matthew Atherton

APPENDIX E

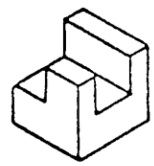
PURDUE VISUALIZATIONS OF ROTATIONS TEST

DIRECTIONS

This test consists of 20 questions designed to see how well you can visualize the rotation of three-dimensional objects. An example of the type of question included in this test is shown below.



IS ROTATED TO



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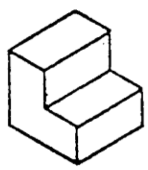
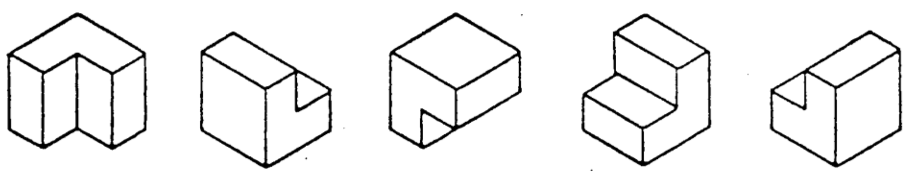


IS ROTATED TO

A B C D E



For each question, you should:

I. Study how the object in the top line of the question is rotated.

II. Picture in your mind what the object shown in the middle line of the question looks like when rotated in exactly the same manner.

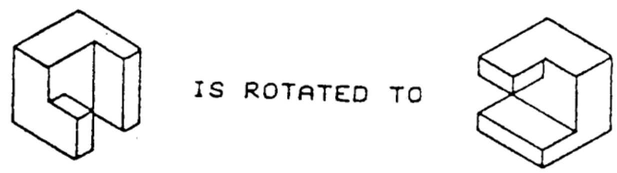
III. Select from among the five drawings (A, B, C, D, or E) given in tbe bottom line of the question the one that looks like the object rotated in the correct position.

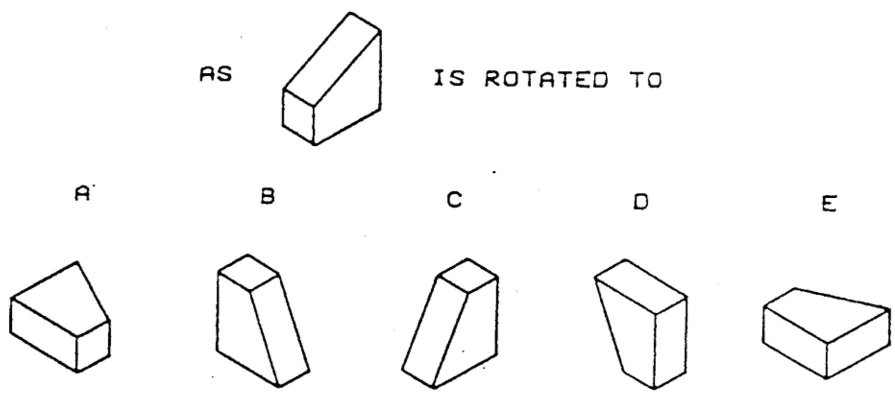
What is the correct answer to the example shown above?

(Continue on to the next page)

Answers A. B. C. and E are wrong. Only drawing D looks like the object after it has been rotated. Remember that each question has only one correct answer.

Now look at the example shown below and try to select the drawing that looks like the object in the correct position when the given rotation is applied

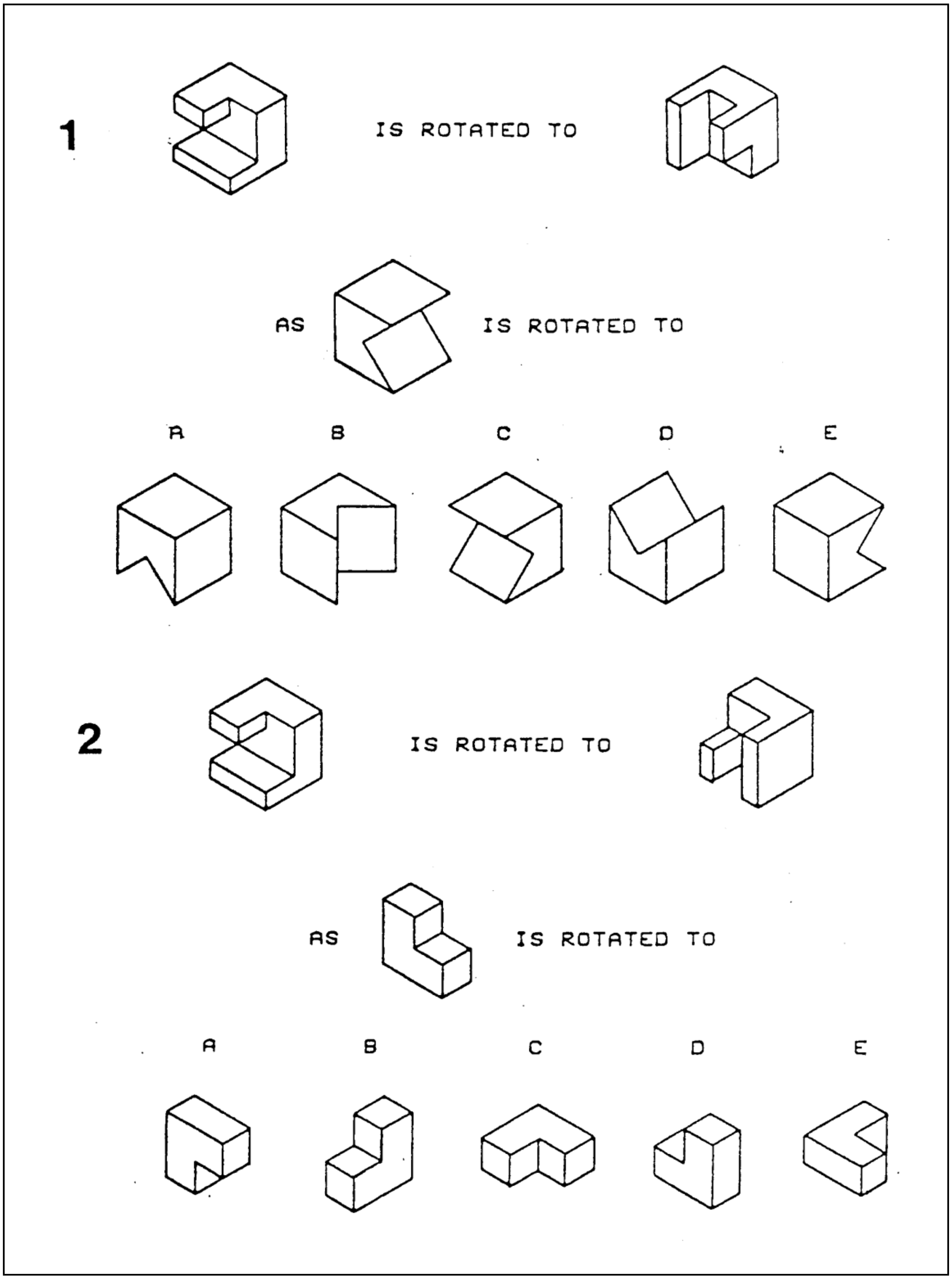




Note that the rotation in this example is more complex. The correct answer for this example is B.

Do NOT make any marks in this booklet.
Mark your answers on the separate answer sheet.
You will be told when to begin

(Stop here until you are instructed to open your booklet)


1
IS ROTATED TO
AS
IS ROTATED TO
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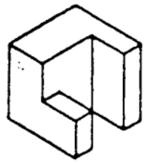
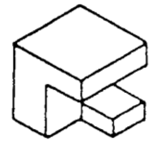
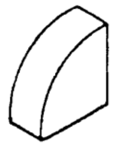
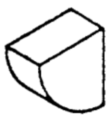
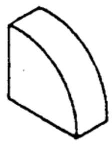
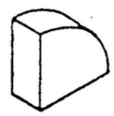
3  IS ROTATED TO 

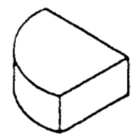
AS  IS ROTATED TO

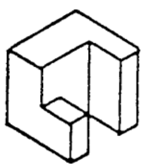
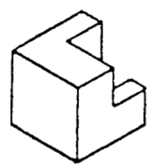
A 

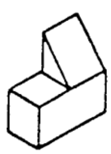
B 

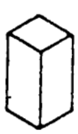
C 

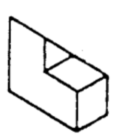
D 

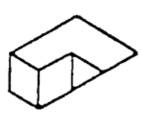
E 

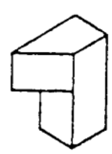
4  IS ROTATED TO 

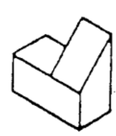
AS  IS ROTATED TO

A 

B 

C 

D 

E 

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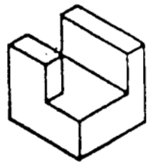

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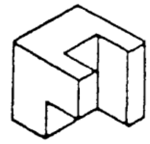

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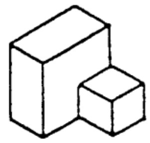

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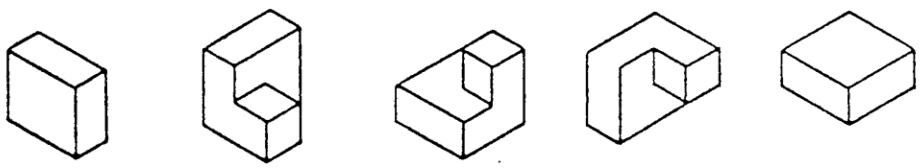
A B C D E



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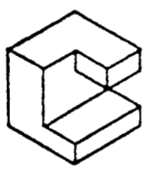

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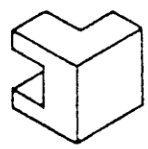

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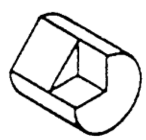

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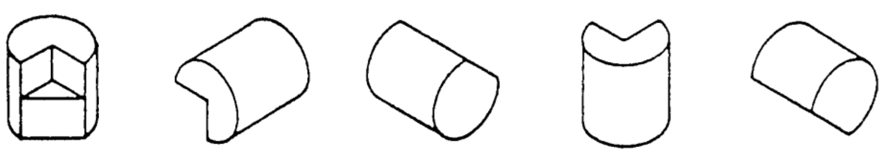
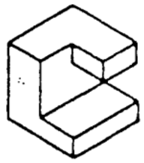
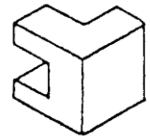
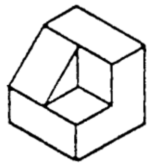
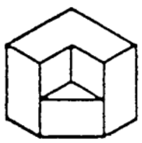
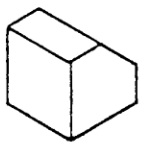
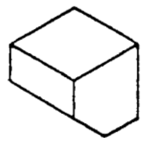
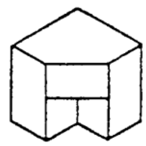
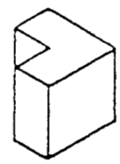
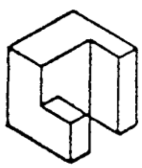
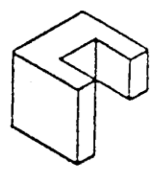
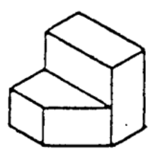


7  IS ROTATED TO 

AS  IS ROTATED TO

A	B	C	D	E
				

8  IS ROTATED TO 

AS  IS ROTATED TO

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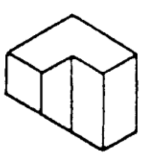
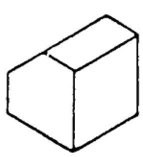
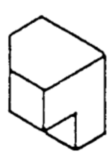
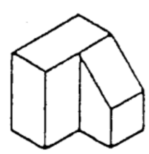
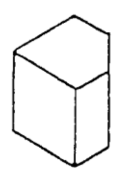
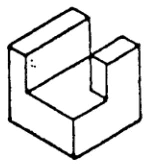
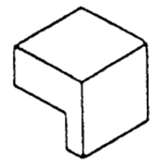
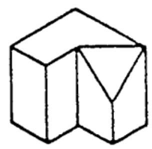
				

9  IS ROTATED TO 

AS  IS ROTATED TO

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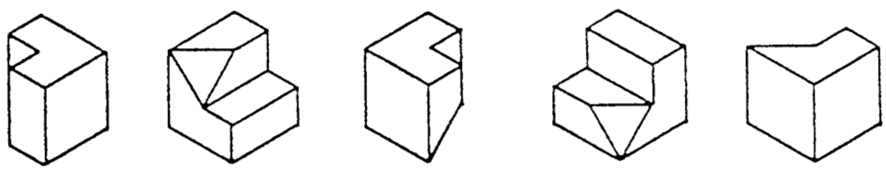
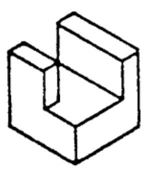
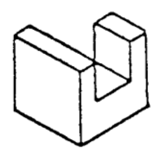
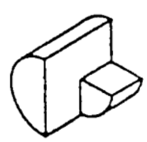


10  IS ROTATED TO 

AS  IS ROTATED TO

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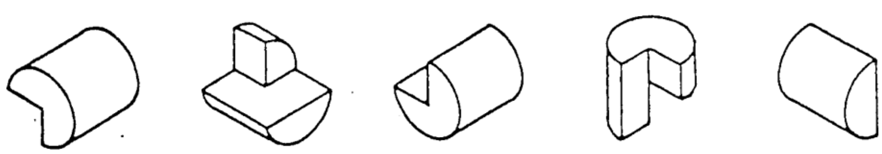
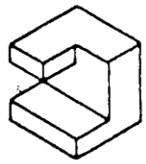
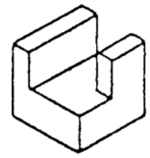
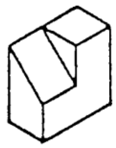


11  IS ROTATED TO 

AS  IS ROTATED TO

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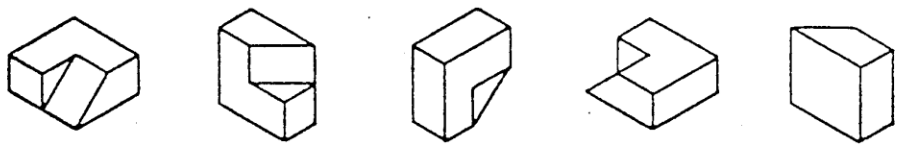
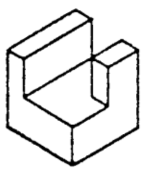
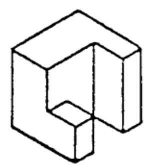
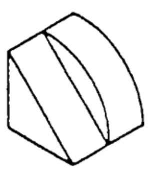


12  IS ROTATED TO 

AS  IS ROTATED TO

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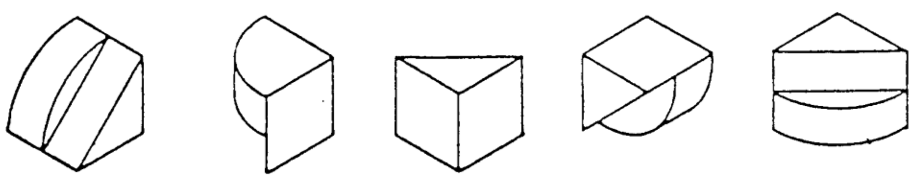
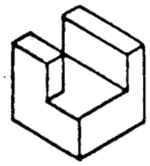
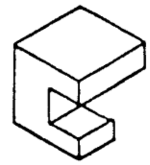
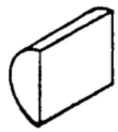


13  IS ROTATED TO 

AS  IS ROTATED TO

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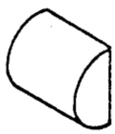
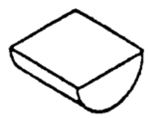
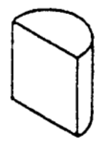
B 

C 

D 

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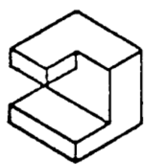
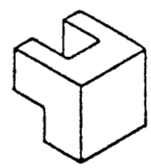
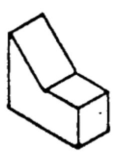
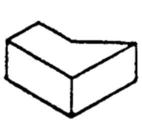
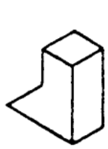
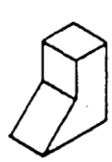
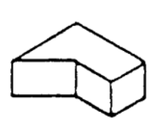
14  IS ROTATED TO 

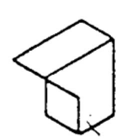
AS  IS ROTATED TO

A 

B 

C 

D 

E 

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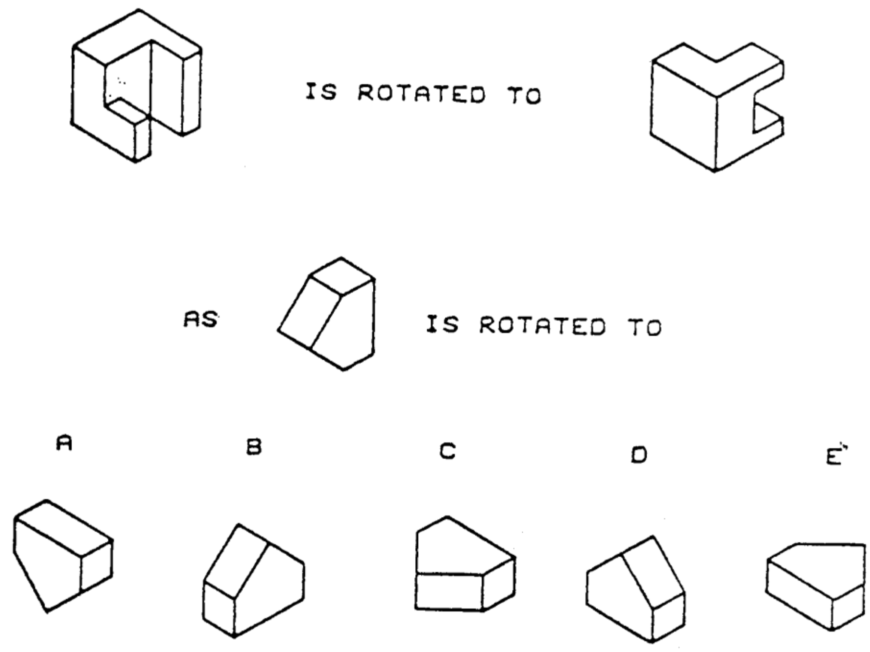
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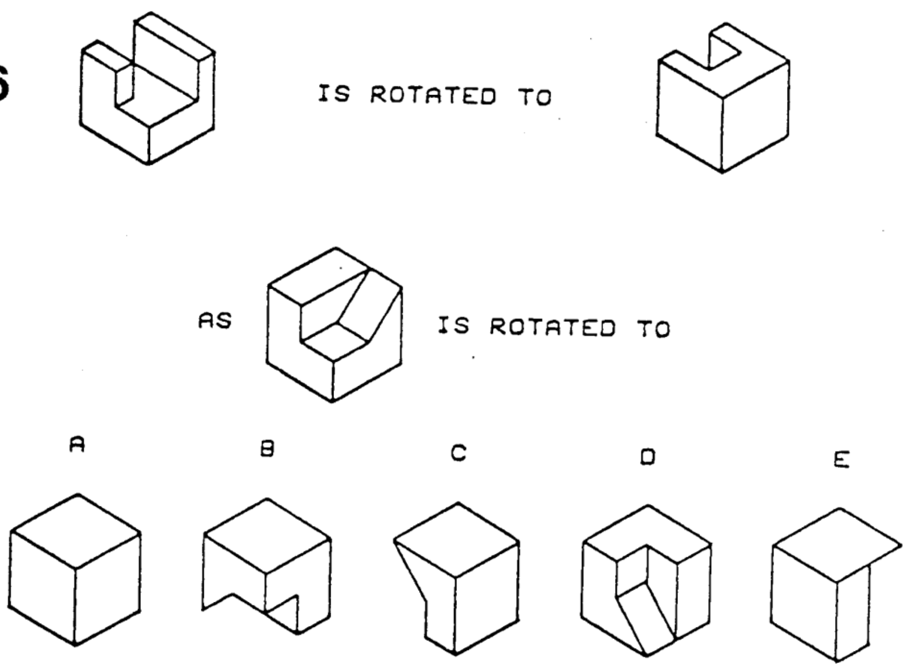
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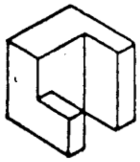
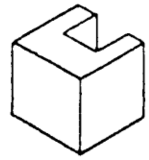
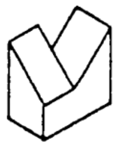
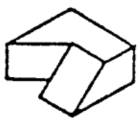
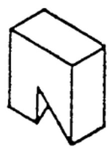
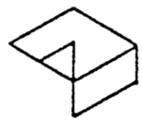
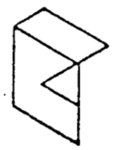
17  IS ROTATED TO 

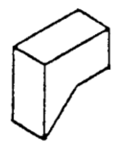
AS  IS ROTATED TO

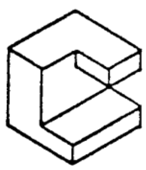
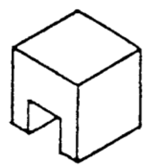
A 

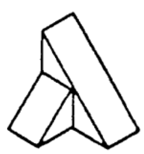
B 

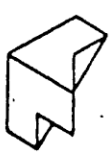
C 

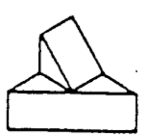
D 

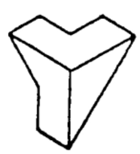
E 

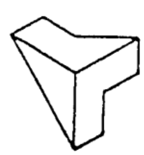
18  IS ROTATED TO 

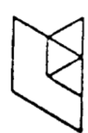
AS  IS ROTATED TO

A 

B 

C 

D 

E 

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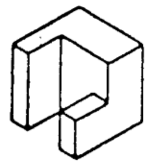

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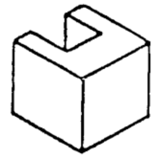

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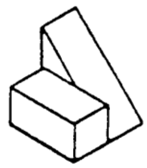

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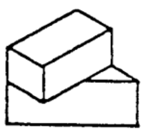

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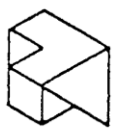

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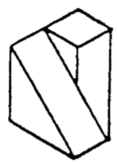

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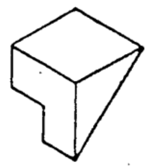

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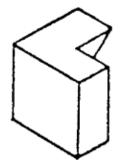

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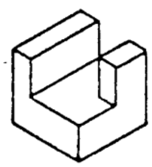

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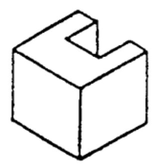

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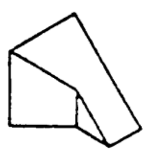

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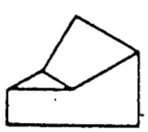

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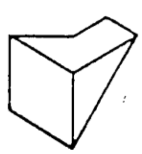

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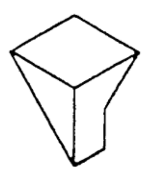

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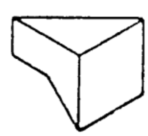


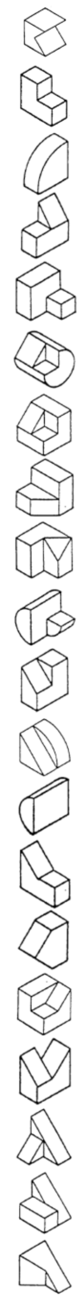
APPENDIX F

PURDUE VISUALIZATIONS OF ROTATIONS TEST ANSWER KEY

Visualizations of Rotations Test

Subject #:

1)	**A**	B	C	D	E
2)	A	B	C	**D**	E
3)	**A**	B	C	D	E
4)	A	**B**	C	D	E
5)	A	B	C	D	**E**
6)	A	B	**C**	D	E
7)	A	**B**	C	D	E
8)	A	B	C	D	**E**
9)	**A**	B	C	D	E
10)	A	B	**C**	D	E
11)	A	**B**	C	D	E
12)	A	B	C	D	**E**
13)	**A**	B	C	D	E
14)	A	B	C	D	**E**
15)	A	B	C	**D**	E
16)	**A**	B	C	D	E
17)	A	**B**	C	D	E
18)	A	B	C	**D**	E
19)	A	B	C	**D**	E
20)	A	B	C	D	**E**



Created by Matthew Atherton

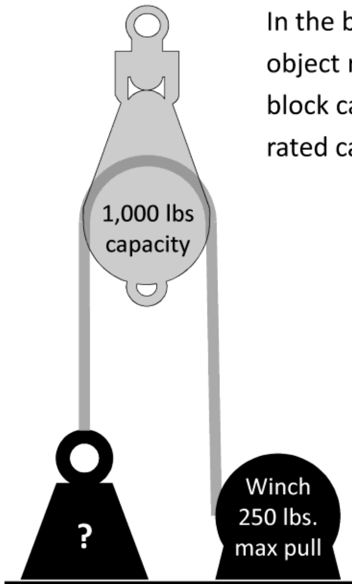
APPENDIX G

RIGGING KNOWLEDGE PRETEST & DEMOGRAPHIC DATA INSTRUMENT

Rigging Knowledge Pre-Test & Demographic Data:

Subject #:

NOTE: You are NOT expected to know these answers yet, but please see what you know and mark all answers with your confidence rating. Thank you!



In the block system pictured, a wire rope is being used to lift an object resting on the ground. A winch placed directly below the block can pull with the force of 250 lbs. maximum. The block's rated capacity is 1,000 lbs.

1) How many "parts of line" are being used in the system pictured?

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

2) Use the system pictured to answer this question: To be lifted off of the ground, what is the maximum the object can weigh?

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

3) Assume the mystery object weighs 300 lbs. and the winch is turned on. How much excess capacity remains unused in the block indicated in the picture?

lbs.

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

4) Replace just the block in the picture with one whose rated capacity is 600 lbs. To be lifted off of the ground, now what is the maximum the object can weigh?

lbs.

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

5) Go back to the original picture and replace just the winch with one that can pull with the force of 600 lbs. maximum. To be lifted off the ground and not exceed the block's 1000 lbs. of capacity, what is the maximum the object can weigh?

lbs.

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

Created by Matthew Atherton

Rigging Knowledge Pre-Test & Demographic Data:

Subject #:

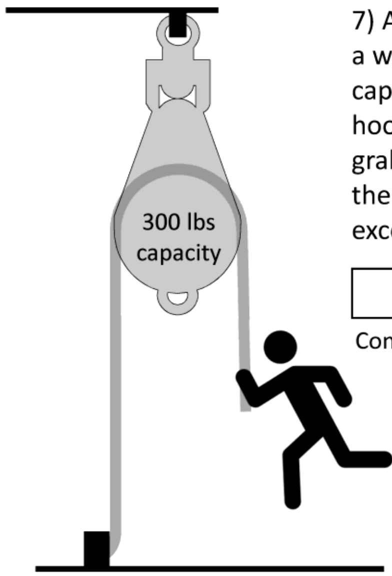
6) Circle the correct word beneath each blank to complete the sentence:

The more ______________ we use correctly in a block and tackle
rope, sheaves, weight

system, the more we can ______________
increase, decrease, ensure

the ______________ of our ______________ .
friction, strength, result *system, effort, blocks*

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing



7) A person sees a block attached to the ceiling with a wire rope hanging down. The block's rated capacity is 300 lbs. The other end of the wire rope is hooked to the floor. If the person jumps up and grabs the rope, suspending himself from it, what is the maximum the person could weigh without exceeding the block's capacity?

[ ] lbs.

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

Why?

8) How many months of rigging experience do you have?

9) What is your age?

10) What is your gender?

Created by Matthew Atherton

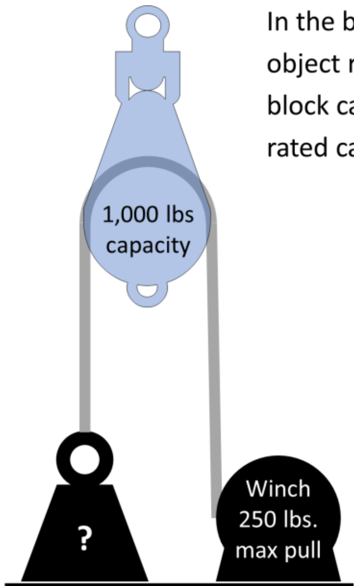
APPENDIX H

RIGGING KNOWLEDGE PRETEST & DEMOGRAPHIC DATA ANSWER KEY

Rigging Knowledge Pre-Test & Demographic Data:

Subject #:

NOTE: You are NOT expected to know these answers yet, but please see what you know and mark all answers with your confidence rating. Thank you!



In the block system pictured, a wire rope is being used to lift an object resting on the ground. A winch placed directly below the block can pull with the force of 250 lbs. maximum. The block's rated capacity is 1,000 lbs.

1) How many "parts of line" are being used in the system pictured?

1

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

2) Use the system pictured to answer this question: To be lifted off of the ground, what is the maximum the object can weigh?

250 lbs.

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

3) Assume the mystery object weighs 300 lbs. and the winch is turned on. How much excess capacity remains unused in the block indicated in the picture?

500 lbs. (1000 – (250 + 250)) lbs.

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

4) Replace just the block in the picture with one whose rated capacity is 600 lbs. To be lifted off of the ground, now what is the maximum the object can weigh?

250 lbs. lbs.

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

5) Go back to the original picture and replace just the winch with one that can pull with the force of 600 lbs. maximum. To be lifted off the ground and not exceed the block's 1000 lbs. of capacity, what is the maximum the object can weigh?

500 lbs. lbs.

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

Created by Matthew Atherton

Rigging Knowledge Pre-Test & Demographic Data:

Subject #:

6) Circle the correct word beneath each blank to complete the sentence:

The more ______________ we use correctly in a block and tackle

rope, sheaves, weight

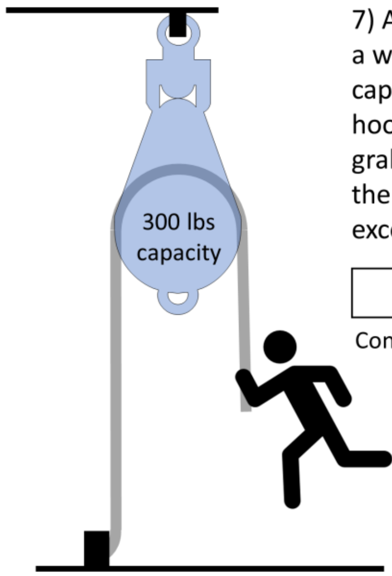
system, the more we can ______________

increase, decrease, ensure

the ______________ of our ______________ .

friction, strength, result *system, effort, blocks*

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing



7) A person sees a block attached to the ceiling with a wire rope hanging down. The block's rated capacity is 300 lbs. The other end of the wire rope is hooked to the floor. If the person jumps up and grabs the rope, suspending himself from it, what is the maximum the person could weigh without exceeding the block's capacity?

150 lbs. lbs.

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

Why?

Because an equal force is exerted on the rope going to the floor.

8) How many months of rigging experience do you have?

9) What is your age?

10) What is your gender?

Created by Matthew Atherton

APPENDIX I

PRACTICE EXERCISE INSTRUMENTS, MATH WORKSHEETS, &

FEEDBACK SHEETS (CONTROL GROUP)

VIDEO 1:

Subject #:

Practice

1. Consider a ***fixed*** block system in which a 800 lb. weight is lifted from the ground.

1a. What line pull is required to lift the 800 lb. weight off the ground?

Confidence (check one): □Low □Medium □High □Guessing

1b. What direction is the line pull?

Confidence (check one): □Low □Medium □High □Guessing

1c. When the line is pulled 2 feet, how high will the load be lifted off the ground?

Confidence (check one): □Low □Medium □High □Guessing

1d. What capacity block is required?

Confidence (check one): □Low □Medium □High □Guessing

2. Circle the correct word beneath each blank to complete the sentence:

The more ______________ we use correctly in a block and tackle

rope, sheaves, weight

system, the more we can ______________

increase, decrease, ensure

the ______________ of our ______________ .

friction, strength, result *system, effort, blocks*

Confidence (check one): □Low □Medium □High □Guessing

Created by Matthew Atherton

VIDEO 1: ***Practice***

Subject #:

After answering the previous questions, please complete the exercises below until instructed to stop (this will take no more than 5 minutes).

Calculate each sum or difference.

8673 − 1448	9759 − 9133	3225 − 2649	8646 + 9848	5574 − 4984
8062 − 1538	7030 + 8803	8105 + 6802	3893 + 4439	5337 − 2864
4598 + 3634	6987 − 5802	5916 − 1806	3204 − 2652	2897 + 5307
8028 − 3275	6911 + 6251	6074 + 2922	3729 − 2402	4245 − 1949
6995 − 6515	8464 + 8067	5751 + 8665	4376 − 1767	8057 + 4061

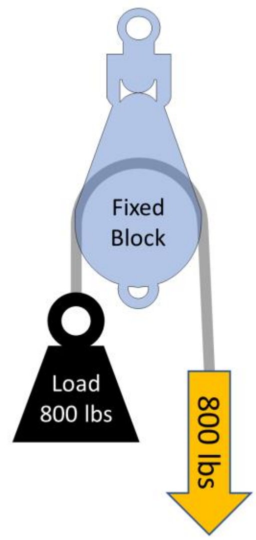
Created by Matthew Atherton

VIDEO 1:

Subject #:

Feedback

1. Consider a ***fixed*** block system in which an 800 lb. weight is lifted from the ground.



1a. What line pull is required to lift the 800 lb. weight off the ground?

800 lbs

1b. What direction is the line pull?

Down

1c. When the line is pulled 2 feet, how high will the load be lifted off the ground?

2 feet

1d. What capacity block is required?

1,600 lbs.

2. Circle the correct word beneath each blank to complete the sentence:

The more ______________ we use correctly in a block and tackle

rope, sheaves, weight

system, the more we can ______________

increase, decrease, ensure

the ______________ of our ______________ .

friction, strength, result *system, effort, blocks*

Created by Matthew Atherton

VIDEO 2:

Subject #:

Practice

1. Consider a ***traveling*** block system in which a 800 lb. weight is lifted from the ground.

1a. What line pull is required to lift the 800 lb. weight off the ground?

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

1b. What direction is the line pull?

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

1c. When the line is pulled 2 feet, how high will the load be lifted off the ground?

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

1d. What capacity block is required?

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

2. Circle the correct word beneath each blank to complete the sentence:

The more _______________ we use, reeved through a combination of
weights, parts of line, wire rope

blocks and sheaves, the _______________ amount of weight we can
greater, smaller, better

move with the _______________ amount of _______________ .
most, least, better *friction, sheaves, effort*

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

Created by Matthew Atherton

VIDEO 2: ***Practice***

Subject #:

After answering the previous questions, please complete the exercises below until instructed to stop (this will take no more than 5 minutes).

Calculate each difference.

21377 − 8207	46017 − 9083	91575 − 2142	95693 − 7133
54254 − 3794	65649 − 9680	86613 − 2069	49192 − 7497
28545 − 3110	35740 − 3888	55870 − 9206	35552 − 2326
61281 − 1710	49044 − 9614	35377 − 4419	16207 − 2126
24242 − 4907	34643 − 1957	15213 − 4606	31227 − 6592

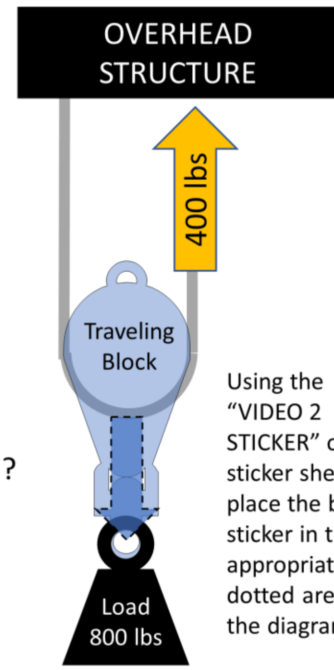
Created by Matthew Atherton

VIDEO 2:

Subject #:

Feedback:

1. Consider a ***traveling*** block system in which an 800 lb. weight is lifted from the ground.



1a. What line pull is required to lift the 800 lb. weight off the ground?

400 lbs

1b. What direction is the line pull?

Up

1c. When the line is pulled 2 feet, how high will the load be lifted off the ground?

1 foot

1d. What capacity block is required?

800 lbs.

Using the "VIDEO 2 STICKER" on the sticker sheet, place the blue sticker in the appropriate dotted area of the diagram.

You'll be using these stickers on the final exam to design your own block system. Placing the sticker on this feedback sheet is just to provide some familiarity with the stickers and how they should be placed.

2. Circle the correct word beneath each blank to complete the sentence:

The more _______________ we use, reeved through a combination of
weights, parts of line, wire rope

blocks and sheaves, the _______________ amount of weight we can
greater, smaller, better

move with the _______________ amount of _______________.
most, least, better *friction, sheaves, effort*

Created by Matthew Atherton

VIDEO 3:

Subject #:

Practice

1. Consider a block system in which a 750 lb. weight is lifted from the ground using one traveling block and ***one*** fixed block where three parts of line are used.

1a. What line pull is required to lift the 750 lb. weight off the ground?

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

1b. What is the required capacity of the fixed block?

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

1c. What is the required capacity of the traveling block?

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

2. Consider a block system in which a 750 lb. weight is lifted from the ground using one traveling block and ***two*** fixed blocks where three parts of line are used.

2a. What line pull is required to lift the 750 lb. weight off the ground?

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

2b. What is the required capacity of the additional fixed block?

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

2c. What is the required capacity of the traveling block?

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

Created by Matthew Atherton

VIDEO 3: ***Practice***

Subject #:

After answering the previous questions, please complete the exercises below until instructed to stop (this will take no more than 5 minutes).

Calculate each sum.

	9	9	6	9
	6	6	7	5
	3	9	7	6
+	4	1	8	1

	1	5	7	3
	7	6	4	4
	5	9	1	5
+	8	5	9	4

	5	7	0	7
	7	8	4	6
	9	9	2	0
+	9	8	0	4

	5	3	6	2
	1	1	4	0
	6	8	2	1
+	5	3	2	5

	6	8	5	6
	7	3	4	3
	3	4	6	8
+	6	6	2	8

	2	4	0	3
	1	8	6	6
	5	0	6	8
+	7	4	3	1

	6	1	5	7
	5	0	0	3
	8	8	9	8
+	7	6	5	5

	2	1	8	6
	8	0	6	6
	8	2	1	6
+	5	3	7	5

	4	5	2	2
	6	2	3	8
	1	6	5	2
+	9	6	6	4

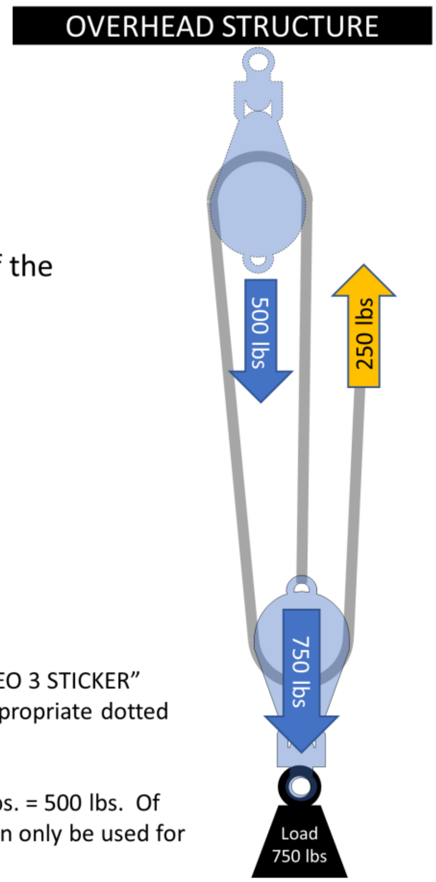
Created by Matthew Atherton

VIDEO 3:

Subject #:

Feedback

1. Consider a block system in which a 750 lb. weight is lifted from the ground using one traveling block and ***one*** fixed block where three parts of line are used.



1a. What line pull is required to lift the 750 lb. weight off the ground?

250 lbs

1b. What is the required capacity of the fixed block?

500 lbs

1c. What is the required capacity of the traveling block?

750 lbs

Remove the .25 TON block sticker from the "VIDEO 3 STICKER" section of the sticker sheet and place it in the appropriate dotted area of the diagram.

Since there are 2000 lbs. in a TON, 0.25 X 2000 lbs. = 500 lbs. Of these two blocks, the 0.25 TON capacity block can only be used for the fixed block.

You'll be using these stickers on the final exam to design your own block system. Placing the sticker on this feedback sheet is just to provide some familiarity with the stickers and how they should be placed.

Created by Matthew Atherton

VIDEO 3:

Subject #:

Feedback

2. Consider a block system in which a 750 lb. weight is lifted from the ground using one traveling block and ***two*** fixed blocks where three parts of line are used.

2a. What line pull is required to lift the 750 lb. weight off the ground?

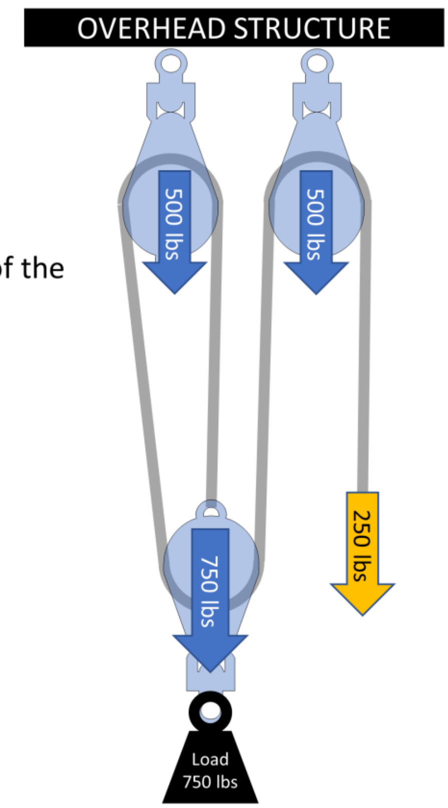
250 lbs

1b. What is the required capacity of the additional fixed block?

500 lbs

1c. What is the required capacity of the traveling block?

750 lbs



Created by Matthew Atherton

APPENDIX J

PRACTICE EXERCISE INSTRUMENTS & FEEDBACK SHEETS (DRAWING GROUP)

VIDEO 1:

Subject #:

Practice: (Paper & Pencil)

1. With the pencil and paper provided, draw a ***fixed*** block system in which a 800 lb. weight is lifted from the ground.

1a. What line pull is required to lift the 800 lb. weight off the ground?

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

1b. What direction is the line pull?

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

1c. When the line is pulled 2 feet, how high will the load be lifted off the ground?

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

1d. What capacity block is required?

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

2. Circle the correct word beneath each blank to complete the sentence:

The more ______________ we use correctly in a block and tackle
rope, sheaves, weight

system, the more we can ______________
increase, decrease, ensure

the ______________ of our ______________ .
friction, strength, result *system, effort, blocks*

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

Created by Matthew Atherton

VIDEO 1: ***Drawing (Paper & Pencil)***

Subject #:

1. *(you may rotate this page and draw in portrait orientation)* **1.**

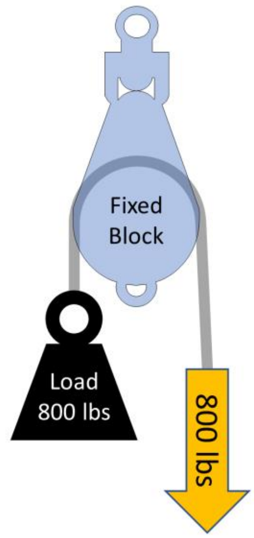
Created by Matthew Atherton

VIDEO 1:

Subject #:

Feedback: (Paper & Pencil)

1. With the pencil and paper provided, draw a ***fixed*** block system in which an 800 lb. weight is lifted from the ground.



1a. What line pull is required to lift the 800 lb. weight off the ground?

800 lbs

1b. What direction is the line pull?

Down

1c. When the line is pulled 2 feet, how high will the load be lifted off the ground?

2 feet

1d. What capacity block is required?

1,600 lbs.

2. Circle the correct word beneath each blank to complete the sentence:

The more ______________ we use correctly in a block and tackle

rope, sheaves, weight

system, the more we can ______________

increase, decrease, ensure

the ______________ of our ______________ .

friction, strength, result *system, effort, blocks*

Created by Matthew Atherton

VIDEO 2:

Subject #:

Practice: (Paper & Pencil)

1. With the pencil and paper provided, draw a ***traveling*** block system in which a 800 lb. weight is lifted from the ground.

1a. What line pull is required to lift the 800 lb. weight off the ground?

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

1b. What direction is the line pull?

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

1c. When the line is pulled 2 feet, how high will the load be lifted off the ground?

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

1d. What capacity block is required?

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

2. Circle the correct word beneath each blank to complete the sentence:

The more _______________ we use, reeved through a combination of
weights, parts of line, wire rope

blocks and sheaves, the _______________ amount of weight we can
greater, smaller, better

move with the _______________ amount of _______________ .
most, least, better *friction, sheaves, effort*

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

Created by Matthew Atherton

VIDEO 2: ***Drawing (Paper & Pencil)***

Subject #:

1. *(you may rotate this page and draw in portrait orientation)* **1.**

Created by Matthew Atherton

VIDEO 2:

Subject #:

Feedback: (Paper & Pencil)

1. With the pencil and paper provided, draw a ***traveling*** block system in which an 800 lb. weight is lifted from the ground.

1a. What line pull is required to lift the 800 lb. weight off the ground?

400 lbs

1b. What direction is the line pull?

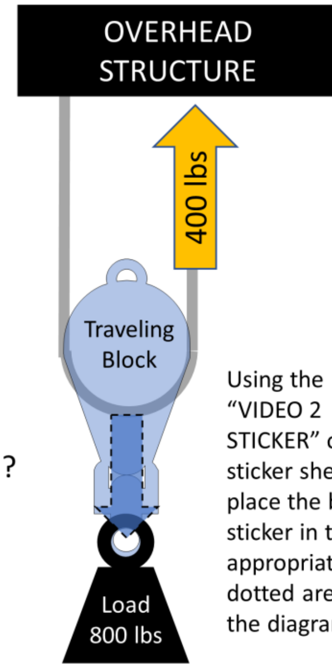
Up

1c. When the line is pulled 2 feet, how high will the load be lifted off the ground?

1 foot

1d. What capacity block is required?

800 lbs.



Using the "VIDEO 2 STICKER" on the sticker sheet, place the blue sticker in the appropriate dotted area of the diagram.

You'll be using these stickers on the final exam to design your own block system. Placing the sticker on this feedback sheet is just to provide some familiarity with the stickers and how they should be placed.

2. Circle the correct word beneath each blank to complete the sentence:

The more _______________ we use, reeved through a combination of
weights, parts of line, wire rope

blocks and sheaves, the _______________ amount of weight we can
greater, smaller, better

move with the _______________ amount of _______________.
most, least, better *friction, sheaves, effort*

Created by Matthew Atherton

VIDEO 3:

Subject #:

Practice: (Paper & Pencil)

1. With the pencil and paper provided, draw a block system in which a 750 lb. weight is lifted from the ground using one traveling block and ***one*** fixed block where three parts of line are used.

1a. What line pull is required to lift the 750 lb. weight off the ground?

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

1b. What is the required capacity of the fixed block?

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

1c. What is the required capacity of the traveling block?

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

2. With the pencil and paper provided, draw a block system in which a 750 lb. weight is lifted from the ground using one traveling block and ***two*** fixed blocks where three parts of line are used.

2a. What line pull is required to lift the 750 lb. weight off the ground?

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

2b. What is the required capacity of the additional fixed block?

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

2c. What is the required capacity of the traveling block?

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

Created by Matthew Atherton

VIDEO 3: ***Drawing (Paper & Pencil)***

Subject #:

1. *(you may rotate this page and draw in portrait orientation)* **1.**

2. *(you may rotate this page and draw in portrait orientation)* **2.**

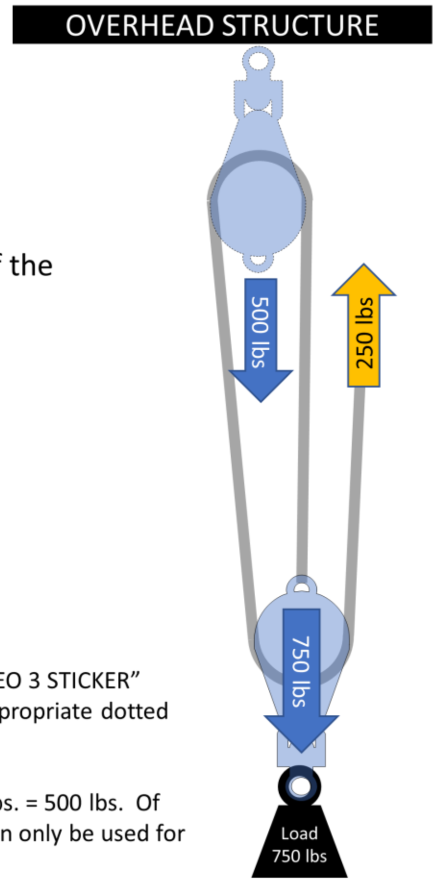
Created by Matthew Atherton

Subject #:

VIDEO 3:

Feedback: (Paper & Pencil)

1. With the pencil and paper provided, draw a block system in which a 750 lb. weight is lifted from the ground using one traveling block and ***one*** fixed block where three parts of line are used.



1a. What line pull is required to lift the 750 lb. weight off the ground?

250 lbs

1b. What is the required capacity of the fixed block?

500 lbs

1c. What is the required capacity of the traveling block?

750 lbs

Remove the .25 TON block sticker from the "VIDEO 3 STICKER" section of the sticker sheet and place it in the appropriate dotted area of the diagram.

Since there are 2000 lbs. in a TON, 0.25 X 2000 lbs. = 500 lbs. Of these two blocks, the 0.25 TON capacity block can only be used for the fixed block.

You'll be using these stickers on the final exam to design your own block system. Placing the sticker on this feedback sheet is just to provide some familiarity with the stickers and how they should be placed.

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VIDEO 3:

Subject #:

Feedback: (Paper & Pencil)

2. With the pencil and paper provided, draw a block system in which a 750 lb. weight is lifted from the ground using one traveling block and ***two*** fixed blocks where three parts of line are used.

2a. What line pull is required to lift the 750 lb. weight off the ground?

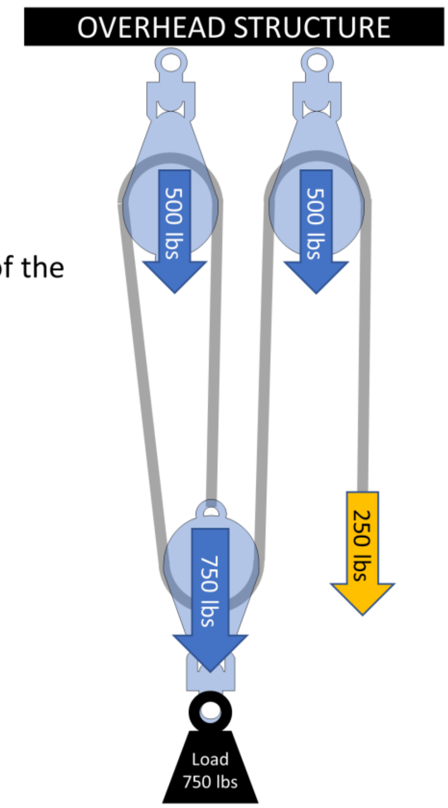
250 lbs

1b. What is the required capacity of the additional fixed block?

500 lbs

1c. What is the required capacity of the traveling block?

750 lbs



Created by Matthew Atherton

APPENDIX K

PRACTICE EXERCISE INSTRUMENTS & FEEDBACK SHEETS (3D MODELS GROUP)

VIDEO 1:

Subject #:

Practice

1. Consider a ***fixed*** block system in which a 800 lb. weight is lifted from the ground. Use the 3D models provided to build such a system and answer the questions below.

1a. What line pull is required to lift the 800 lb. weight off the ground?

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

1b. What direction is the line pull?

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

1c. When the line is pulled 2 feet, how high will the load be lifted off the ground?

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

1d. What capacity block is required?

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

2. Circle the correct word beneath each blank to complete the sentence:

The more ______________ we use correctly in a block and tackle
rope, sheaves, weight

system, the more we can ______________
increase, decrease, ensure

the ______________ of our ______________ .
friction, strength, result *system, effort, blocks*

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

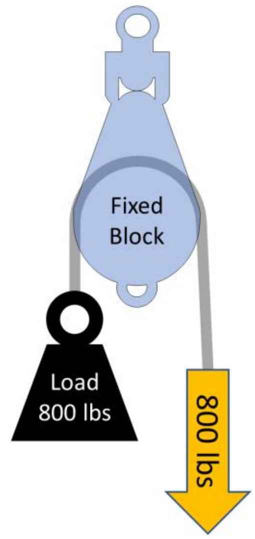
Created by Matthew Atherton

VIDEO 1:

Subject #:

Feedback

1. Consider a ***fixed*** block system in which an 800 lb. weight is lifted from the ground. Use the 3D models provided to build such a system and answer the questions below.



1a. What line pull is required to lift the 800 lb. weight off the ground?

800 lbs

1b. What direction is the line pull?

Down

1c. When the line is pulled 2 feet, how high will the load be lifted off the ground?

2 feet

1d. What capacity block is required?

1,600 lbs.

2. Circle the correct word beneath each blank to complete the sentence:

The more _____________ we use correctly in a block and tackle

rope, sheaves, weight

system, the more we can _____________

increase, decrease, ensure

the _____________ of our _____________ .

friction, strength, result *system, effort, blocks*

Created by Matthew Atherton

VIDEO 2:

Subject #:

Practice

1. Consider a ***traveling*** block system in which a 800 lb. weight is lifted from the ground. Use the 3D models provided to build such a system and answer the questions below.

1a. What line pull is required to lift the 800 lb. weight off the ground?

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

1b. What direction is the line pull?

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

1c. When the line is pulled 2 feet, how high will the load be lifted off the ground?

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

1d. What capacity block is required?

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

2. Circle the correct word beneath each blank to complete the sentence:

The more _______________ we use, reeved through a combination of
weights, parts of line, wire rope

blocks and sheaves, the _______________ amount of weight we can
greater, smaller, better

move with the _______________ amount of _______________ .
most, least, better *friction, sheaves, effort*

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

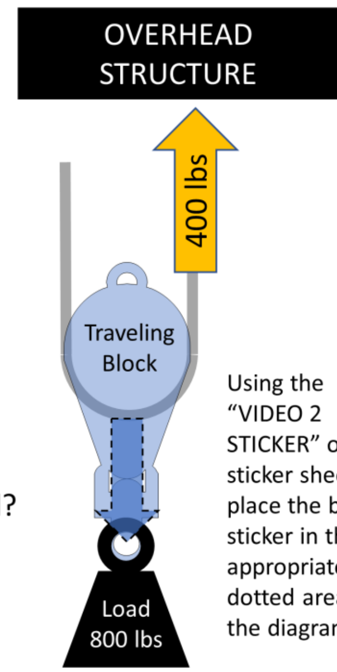
Created by Matthew Atherton

VIDEO 2:

Subject #:

Feedback:

1. Consider a ***traveling*** block system in which an 800 lb. weight is lifted from the ground. Use the 3D models provided to build such a system and answer the questions below.



Using the "VIDEO 2 STICKER" on the sticker sheet, place the blue sticker in the appropriate dotted area of the diagram.

1a. What line pull is required to lift the 800 lb. weight off the ground?

400 lbs

1b. What direction is the line pull?

Up

1c. When the line is pulled 2 feet, how high will the load be lifted off the ground?

1 foot

1d. What capacity block is required?

800 lbs.

You'll be using these stickers on the final exam to design your own block system. Placing the sticker on this feedback sheet is just to provide some familiarity with the stickers and how they should be placed.

2. Circle the correct word beneath each blank to complete the sentence:

The more ______________ we use, reeved through a combination of

weights, parts of line, wire rope

blocks and sheaves, the ______________ amount of weight we can

greater, smaller, better

move with the ______________ amount of ______________.

most, least, better *friction, sheaves, effort*

Created by Matthew Atherton

VIDEO 3:

Subject #:

Practice

1. Consider a block system in which a 750 lb. weight is lifted from the ground using one traveling block and ***one*** fixed block where three parts of line are used. Use the 3D models provided to build such a system and answer the questions below.

1a. What line pull is required to lift the 750 lb. weight off the ground?

Confidence (check one): □Low □Medium □High □Guessing

1b. What is the required capacity of the fixed block?

Confidence (check one): □Low □Medium □High □Guessing

1c. What is the required capacity of the traveling block?

Confidence (check one): □Low □Medium □High □Guessing

2. Consider a block system in which a 750 lb. weight is lifted from the ground using one traveling block and ***two*** fixed blocks where three parts of line are used. Use the 3D models provided to build such a system and answer the questions below.

2a. What line pull is required to lift the 750 lb. weight off the ground?

Confidence (check one): □Low □Medium □High □Guessing

2b. What is the required capacity of the additional fixed block?

Confidence (check one): □Low □Medium □High □Guessing

2c. What is the required capacity of the traveling block?

Confidence (check one): □Low □Medium □High □Guessing

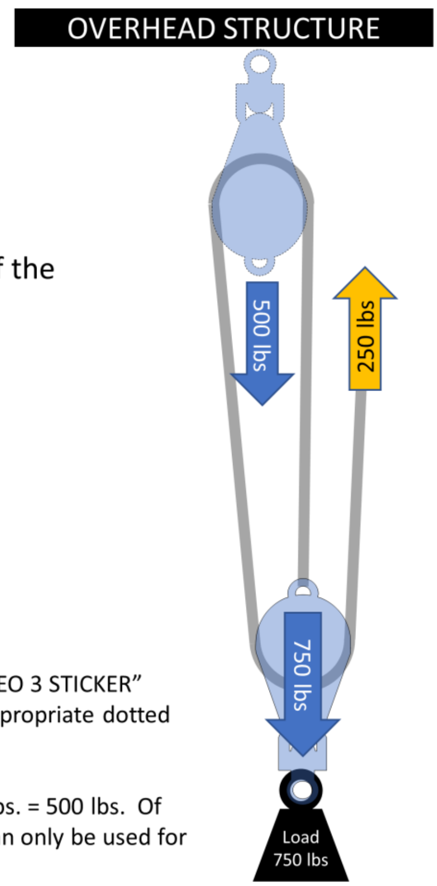
Created by Matthew Atherton

VIDEO 3:

Subject #:

Feedback

1. Consider a block system in which a 750 lb. weight is lifted from the ground using one traveling block and ***one*** fixed block where three parts of line are used. Use the 3D models provided to build such a system and answer the questions below.



1a. What line pull is required to lift the 750 lb. weight off the ground?

250 lbs

1b. What is the required capacity of the fixed block?

500 lbs

1c. What is the required capacity of the traveling block?

750 lbs

Remove the .25 TON block sticker from the “VIDEO 3 STICKER” section of the sticker sheet and place it in the appropriate dotted area of the diagram.

Since there are 2000 lbs. in a TON, 0.25 X 2000 lbs. = 500 lbs. Of these two blocks, the 0.25 TON capacity block can only be used for the fixed block.

You’ll be using these stickers on the final exam to design your own block system. Placing the sticker on this feedback sheet is just to provide some familiarity with the stickers and how they should be placed.

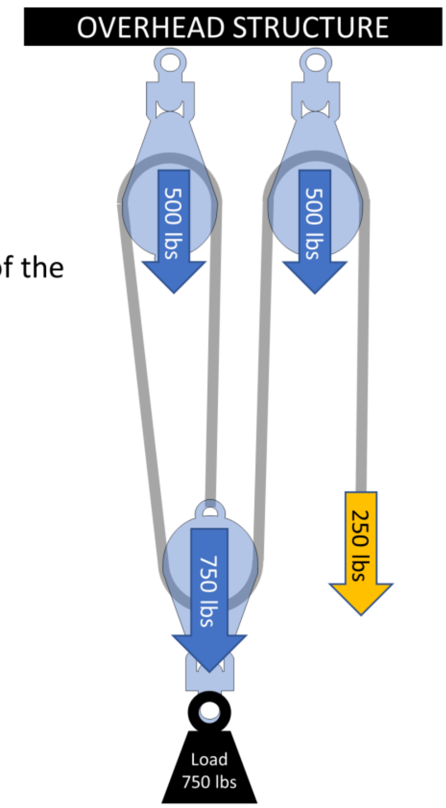
Created by Matthew Atherton

VIDEO 3:

Subject #:

Feedback

2. Consider a block system in which a 750 lb. weight is lifted from the ground using one traveling block and ***two*** fixed blocks where three parts of line are used. Use the 3D models provided to build such a system and answer the questions below.



2a. What line pull is required to lift the 750 lb. weight off the ground?

250 lbs

1b. What is the required capacity of the additional fixed block?

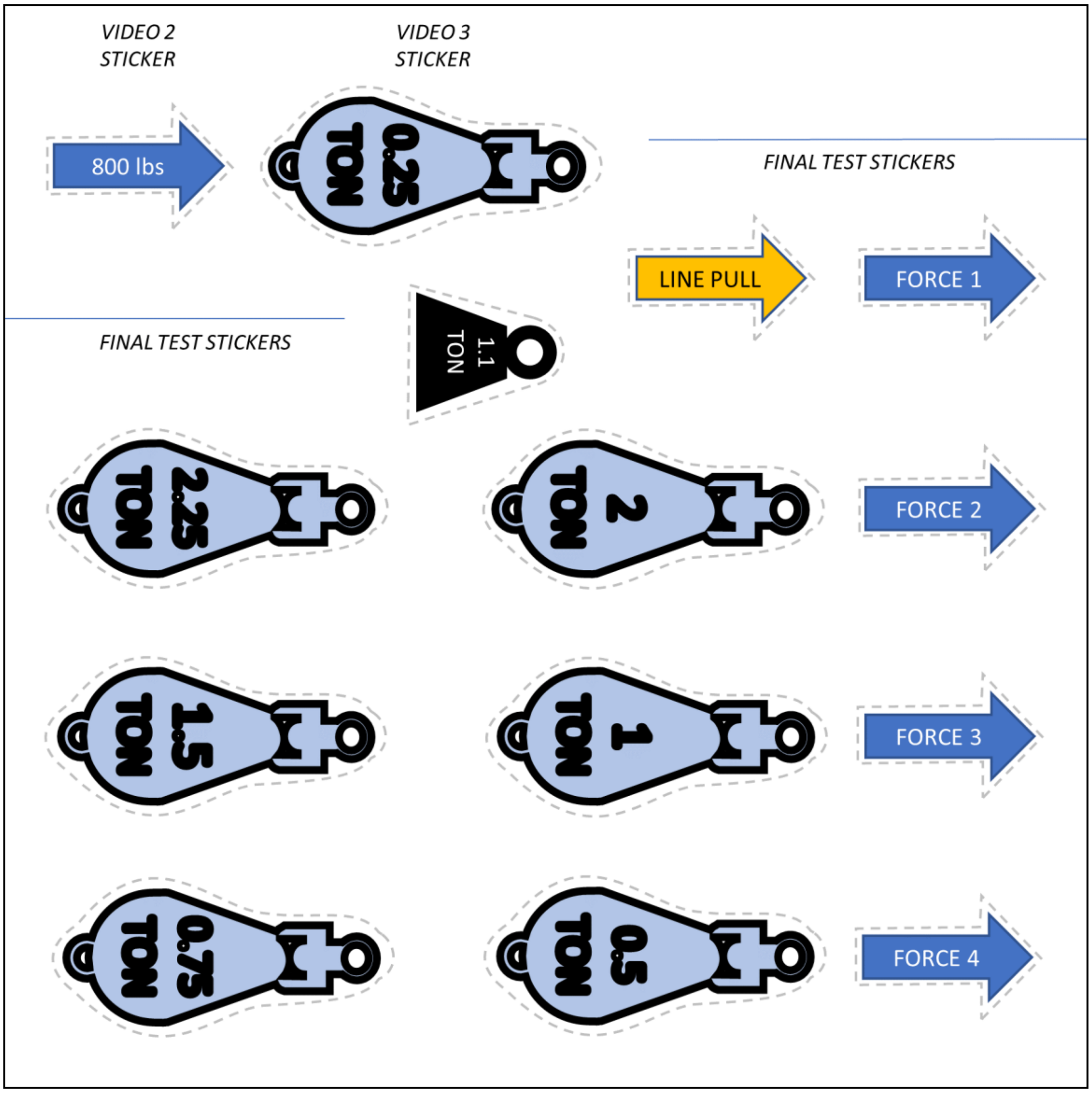
500 lbs

1c. What is the required capacity of the traveling block?

750 lbs

APPENDIX L

STICKERS FOR PRACTICE EXERCISE FEEDBACK SHEETS & FINAL TEST



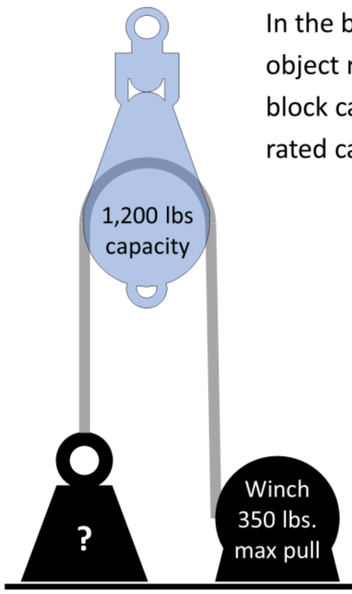
Created by Matthew Atherton

APPENDIX M

FINAL TEST INSTRUMENT

Final Test Questions:

Subject #:



In the block system pictured, a wire rope is being used to lift an object resting on the ground. A winch placed directly below the block can pull with the force of 350 lbs. maximum. The block's rated capacity is 1,200 lbs.

1) How many "parts of line" are being used in the system pictured?

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

2) Use the system pictured to answer this question: To be lifted off of the ground, what is the maximum the object can weigh?

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

3) Assume the mystery object weighs 300 lbs. and the winch is turned on. How much excess capacity remains unused in the block indicated in the picture?

lbs.

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

4) Replace just the block in the picture with one whose rated capacity is 800 lbs. To be lifted off of the ground, now what is the maximum the object can weigh?

lbs.

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

5) Go back to the original picture and replace just the winch with one that can pull with the force of 800 lbs. maximum. To be lifted off the ground and not exceed the block's 1200 lbs. of capacity, what is the maximum the object can weigh?

lbs.

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

page 1

Created by Matthew Atherton

Final Test Questions:

Subject #:

6) Which one of these determines the *mechanical advantage*:

____The number of sheaves used in the block and tackle system

____The number of parts of line used in the block and tackle system that support the load

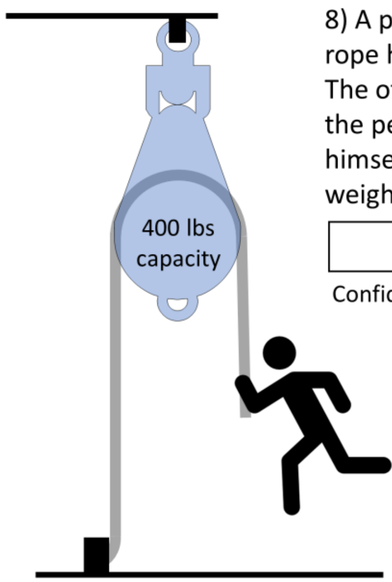
____The number of blocks used in the block and tackle system

____The amount of wire rope used in the block and tackle system that support the load

Confidence (check one): □Low □Medium □High □Guessing

7) If you had to lift a 200 lb. load, and could only use one block, would you rather use a fixed block or a traveling block, and why?

Confidence (check one): □Low □Medium □High □Guessing



8) A person sees a block attached to the ceiling with a wire rope hanging down. The block's rated capacity is 400 lbs. The other end of the wire rope is hooked to the floor. If the person jumps up and grabs the rope, suspending himself from it, what is the maximum the person could weigh without exceeding the block's capacity?

______ lbs.

Confidence (check one): □Low □Medium □High □Guessing

Why?

page 2

Created by Matthew Atherton

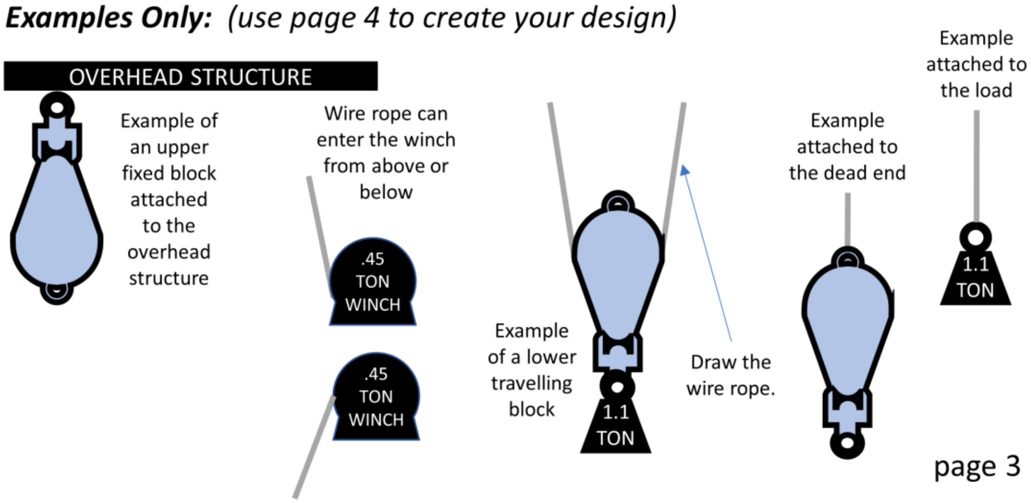
Final Test Questions:

Subject #:

9) *Place this page next to page 4 of the test so you can see both pages.* **Use the stickers provided** to design a block system to lift a 1.1 TON (2200 lb.) load. The winch has a maximum line pull of 0.45 TON (900 lbs.) and your choice of blocks range between 0.5 TON and 2.25 TON. The maximum capacity of each block is shown on its label.

- ❑ Select the "***best***" ***block*** (or blocks) ***and position***. (See position examples below.) The "best" block is the minimum Working Load Limit block available that meets the total load.
- ❑ Blocks and / or line terminations can be attached anywhere along the overhead structure.
- ❑ Place the block stickers in your drawing. (Note that you may use a block sticker with more capacity than is required, but the "best" block will be the closest to what is needed.)
- ❑ Place the orange sticker to indicate the direction of the "line pull" and indicate the required amount of line pull in question 10.
- ❑ Place the blue "force" stickers to show the correct direction of the force on each block.
- ❑ Use as many blue "force" stickers as you have blocks in your design and indicate the force withstood by each block in question 11.
- ❑ Be sure to draw the wire rope in the diagram and to place the load sticker.
- ❑ You may use calculators to determine the line pull and the force(s) on the block(s).

Examples Only: *(use page 4 to create your design)*

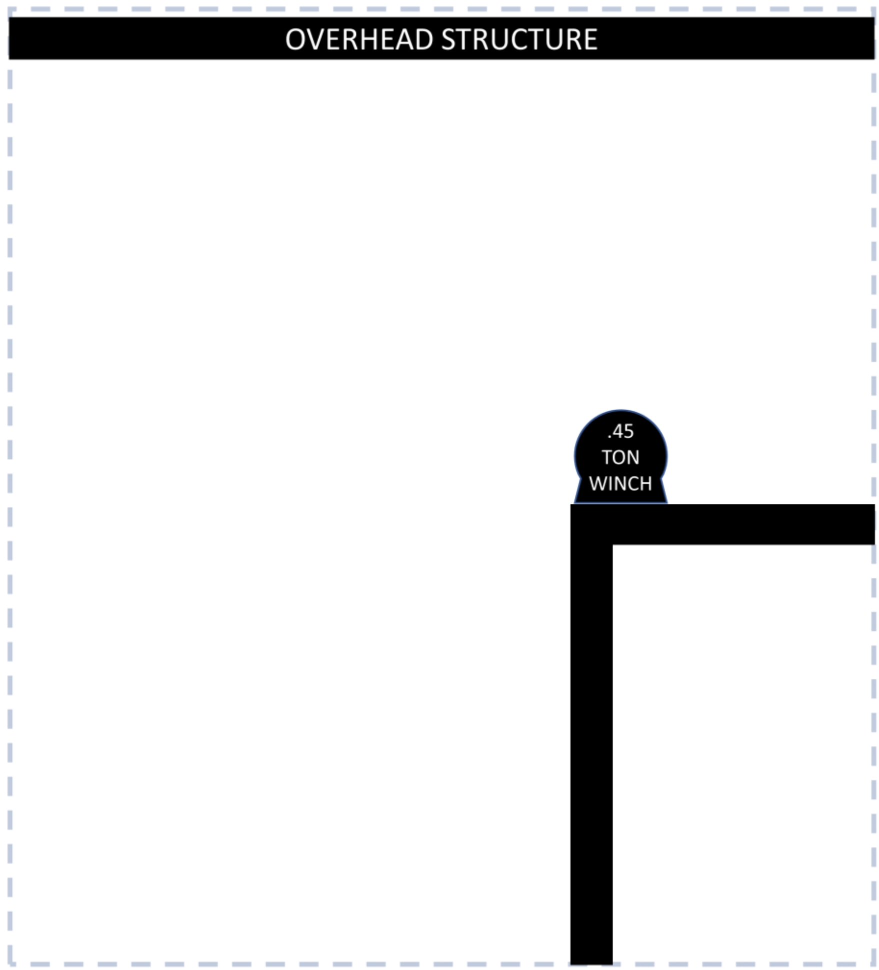


page 3

Created by Matthew Atherton

Final Test Questions:

Subject #:



10) What is the line pull? (Use lbs.)

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

11) What are the forces on the blocks? (Use lbs. Only fill in values for the arrows you used.)

1 ☐ 2 ☐ 3 ☐ 4 ☐

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

page 4

Created by Matthew Atherton

Final Test Questions:

Subject #:

12) Please rate your confidence in your block design answer:

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

13) You may provide comments here to explain your block design.

14) Please describe what you are taking away from this learning experience today and your belief in the effectiveness of the training materials.

Helpfulness of media and materials (please describe):

Ineffectiveness of media and materials (please describe):

Open area to discuss any feedback for which there is no other space:

page 5

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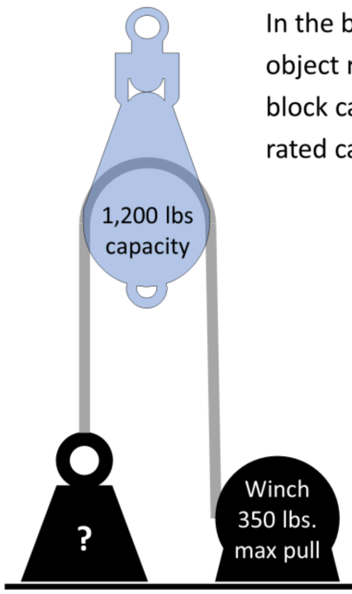
APPENDIX N

FINAL TEST ANSWER KEY

Final Test Questions:

Subject #:



In the block system pictured, a wire rope is being used to lift an object resting on the ground. A winch placed directly below the block can pull with the force of 350 lbs. maximum. The block's rated capacity is 1,200 lbs.

1) How many "parts of line" are being used in the system pictured?

1

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

2) Use the system pictured to answer this question: To be lifted off of the ground, what is the maximum the object can weigh?

350 lbs.

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

3) Assume the mystery object weighs 300 lbs. and the winch is turned on. How much excess capacity remains unused in the block indicated in the picture?

1200 – (300 + 300) = 600 lbs. lbs.

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

4) Replace just the block in the picture with one whose rated capacity is 800 lbs. To be lifted off of the ground, now what is the maximum the object can weigh?

350 lbs. lbs.

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

5) Go back to the original picture and replace just the winch with one that can pull with the force of 800 lbs. maximum. To be lifted off the ground and not exceed the block's 1200 lbs. of capacity, what is the maximum the object can weigh?

600 lbs. lbs.

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

page 1

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Final Test Questions:

Subject #:

6) Which one of these determines the *mechanical advantage*:

____The number of sheaves used in the block and tackle system

__X__The number of parts of line used in the block and tackle system that support the load

____The number of blocks used in the block and tackle system

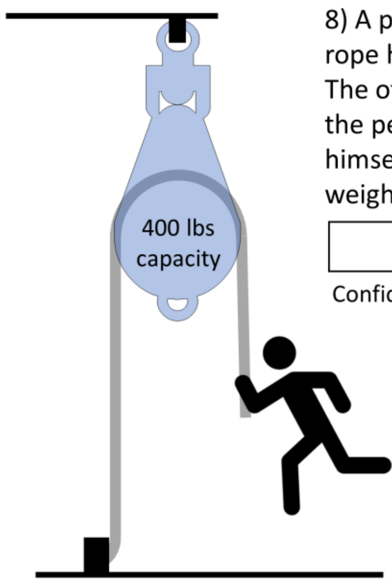
____The amount of wire rope used in the block and tackle system that support the load

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

7) If you had to lift a 200 lb. load, and could only use one block, would you rather use a fixed block or a traveling block, and why?

A fixed block, because you only have to supply 100 lbs. of force to lift the load.

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing



8) A person sees a block attached to the ceiling with a wire rope hanging down. The block's rated capacity is 400 lbs. The other end of the wire rope is hooked to the floor. If the person jumps up and grabs the rope, suspending himself from it, what is the maximum the person could weigh without exceeding the block's capacity?

200 lbs. lbs.

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

Why?

The block will experience 200 lbs. of force on both the side attached to the floor and the side supporting the person

page 2

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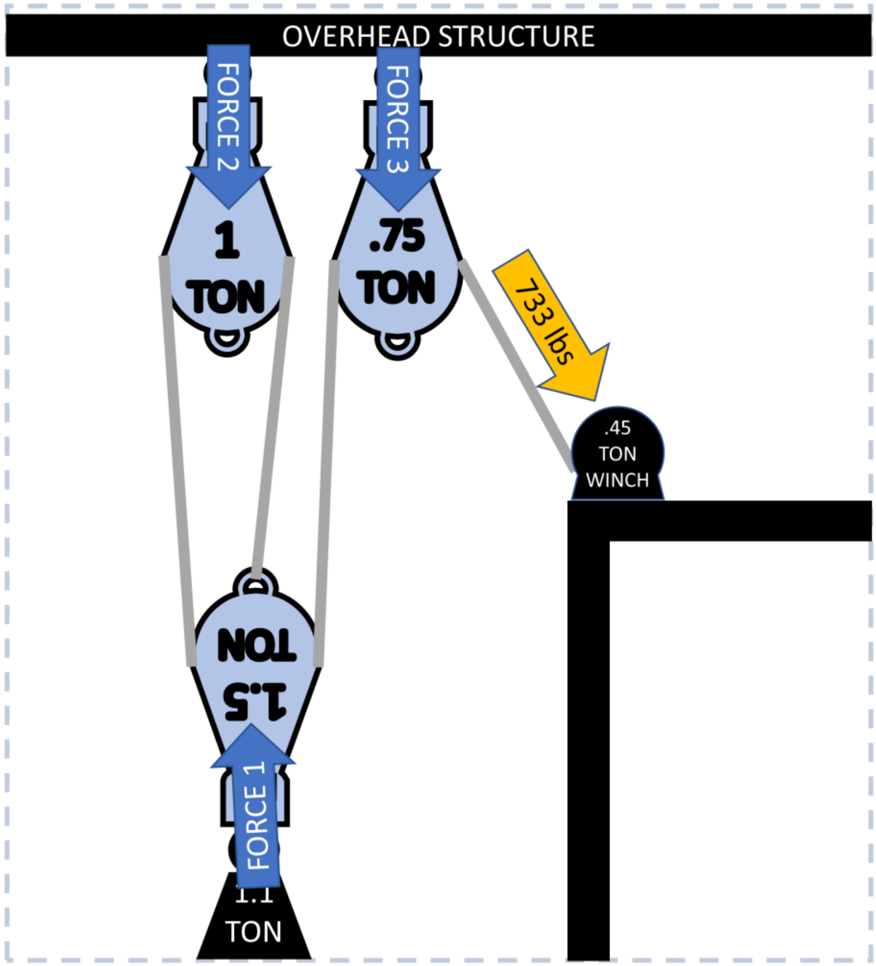
Final Test Questions:

Subject #:



10) What is the line pull? (Use lbs.)

733

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

11) What are the forces on the blocks? (Use lbs. Only fill in values for the arrows you used.)

1	2	3	4
2200	1467	1467	

Confidence (check one): ☐Low ☐Medium ☐High ☐Guessing

page 4

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