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Comparison of Simulation and Hands-On Labs in Helping High School Students Learn Physics Concepts

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School Students Learn Physics Concepts

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ABSTRACT

Comparison of Simulation and Hands-On Labs in Helping
High School Students Learn Physics Concepts

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The purpose of the research was to determine whether PhET simulation labs or hands-on labs were more effective in helping students learn physics concepts. This measure was done by comparing quiz scores using recall, calculation, and transfer questions. Additionally, student perceptions of learning from both hands-on and simulation lab experiences were measured. Six labs were conducted with high school physics students on the topics of momentum, energy, circuits, angular momentum, pendulums, and friction. It was found that PhET simulation labs were as effective at creating student understanding, and sometimes more effective, as measured by quizzes given after the labs. Additionally, the survey data revealed that students were more engaged by hands-on lab experiences, and viewed the hands-on labs to be more effective than the simulation labs.

ACKNOWLEDGEMENTS

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1   INTRODUCTION

1.1   Background

Engineering jobs are a vital part of the United States' economy, and one of the most consistently under-filled professional occupations (ManpowerGroup 2012 Survey). One solution to the employment gap has been to improve and promote STEM education, specifically in K-12 settings. Various methods have and are being employed in K-12 classrooms, such as new and revised curriculum, improved STEM assessments, increased use of technology and increased funding (i.e. Engineering is Elementary, Race to the Top, Project Lead the Way, etc). One avenue that is being utilized to meet this need is the use of online courses, tutorials, and simulations (Gibson, 2007). The eLearning market increased at an average of 9.2% annually from 2010-2015 and 33% of U.S. companies use simulation applications for their employees (Pappas 2015). The use of simulations is especially applicable to STEM because many STEM courses involve learning concepts through performing labs and designing and creating products (i.e. CAD). With the rising use of simulations, the concern is whether students learn as effectively from these as from using hands-on procedures (Rutten, 2012).

The use of laboratory experiences to aid student learning has been a part of American education since the late 1800's. The prevailing viewpoint at that time was that since scientists engaged in meticulous observation of phenomena to identify and accumulate data in support of new theories, students should engage in similar activities to better prepare themselves for higher

education and to understand the scientific method (National Research Council, 2005). While the exact emphasis that should be placed on laboratory experiences has shifted overtime, the National Research Council and National Science Foundation have concluded that lab activities provide important benefits to students. Specifically, they feel that "laboratory experiences provide opportunities for students to interact directly with the material world (or with data drawn from the material world), using the tools, data collection techniques, models, and theories of science." (National Research Council, 2005)

The College Board, the publishers of Advance Placement (AP) tests and courses, has recently – in 2012 – revamped many of its courses in an effort to better prepare students for college and careers. As part of this curriculum change they have emphasized the need for student lab work, favoring the use of hands-on activities over simulation labs citing the study done by the National Research Council in 2005 (AP Physics Teachers Manual and NSF 1996, NSF 2012, AAPT Committee on Physics in High Schools, 1992). They felt that the opportunity for students to "interact directly with the material world" was important (NRC, 2005). In fact, they now require "25 percent of the instructional time will be spent in laboratory work, with an emphasis on inquiry-based investigations" believing that this "provide[s] students with opportunities to demonstrate the foundational physics principles".

Some physics principles (i.e. universal gravity and small charge interactions) are not easily observed or reproduced in the classroom. Lab simulations have been developed to give students experiences with these phenomena. The University of Colorado developed PhET, a collection of interactive math and science simulations. While they are not the only such collection, they do offer one of the largest number of such simulations that are used by educators nationwide (PhET, 2002).

Further, proponents of simulations point out that many fields such as medicine, military, aerospace, and law enforcement use simulations to teach "real world" skills that are normally performed outside the simulation during regular work activity (Lateef, 2010). Case studies have shown that simulations can teach concepts as well or better than in-person observations (Hensberry, 2015). As will be shown in Chapter 2, while several studies have been conducted analyzing the effectiveness or other characteristics of simulation labs, few have compared them directly to hands-on labs. This research project investigated these questions of which method do students prefer and which method is more effective in the context of a high school physics class.

1.2   Research Questions

This study will attempt to answer two questions:

- Do simulations lead to better understanding for students in high school physics classes?

- Do simulations lead to better perceptions of learning for high school physics students?

The research methodology of this study was of a quasi-experimental design. Four classes were tracked over the course of a year. Two classes used simulations to explore physics concepts while two other classes used hands-on activities. Student understanding was measured through quizzes completed soon after the experiences. Students also took surveys on perceived learning after the labs to see how they respond to the two methods of instruction. It is hoped that data from this study will give educators a better understanding of the benefits and limitations of online and virtual lab experiences and their place in education.

2   REVIEW OF LITERATURE

The best educators are always looking for ways to improve their effectiveness as teachers (Kentucky Dept. of Ed, 2015). With the advent of easily accessible computer simulations, teachers have quickly integrated computer simulations into their curriculum This has been further encouraged by the availability of simulations on a wide range of subjects (Damassa, 2010). The question then arises whether these simulations are as effective as traditional teaching methods and if they should be included as supplementary material or in lieu of other activities.

2.1   Definitions

This study focused on the examination of both simulation and hands-on labs. It is necessary to then define what is meant by a lab in a physics classroom. The College Board's 2015 publication, *AP Physics 1 and 2 Inquiry-Based Lab Investigations Teachers Manual,* emphasized that labs should provide students the opportunity to model certain scientific principles such as using models to study scientific phenomenon, using mathematics, developing questions and planning investigations, collecting and analyzing data, and developing explanations. Thus, in a lab, emphasis is shifted from problem-solving through a known equation to developing an equation or model through testing of variables. In this study, both the simulation and hands-on versions of the labs encouraged students to do most, if not all, of these tasks the College Board identified as crucial aspects of physics lab. All simulation labs were

performed on a computer using resources from phet.colorado.edu while the hands-on labs were performed using various equipment in the classroom.

2.2 Effectiveness of Simulations

Early studies on this topic focused on whether computer simulations could be used at all as a part of guided inquiry or discovery learning. Computer simulations seemed to provide many advantages to support calls for inquiry-based, learner- and knowledge-centered instruction (National Research Council, 1996). For example, simulations offered the advantage of flexibility, promoting students' active engagement in problem-solving and higher-order thinking and reinforced practice (Hargrave and Kenton, 2000; Lee, 1999). In Hargrave and Kenton's study, for example, they found that using simulations gave teachers more time to guide students through deeper conceptual questions and engage them in more rigorous practice. Computer simulations had the potential to make instruction more interactive and help with abstract concepts by providing a way to visualize otherwise difficult principles (Ramasundarm et al. 2005). Ramasudarm et al. created simulations to give students opportunities to engage in inquiry-based learning with geological and other earth science field work that were difficult to do in person because of distance and time constraints. Simulations offered the opportunity to re-create aspects of the real world that would otherwise be too complex, time-consuming, or dangerous to do in a conventional classroom setting (Akpan, 2002). Specifically, Akpan looked at the use of simulations to replace conventional dissection labs which have several drawbacks due to the tools and ethics involved. He found that students performed a slightly better on a post-assessment after the simulated dissection than students who had performed the dissection in the classroom. Teachers could better focus students' attention on learning objectives when real-world

environments are simplified and extraneous cognitive load are reduced through the simulation (de Jong & van Joolingen, 1998). In general, it was found that students were able to interact well with the simulations and did need less guidance – as long as everything went smoothly. Students still struggled in similar areas to students in traditional settings, namely forming hypotheses, reaching conclusions, and explaining unexpected results as was found when a college chemistry class was asked complete a lab using a simulation instead of the traditional way. When asked to take more autonomy they still struggled to explain their reasoning or handle unexpected results (Moore, 2013).

One benefit to simulations was that students seemed to like them better (Eichinger, Nakhleh, & Auberry, 2000; Zacharia, 2003). During focus groups conducted by Eichinger, et al., students cited several perceived advantages of using computer lab modules integrated into their introductory non-majors biology course, including the flexibility of the program, the ability to cover more topics in a shorter time period, the ability to work at their own pace, and to quickly run and repeat experiments. Additionally, students consistently reported that the programs helped them to visualize and clarify the concepts involved in the experiments; however, no quantitative evidence was collected to show that the programs influenced their knowledge. The idea that students report enjoying simulations is meaningful because another study revealed that student attitudes could affect learning. Perkins et al. (2005) showed that students' beliefs about learning did not always line up with actual learning. For instance, many students thought that they learned better hands-on, although that was not always accurate. Also, students' conceptual understanding frequently deteriorated over the course of a semester (16 weeks). Yet, students who held a better view of the class (meaning, they enjoyed the content or teacher) tended to perform better. This literature finding is pertinent to this study because students in this study were given a self-

efficacy survey to rate the effectiveness of the STEM lab in which they received the treatment. It was of interest to see if their beliefs about the effectiveness of the lab matched their actual scores on the assessments. There was a chance the students in this research study would be more accurate in their perception of learning as previous studies had shown that students in science courses tend to have a more accurate perception of how well they learned (Falchikov, 1989).

Simulations have become an important part of training in many fields, including education. Research has been done to see how computer simulations or lessons can be used to supplement or replace traditional teaching. For example, in a study by Hensberry, et al (2015) fourth graders were taught fractions using a computer simulation instead of traditional instruction. The intervention involved two classes of fourth grade students using the interactive simulation over the course of four days to learn early fraction concepts. Pretests, posttests, a student attitude survey, and student focus group interviews were performed. Both procedural and conceptual knowledge of fractions improved. Student attitudes toward learning fractions with the simulation were also generally positive. This particular study was not a comparison to traditional instruction, it simply showed that simulation learning can be effective. Similar studies have been done in the fields of medicine (Stegmann, 2012), chemistry (Moore, 2013), microbiology (Huppert, 2002), and spatial reasoning (Lindgren, 2009).

The main gap in the available research is in comparing simulation labs to hands-on labs. Many aspects of computer-based learning have been studied, but this area has had limited research. For example, a study was done with high school students in Kenya in the field of biology. There students were divided into those who would undergo traditional lecture instruction and those who would participate in a simulation lab. Despite the pre-assessment

scores being essentially the same, the post-assessment scores showed a statistically significant gain in favor of those who had completed the simulation (Kiboss, 2004). This comparison of simulation labs to traditional learning has looked at other elements such as improvement in student discussion (Stern, 2008) and attitudes (Duran, 2007). Even the few studies that do compare simulation labs and hands-on labs compare things other than achievement. For example, Gibbons et al. looked at augmenting lab courses at the university level and focused on the results of decreased study time for students who did the simulation lab (Gibbons, 2004).

One study that did actually compare hands-on and simulation labs for student learning was a physics study, consequently it was of special interest because of the shared content field. Zacharia (2007) performed a case study comparing student learning with circuits between simulations and physical lab experiences. He found that simulations led to greater conceptual understanding of how electrons moved in a circuit and Ohm's law. His finding supports an earlier study which showed that students studying circuits showed greater conceptual understanding from simulations (Finkelstein, 2005). However, the limited scope of these studies highlights the limited reported research in physics and shows the need for a more robust study, which this current research project attempted to provide by comparing several topics over several months. In other words, the problem is that limited has been done comparing the effectiveness of hands-on and simulation labs, specifically in the realm of physics.

It is important to note that some early studies reported inconclusive findings. These were often plagued by several methodological concerns including test validity, potential teacher differences between the treatment and control classes, and students being distracted by the

novelty of the computer simulation (Smentana, 2012). In this study, we will attempt to mitigate these factors as described in Chapter 3.

2.3 Effectiveness of Hands-On

It is of note that when this study was discussed with others, the researcher found that many volunteer their opinion that hands-on learning would clearly be more effective. Why is this view of the supremacy of hands-on learning so prevalent? Perhaps it stems from the strength of the constructivist theory of learning. In constructivism, there is a belief that learning happens only when students assimilate knowledge into their own framework (Hein, 1991). Hein further explains that this is aided through "hands-on learning, with opportunities to experiment and manipulate the objects of the world." He clarifies that a teacher who accepts the constructivist theory is inevitably required to provide learners with the opportunity to interact with sensory data. Constructivism also ties into inquiry-based learning with an emphasis on teachers not just dispensing information, but rather helping students construct knowledge through experiments and real-world problem solving (EBC, 2004).

Beyond this pedagogical argument, there are studies that show that hands-on activities are effective at teaching concepts. Gernster, et al. (2010) showed that hands-on activities had distinct advantages over direct instruction. The main advantage was in retention ability, which is also a question for this current study, namely can students transfer information from short-term to long-term memory. Another study showed that hands-on activities not only helped students learn the content, but also fostered critical thinking skills (Hmelo-Silver, 2004). There is also evidence that students are more engaged during hands-on activities and that they score better on tests than students who do not have frequent opportunities for hands-on learning (Store-Hunt, 1996 and

Bass). Again, these do not compare hands-on to simulation, but rather compare hands-on

learning to traditional classroom instruction. As discussed in Chapter 1, the National Research

Council found that hands-on learning is an effective way to teach students not only science

concepts, but scientific principles (NRC, 2005). Thus, there is evidence that both types of

learning activities – hands-on and simulations – can be effective but the limited existing

comparison in literature sets the stage for this study.

3   METHODOLOGY

3.1   Overview

The purpose of this study was to measure whether computer simulations or hands-on labs lead to better understanding of physics concepts and better perception of learning for high school students (10th – 12th grades). Two data collection techniques were used to answer these questions.

The first method involved measuring student learning perceptions by conducting brief surveys after each lab. Perkins, et al (2005) suggests that student retention is often based on student interest and participation. The second method involved measuring student achievement on concepts after participating in the intervention through quizzes given the next school day after the lab.

The sample groups consisted of four classes of Introduction to Physics at Pleasant Grove High School. All the classes were taught the same day. Two of these classes were selected to receive the computer simulations while the other two were chosen to receive the hands-on labs for the first three labs and then both switched to the other lab type for the final three labs. The computer simulations were all drawn from the PhET website developed by the University of Colorado and were largely individual learning experiences, while the hands-on labs were largely group experiences, and were created, or modified from existing labs, by the researcher.

3.2   Pre-Intervention data

The study was conducted at Pleasant Grove High School located in Pleasant Grove, Utah. The school has a student population of approximately 2000 with about 85% identifying as white and 10% as Hispanic. Approximately 20% qualify for free or reduced lunch. Overall, the school serves a largely suburban community (Start Class, 2016). Students were quasi-randomly assigned to the various classes. They choose when to take the class so it cannot be called truly random, but the end result of this self-selection is fairly random with regard to gender, grade level, and achievement as shown in Table 3-1. The students did not begin the intervention until the second unit of the year, because 1) the scores of the students on the first unit test were also analyzed to look for distinctions between class periods, and 2) students participated in one physical lab and one computer simulation during the first unit to give them exposure to both types and limit biases caused by unfamiliarity. After looking at the results of the first test it was seen that period A1 had a mean score of 46.4, A2 had a mean score of 51.4, A3 had a mean score of 51.8, and A4 had a mean score of 48.6. Since a different academic level was most concerning for this research, the periods were grouped so that A1 and A3 were together and A2 and A4 were together. This also led to a final distribution, as shown in Table 3-1, of slightly more boys than girls in this second group and slightly more upperclassmen in the first group. Ultimately it was felt that minimizing academic disparity was more pertinent, and when these groups were compared the mean difference between the group was only 1.5 ($p = .20$) out of 70 points and the standard deviations for the two groups were 11.2 and 10.7. This shows that the groups were not statistically different from each other in regards to their prior academic performance in the class up to the start of the intervention.

Table 3-1: Descriptive Statistics of Intervention Groups

Intervention Group	Boys	Girls	Sophomores	Juniors	Seniors
A1 and A3	37	38	20	47	8
A2 and A4	39	31	28	38	6

3.3   Intervention

The premise of this study was that one type of lab experience may be more effective in teaching physics concepts or may lead to better student perceptions of learning. To test this, students took a survey about the lab and a quiz over the concepts covered in the lab the next class period after completing the lab. This was done so students would have to retain the information without further instruction or influence from the teacher.

Throughout the year, students participated in labs in order to explore new concepts (for example, how velocity relates to position, how force affects acceleration, or what affects friction) and developed an equation that could describe the relationship studied. The students conducted each lab either in a hands-on manner using equipment in the classroom or using a computer simulation. The computer simulations used were developed by PhET, a program created by the University of Colorado that is used by many science teachers around the country. In both cases, students completed a lab that had the same objectives and studied the same phenomena. Samples of these can be found in Appendix A. The labs were completed, and the next class period (Pleasant Grove High School uses an A day/B day schedule) students took the same quiz covering the concepts studied in the lab. This had the goal of measuring which lab experience taught the concepts better without other instruction, clarification, or reinforcement from the teacher. This gap in time, rather than taking the quiz directly after the lab, means that students had to transfer the knowledge from working memory to long-term memory. In spite of the name,

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long-term memory is technically defined as something retained even past a few minutes. (Cowan, 2008) The wait between experiencing the lab and taking the quiz forced the students retain the information from the working memory stage to long-term.

The lab process itself is similar for both the lab and computer simulation interventions, but each has unique limitations and advantages. For physical labs, students are divided into groups of four to five students. This is largely due to equipment constraints, but is also affected by the number of tasks students are required to accomplish during the lab. Division of labor is essential for the number of measurements that have to be made. Students then carry out the lab by recording their observations and data and creating a graph or performing calculations to study the relationships highlighted by the lab. This form of lab encourages team work, delegation, accuracy of measurement (or at least awareness of where error is introduced) and physical manipulation. Students are also given more autonomy in designing lab procedure. This method generally takes longer due to the extra data collected, and thus there is sometimes a smaller scope to the actions taken in the lab. For example, in the energy lab the hands-on students only had time to use the equation for gravitational potential energy to look the effect of height or mass but the simulation provided the time and means to additionally look at the effect of the gravitational field.

Simulation labs, on the other hand, are more individual. Students complete these on the computer so the only resource limitation is how many computers are available. Students were encouraged to perform the lab themselves, but were allowed to compare notes and work with neighbors. This form of lab encourages experimentation and exploration as the ease of manipulation with the simulation lets students try multiple variations. There is little concern about accuracy of measurements as the computer provides the data automatically. Students

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instead focus on effects of changes they make. These labs generally have more instructions in order to focus the students on examining certain effects out of the many that can be seen.

Both types have interaction with the teacher. In each type the teacher will begin the lab with a brief introduction to the concepts, guide the students through the general procedure and demonstrate the equipment or simulation. Throughout the lab, the teacher is involved with helping students work through difficult situations and answering their questions. If a certain question occurs multiple times the teacher would often make an announcement to the entire class to clarify the issue. To measure whether one type encourages more interaction with the teacher than the other, two labs (angular momentum and pendulums) were observed by an outside observer and the number of teacher-student interactions was counted.

The scope of the intervention included six lab pairs and subsequent quizzes and surveys. The six labs covered the concepts of linear momentum, energy, circuits, angular momentum, pendulums, and friction. These labs were written or modified by the researcher. The simulation labs were all based on PhET simulations. The hands-on labs were labs that the researcher had used previously that were adapted to better match the focus of the simulation labs. In all cases, the researcher sought to align the hands-on and simulation labs as closely as possible in regard to tasks and objectives. The quizzes were written by the researcher. They were modelled after questions from reputable sources such as Tippers, the Force Concept Inventory, and *Mastering Physics*. *Mastering Physics* is a database of questions designed to match the book, *Physics* by James Walker. While modeled after these sources, the questions were created by the researcher. The questions were shown to another physics teacher at the high school to ensure the quality were acceptable. This was not to claim "face validity" but rather a device to ensure quality and accuracy of contemporary physics questions. Because both groups received the same quiz, any

issue with how the questions were written affected both groups and inferences about the relative effectiveness can still be drawn.

The quizzes were written with the goal of having two recall questions, two calculation/problem-solving questions, and two transfer questions for a total of six questions per quiz. Recall questions were directly related to relationships or facts expressed in the lab. Calculation questions forced students to use the equations derived from or used in the lab. Transfer is considered the ability to apply learning in a new context (Perkins and Solomon, 1988) and so transfer questions encouraged students to integrate multiple resources or apply the principles to new situations. Educators in the state of Utah have recently begun thinking of their assessment questions in terms of Depth of Knowledge (DOK). As questions move from DOK 1 to DOK 4 students are forced to take more autonomy and integrate more information to create their answer (Naylor, 2015). The quiz questions correlate roughly to recall being DOK 1, calculation being DOK 2, and transfer being DOK 3. Quiz questions were either multiple-choice or had only one possible correct response from a calculation so that no rubric was needed to grade the student responses.

Before each quiz, students were given a survey about their perceptions of the lab. The survey consisted of two questions and focused on whether students thought the lab helped them understand the concepts and if the lab was engaging. The students responded using a sliding scale from 1 to 7 rating how effective and engaging they felt the labs were. These were given before the quiz so that student performance on the quiz would not bias their responses. Examples of the quizzes and surveys given can be found in Appendix B.

3.4   Analysis

The data collected through the quizzes and surveys was analyzed using independent sample *t*-tests to measure the size and significance of the differences between the means. Separate tests were conducted for the quiz score and survey questions for each lab. The quiz scores were further analyzed with respect to the question type. A combined effect was also measured by combining all the quiz scores and survey responses to see if there were statistically significant general trends in terms of student performance or learning perceptions based the type of lab completed. Effect size of differences was calculated using Cohen's d with the interpretation that an effect of .2 - .49 is considered small, .5 - .79 is considered medium, and .8 and higher is considered large (Ellis, 2009). An ANOVA was performed to see whether the averages on question type were statistically different. Further, a correlation was performed between student responses on the survey and their quiz scores to examine if there was a significant interaction between these factors.

4 QUANTITATIVE AND QUALITATIVE DATA

Data was collected both quantitatively – through student quiz scores, and qualitatively – through student survey responses. Both measures followed a lab experience in which the students did either a hands-on or simulation lab. The quizzes consisted of six multiple choice or free response questions. These questions consisted of three pairs of recall questions, calculation questions, and transfer questions. These questions were designed by the researcher but were based on questions from Tippers, the Force Concept Inventory, and *Mastering Physics*, a database of questions based on the book, *Physics* by James Walker. While these quiz questions changed based on the lab, the survey (rated on a scale from 1 to 7) consisted of the same two questions:

- How effective did you feel the lab was at relating the objectives?

- How engaging was the lab?

In this chapter, each of the six labs conducted: momentum, energy, circuits, angular momentum, pendulums, and friction are addressed treating each as a case study. For each, the quiz results are discussed followed by the survey results. The data was also combined to perform a meta-analysis on the quantitative and qualitative results. In analyzing the data, means were compared using an independent samples *t*-test with significance being defined as p being less than .05, and approaching significance being defined as p falling between .10 and .05. All

reported confidence intervals are at the 95% confidence level. For examples of all labs see

Appendix A. To see all quizzes and surveys see Appendix B.

4.1 Momentum Lab

Students performed a lab studying conservation of momentum. The hands-on lab asked

students to use Vernier carts and motion detectors to measure the velocity of carts before and

after elastic and inelastic collisions. The mass of the carts was also measured. The simulation lab

also asked students to analyze the momentum of objects before and after elastic and inelastic

collisions. Both groups were asked to calculate momentum to determine if it was conserved.

4.1.1   Quiz Results

The number of students that completed the lab and quiz was 111, with 51 completing the

hands-on version and 60 performing the simulation. As shown in Table 4-1, the average score

on the quiz following the hands-on lab was 4.02 [3.67, 4.37] and 4.33 [4.02, 4.65] following the

simulation lab. This mean difference of .31 was not significant (p = .094). There were no

significant differences in the analysis of scores on the three types of questions: recall,

calculation, and transfer.

4.1.2   Survey Results

The survey, however, did show significant differences. Students rated the hands-on labs

higher on both perceived effectiveness and engagement. As shown in Table 4-1, the mean rating

on the hands-on lab regarding effectiveness was 5.05 [4.73, 5.39] and 5.25 [4.93, 5.58] for

engagement. The simulation lab was only rated at 4.52 [4.17, 4.87] and 4.54 [4.11, 4.97]. The

difference between the hands-on and simulation ratings on both measures were statistically

significant. As shown in Figure 4-1, the difference on effectiveness was .54 (p = .013) with *d* = .43. The difference on engagement was .71 (p = .005) with *d* = .51. Both effects are similar and near what is considered a medium effect (Ellis, 2009).

Table 4-1: Results of Momentum Lab

Lab Type	Quiz mean [CI]	Recall mean	Calculation mean	Transfer mean	Effectiveness mean [CI]	Engagement mean [CI]
Hands-On	4.02 [3.67, 4.37]	1.43	1.49	1.10	5.05 [4.73, 5.39]	5.25 [4.93, 5.58]
Simulation	4.33 [4.02, 4.65]	1.57	1.52	1.25	4.52 [4.17, 4.86]	4.54 [4.11, 4.98]
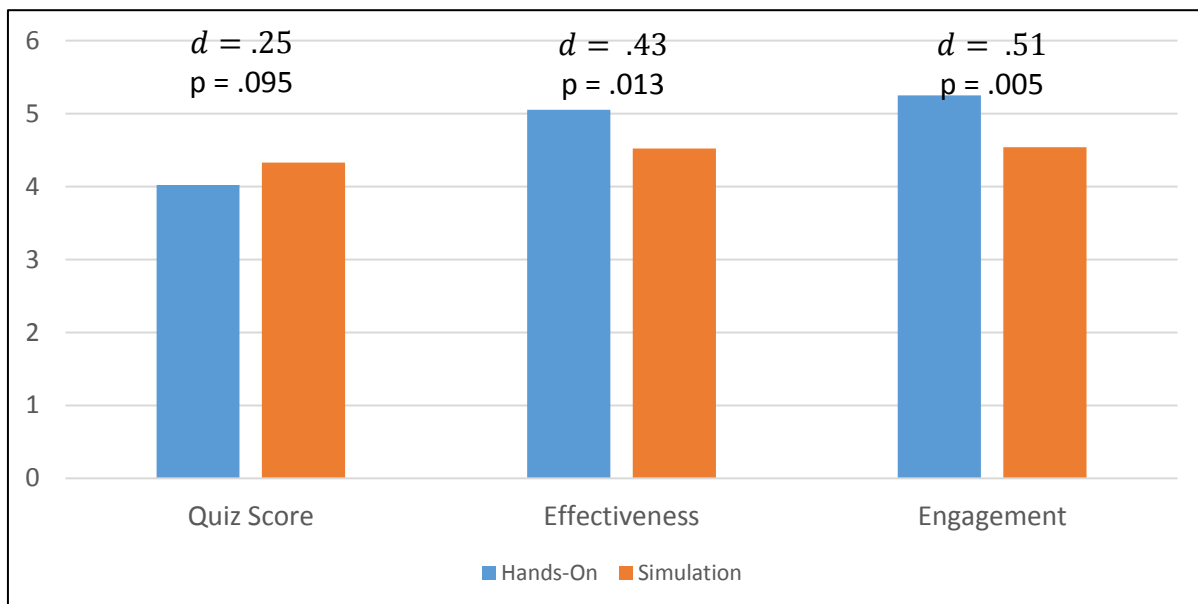
Figure 4-1: Momentum Lab Results

4.2 Energy Lab

In the energy lab, students studied both the concept of conservation of energy and the relationships between mass, height, gravity, and velocity to potential and kinetic energy. For the hands-on lab, students used a ramp to allow a ball to transition from gravitational potential

energy to kinetic energy. Students used different heights and balls to study how the kinetic energy at the end differed from the gravitational potential energy at the beginning. They were also asked to construct graphs illustrating the comparative amounts of energy throughout the motion of the ball. They were directed to observe the presence of dissipated energy because the final kinetic energy did not match the initial gravitational potential energy. The simulation lab also provided students the opportunity to study graphs of energy distributions and to allow an object to transition between gravitational potential energy and kinetic energy. By introducing friction, the students would also study how much energy was dissipated.

4.2.1   Quiz Results

The number of students that completed the lab and quiz was 112, with 59 completing the hands-on version and 53 performing the simulation. As shown in Table 4-2, the average score on the quiz following the hands-on lab was 3.85 [3.47, 4.22] and 3.89 [3.50, 4.28] following the simulation lab. This mean difference of .039 was very small for this lab and was not significant ($p = .442$). However, when the question types were analyzed individually there were some significant differences. For example, both recall and calculation questions showed that the mean score for students who had done the simulation lab were higher. The simulation students scored higher on recall (.156: $p = .076$) and higher on calculation questions (.186: $p = .065$). Both of the mean differences are approaching statistical significance. The transfer questions revealed that the hands-on students actually performed better than the simulation lab students. The data is considered statistically significant, having a difference of .37 ($p = .007$). The net effect of these differences, with smaller increases for the simulation in two categories and a larger effect for hands-on in the other, negate each other causing no statistically significant difference on the quiz as a whole. For example, the effect size of recall ($d = .27$) and calculation ($d = .29$) cancelled out

the effect of transfer ($d = -.47$). While each of these is individually a small to medium effect, the combined effect is less than .1 for the total quiz score.

4.2.2   Survey Results

The survey also showed similar statistically significant differences as in the momentum lab. As Table 4-2 shows, students rated the hands-on labs higher on both perceived effectiveness and engagement. The mean rating of effectiveness for the hands-on lab was 5.25 [4.94, 5.57] and 5.19 [4.87, 5.52] for engagement, while it was only 4.89 [4.54, 5.23] and 4.77 [4.42, 5.12] for the simulation labs. The difference between the hands-on and simulation ratings on both measures were statistically significant. As shown in Figure 4-2, the difference on effectiveness was .367 (p = .059) with $d = .3$. The difference on engagement was .42 (p = .04) with $d = .33$. These effect sizes are both small.
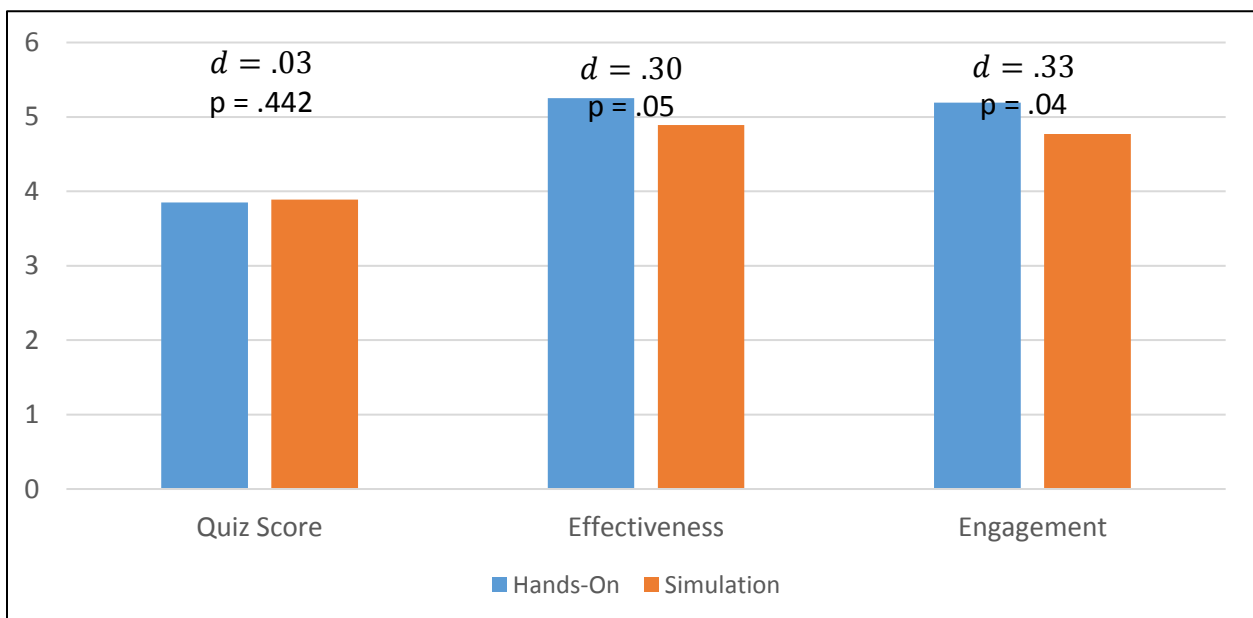
Figure 4-2: Energy Lab Results

Table 4-2: Results of Energy Lab

Lab Type	Quiz mean [CI]	Recall mean	Calculation mean	Transfer mean	Effectiveness mean [CI]	Engagement mean [CI]
Hands-On	3.85 [3.47, 4.22]	1.54	1.47	.898	5.25 [4.94, 5.57]	5.19 [4.87, 5.52]
Simulation	3.89 [3.50, 4.28]	1.70	1.66	.775	4.89 [4.54, 5.23]	4.77 [4.42, 5.12]

4.3 Circuits Lab

In this lab, students were able to study the relationship between voltage, current, and resistance (Ohm's law). Further, they investigated how voltage, current, and resistance are affected when elements are connected in series or parallel. The students who did the hands-on lab built a circuit and used a multi-meter to measure voltage and current. The simulation lab provided an internal voltmeter and ammeter students could manipulate into various parts of the circuit to take readings.

4.3.1 Quiz Results

The number of students that completed the circuit lab and associated quiz was 115, with 62 completing the hands-on version and 53 performing the simulation. As shown in Table 4-3, the average score on the quiz following the hands-on lab was 3.06 [2.76, 3.37] and 3.25 [2.94, 3.55] following the simulation lab. The mean difference of .18 was not statistically significant (p = .20). There were also no statistically significant differences in the analysis of scores on the recall, calculation, or transfer question categories.

4.3.2 Survey Results

The survey, as shown in Table 4-3, again showed that students rated the hands-on lab higher. Students rated the hands-on labs higher on both perceived effectiveness and engagement. The mean rating on the hands-on lab for effectiveness was 4.71 [4.38, 5.03] and 5.19 [4.88, 5.50]

for engagement. In comparison, the simulation lab was rated 4.49 [4.11, 4.87] for effectiveness and 4.4 [3.93, 4.88] for engagement. The difference between the hands-on and simulation ratings on engagement was statistically significant, but the difference on effectiveness was not. As shown in Figure 4-3, the difference on effectiveness was .22 (p = .19). The difference for engagement was .79 (p = .003) with d = .53. This is considered a medium effect. Notwithstanding, students felt that both labs were equally effective, albeit not because they felt the simulation lab was more effective than others, but because the hands-on was viewed as more ineffective than the previous two. Students appeared to struggle with the newness of the multi-meter and learning how to operate it. Despite the equipment difficulties, students rated their engagement as higher for the hands-on lab.
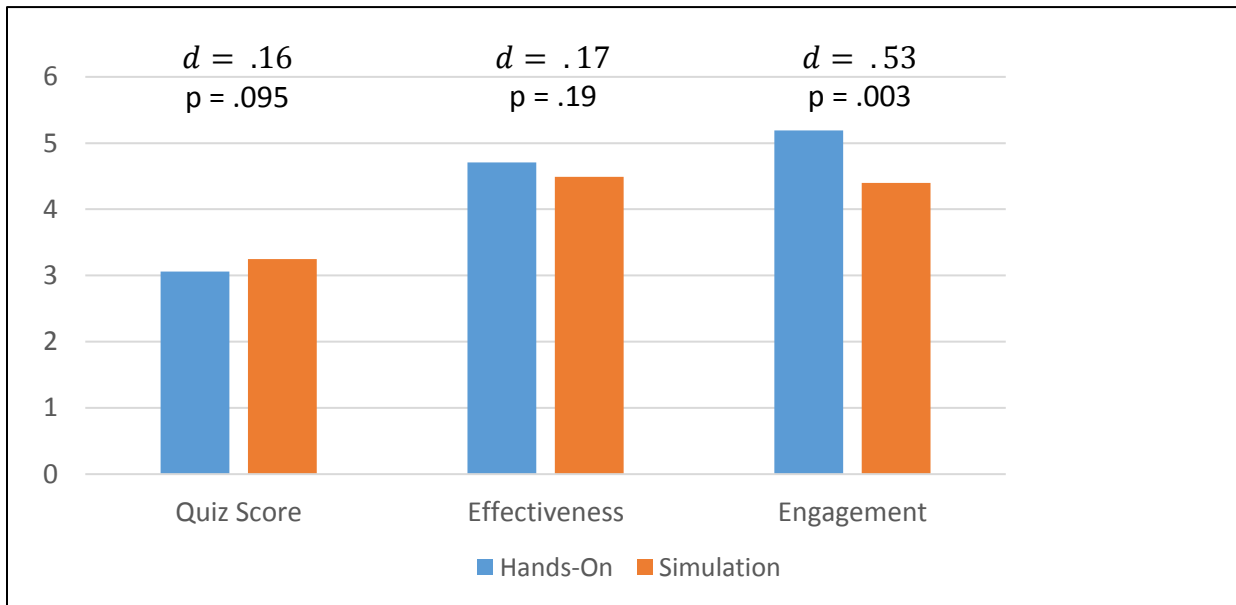
Figure 4-3: Circuit Lab Results

Table 4-3: Results of Circuits Lab

Lab Type	Quiz mean [CI]	Recall mean	Calculation mean	Transfer mean	Effectiveness mean [CI]	Engagement mean [CI]
Hands-On	3.06 [2.76, 3.37]	1.44	1.08	.532	4.71 [4.38, 5.03]	5.19 [4.88, 5.50]
Simulation	3.25 [2.94, 3.55]	1.42	1.17	.642	4.49 [4.11, 4.87]	4.4 [3.93, 4.88]

4.4 Angular Momentum Lab

As a part of angular motion, students conducted a lab studying the conservation of angular momentum. Unlike linear momentum, angular momentum is not generally studied through collisions, but through changing an object's moment of inertia while it is rotating. The hands-on lab had students calculate rate of spin of a disk by using a sensor to measure its angular velocity. They then dropped a ring onto the disk while it was spinning and measured the new velocity. Students then calculated the moment of inertia through conservation of momentum. In the simulation, students also calculated the moment of inertia and analyzed the change in rotation speed of a disk when either another object was dropped onto it or if the size of the disk was change.

4.4.1 Quiz Results

The number of students that completed the labs and quiz was 126, with 58 completing the hands-on version and 68 performing the simulation. As shown in Table 4-4, the average score on the quiz following the hands-on lab was 3.34 [3.10, 3.59] and 3.58 [3.24,3.88] following the simulation lab. This mean difference of .21 was not statistically significant (p = .15). There were also no statistically significant differences in the analysis of scores on the three types of questions.

4.4.2　Survey Results

The survey did show interesting and statistically significant differences. For the first and only time, students rated the simulation lab higher on both perceived effectiveness and engagement. As shown in Table 4-4, the mean rating for effectiveness on the hands-on lab was 3.55 [3.21, 3.89] and 4.05 [3.71, 4.39] for engagement. The effectiveness rating for the simulation lab was 4.25 [3.95, 4.56] and 4.26 [3.89, 4.62] for engagement. The difference between the hands-on and simulation ratings on both measures were statistically significant. As shown in Figure 4-4, the difference on effectiveness was .70 (p = .001) with d = .55. The difference on engagement was .21 (p = .20) and was not statistically significant, but it was unusual in comparison to the other labs. It is also interesting to note that while this was the lowest rating a hands-on lab received, again this simulation lab rating was not dissimilar to the other simulation labs. The quiz scores were also not the lowest of the labs despite the effectiveness being so poorly perceived by the students.
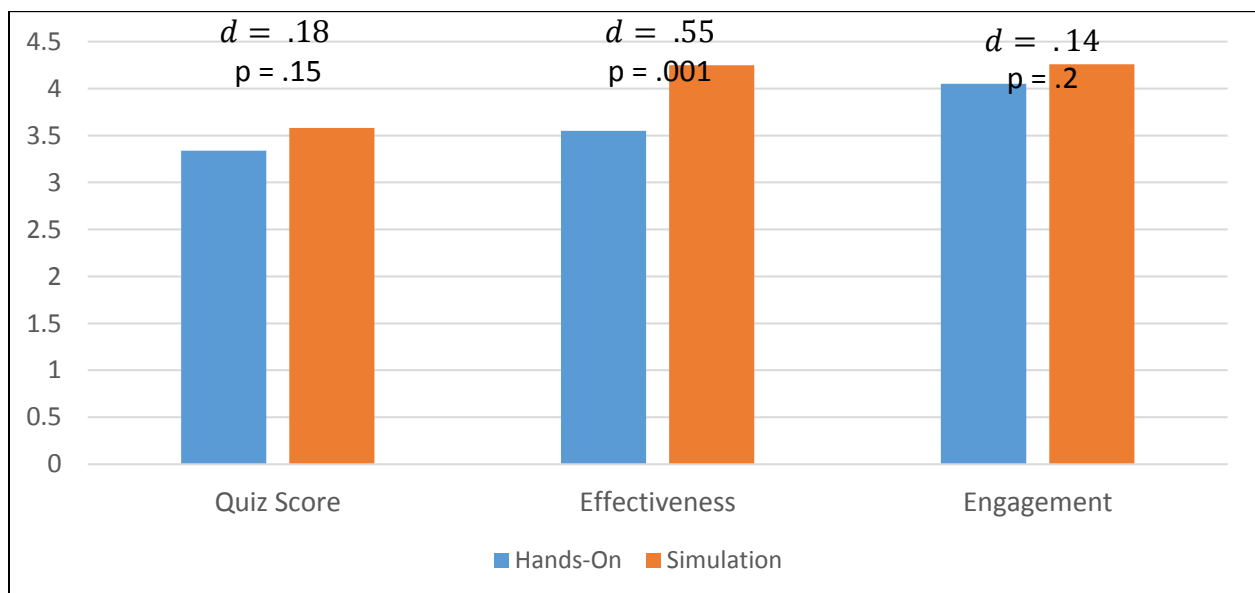
Figure 4-4: Angular Momentum Lab Results

Table 4-4: Results of Angular Momentum Lab

Lab Type	Quiz mean [CI]	Recall mean	Calculation mean	Transfer mean	Effectiveness mean [CI]	Engagement mean [CI]
Hands-On	3.34 [3.10, 3.59]	.79	1.05	1.46	3.55 [3.21, 3.89]	4.05 [3.71, 4.39]
Simulation	3.58 [3.24,3.88]	.85	1.15	1.45	4.25 [3.95, 4.56]	4.26 [3.89, 4.62]

4.5 Pendulum Lab

Students studied the effect of mass, length, and angle on the period of a pendulum. In the hands-on lab, students timed the period of the pendulum's swing while varying either the mass of the pendulum, its length, or the angle of the swing. In the simulation lab, students also adjusted those same three variables. They were also free to modify gravity, which obviously cannot be done in the classroom.

4.5.1 Quiz Results

The number of students that completed the lab and quiz was 117, with 56 completing the hands-on lab and 61 performing the simulation lab. As seen in Table 4-5, the average score on the quiz following the hands-on lab was 3.23 [2.86, 3.60] and 3.65 [3.32, 3.99] following the simulation lab. This mean difference of .42 was statistically significant (p = .048) in favor of the simulation lab. There were also statistically significant differences between the lab groups in their scores on recall and transfer questions. The simulation students scored an average of .25 (p = .01) higher on recall (d = .43). The simulation students also scored an average of .18 (p = .09) higher than the hands-on students with transfer. This difference is approaching statistical significance and the effect size (d = .24) is considered small. The largest effect was seen in the recall questions, which is unusual. Normally that category has the smallest mean difference for the two lab types.

4.5.2   Survey Results

As Table 4-5 shows, the mean rating for effectiveness on the hands-on lab was 5.84 [5.59, 6.09] and 5.54 [5.20, 5.88] for engagement. In comparison, the rating for effectiveness on the simulation lab was 5.55 [5.30, 5.81] and 5.00 [4.66, 5.34] for engagement. The difference between the hands-on and simulation ratings was statistically significant for engagement and approaching statistical significance for effectiveness. As seen in Figure 4-5, the difference on effectiveness was 0.28 (p = 0.058) with d = 0.30. The difference on engagement was 0.54 (p = 0.012) with d = 0.43. This lab displayed effect sizes that are considered small for both measures of students' ratings.
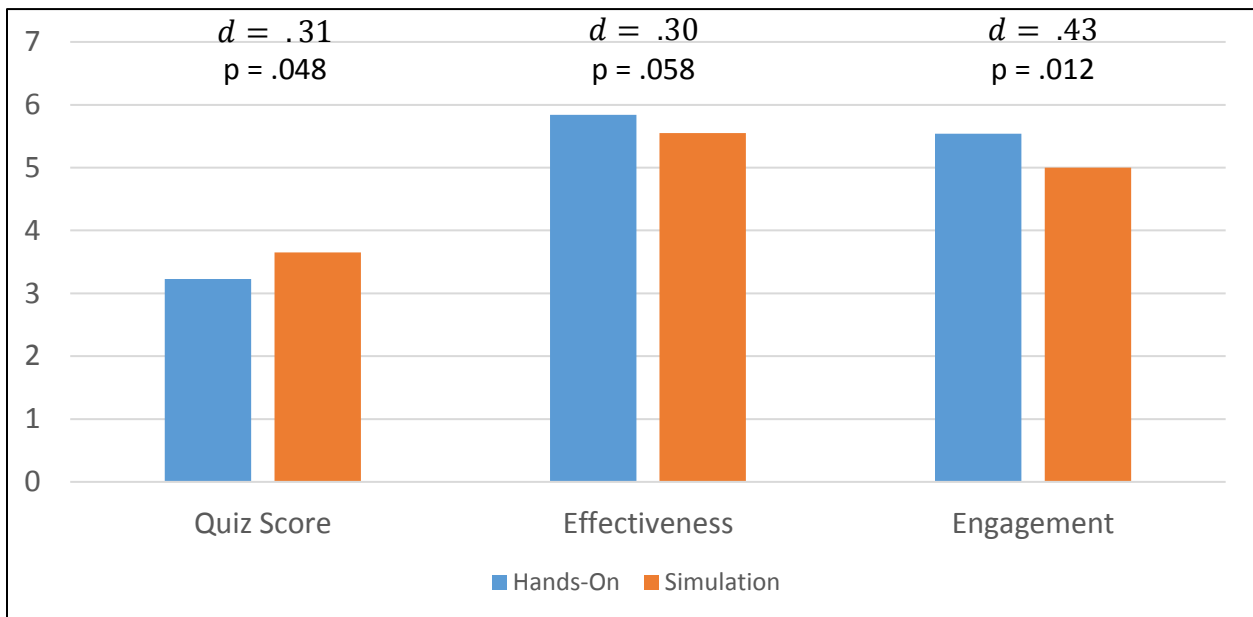
Figure 4-5: Pendulum Lab Results

Table 4-5: Results of Pendulum Lab

Lab Type	Quiz mean [CI]	Recall mean	Calculation mean	Transfer mean	Effectiveness mean [CI]	Engagement mean [CI]
Hands-On	3.23 [2.86, 3.60]	1.34	1.11	.78	5.84 [5.59, 6.09]	5.54 [5.20, 5.88]
Simulation	3.65 [3.32, 3.99]	1.59	1.10	.96	5.55 [5.30, 5.81]	5.00 [4.66, 5.34]

4.6 Friction Lab

Students studied the relationship between friction and the normal force. The hands-on lab asked students to use force sensors to measure the force required to start a block moving and the force required to keep it moving at a constant velocity. This force was equivalent to the friction force as long as the object did not accelerate. They increased the normal force acting on the block by adding mass to it. By plotting measured friction and normal forces, they could calculate the coefficients of static and kinetic friction between their blocks and surfaces. The simulation lab also asked students to analyze the relationship between friction and normal force through modifying an object's mass and the gravitational field it was in. By plotting the resultant normal and friction forces they also calculated the coefficient of friction for their object. Both groups derived the equation for calculating the force of friction.

4.6.1   Quiz Results

The number of students that completed the labs and quiz was 130, with 68 completing the hands-on version and 62 performing the simulation. As shown in Table 4-6, the average score on the quiz following the hands-on lab was 2.87 [2.59, 3.14] and 2.92 [2.58, 3.25] following the simulation lab. This mean difference of only .05 was not statistically significant (p = 0.41). There were statistically significant differences in both recall and calculation questions, however. The hands-on students' scores were higher on recall questions with a mean difference of .47 (p <.001) and d = .67. The simulation students received higher scores on calculation questions with

a mean difference of .38 (p < .001) and *d* = .62. These are both considered medium effects and may indicate that there were unintended differences in the design of the labs that highlighted differing aspects of friction.

4.6.2 Survey Results

The survey showed statistically significant differences in both effectiveness and engagement ratings with students rating the hands-on lab higher on both measures. As shown in Table 4-6, the mean rating of effectiveness on the hands-on lab was 5.02 [4.79, 5.26] and 5.02 [4.75, 5.30] for engagement. The effectiveness rating for the simulation lab was 4.28 [3.95, 4.61] and 4.03 [3.64, 4.43] for engagement. As seen in Figure 4-6, the difference between the hands-on and simulation ratings on both measures were statistically significant. The difference on effectiveness was .74 (p < .001) with *d* = .67. The difference on engagement was 1.00 (p < .001) with *d* = .74. These are the largest effects seen in student perception of the labs.
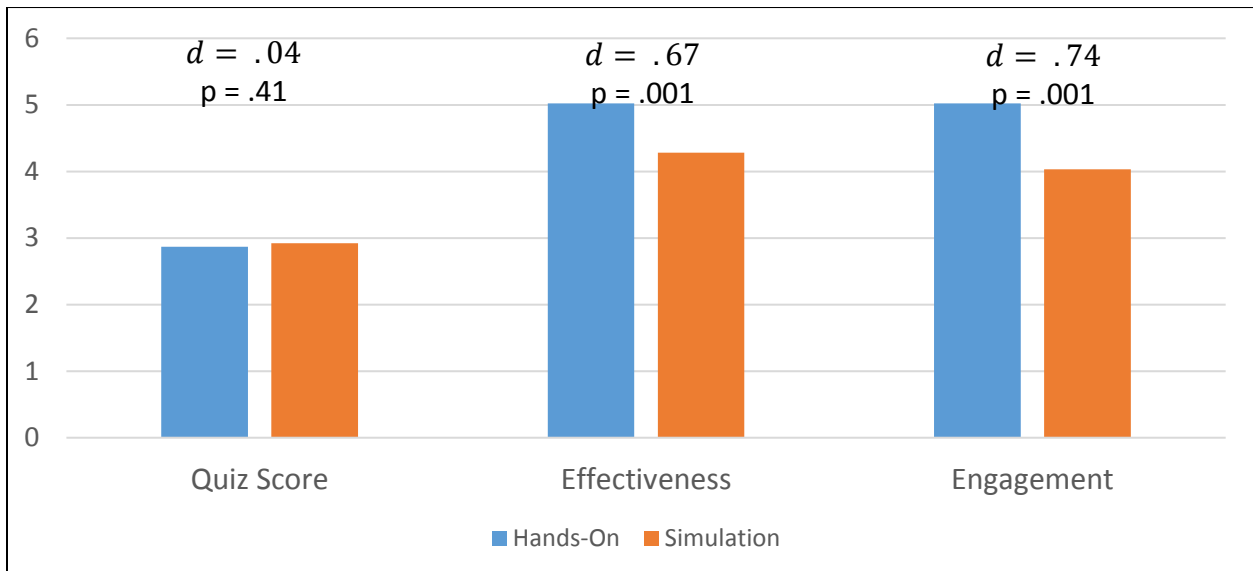
Figure 4-6: Friction Lab Results

Table 4-6: Results of Friction Lab

Lab Type	Quiz mean [CI]	Recall mean	Calculation mean	Transfer mean	Effectiveness mean [CI]	Engagement mean [CI]
Hands-On	2.87 [2.59, 3.14]	1.51	0.41	0.94	5.02 [4.79, 5.26]	5.02 [4.75, 5.30]
Simulation	2.92 [2.58, 3.25]	1.05	0.79	1.04	4.28 [3.95, 4.61]	4.03 [3.64, 4.43]

4.7 Combined Effects

When looking at the labs as a whole, the general trends become more apparent. All quiz scores and survey results that followed simulation labs were combined into one data set. All scores that followed hands-on labs were also combined.

4.7.1 Quiz Results

There was a statistically significant difference in the average scores of quizzes conducted following a hands-on lab and those following a simulation lab as seen in Table 4-7. Simulation scores were an average of .23 points higher ($p = .01$) with $d = .17$ (which is considered a small effect size). When looking at question type, only calculation questions showed a statistically significant difference in their means with simulation students scoring .14 ($p = .003$) higher with the effect size again being considered small ($d = .21$).

The overall scores on the three question types were compared by combining all quiz scores from hands-on labs and simulation labs only sorting by recall, calculation, and transfer. An ANOVA test showed that students performed best on recall questions where students scored an average of 8.07 [7.77, 8.38] points out of 12. The mean on calculation questions was next highest with an average of 6.90 [6.59, 7.20]. The mean on transfer was lowest at 5.86 [5.56, 6.17]. These were statistically different ($p < .001$).

4.7.2 Survey Results

The survey results showed statistically significant differences in both perceived effectiveness and engagement. These results are displayed in Table 4-7. Hands-on labs were rated higher in both cases with a difference on effectiveness of .24 (p = .007) and .54 (p < .001) for engagement. The effect size of $d = .18$ for effectiveness and $d = .38$ for engagement are each considered to be in the small to medium range.

4.7.3 Correlation

A correlation comparison was also conducted between quiz scores and students' survey responses on perceived effectiveness and engagement. These results are displayed in Table 4-8. The correlation between quiz score and the effectiveness rating was r =.111 (p = .003) indicating very little relation between the two measures. Likewise, there was little relation between engagement and quiz score with r = .121 (p = .001) (Ellis, 2009). However, there was a relationship between effectiveness and engagement that is considered large with r = .55 (p < .001). This indicates that there was a relationship between students' perception of effectiveness and their level of engagement.

Table 4-7: Mean Difference Between Hands-On and Simulation by Lab

Lab	Quiz mean difference (p)	Recall mean difference (p)	Calculation Mean difference (p)	Transfer Mean difference (p)	Effectiveness mean difference (p)	Engagement mean difference (p)
Momentum	.314 (.094)*	.135 (.146)	.026 (.401)	.152 (.110)	-.542 (.013)**	-.712 (.005)**
Energy	.039 (.442)	.156 (.076)*	.186 (.065)*	-.370 (.007)**	-.367 (.059)*	-.421 (.040)**
Circuits	.181 (.202)	-.020 (.433)	.089 (.197)	.109 (.176)	-.219 (.190)	-.790 (.003)**
Angular Momentum	.214 (.148)	.060 (.309)	.103 (.157)	-.010 (.463)	.702 (.001)**	.206 (.205)
Pendulums	.424 (.048)**	.251 (.010)**	-.009 (.474)	.181 (.096)*	-.282 (.058)*	-.545 (.012)**
Friction	.052 (.406)	-.466 (<.001)**	.379 (<.001)**	.107 (.188)	-.747 (<.001)**	-.997 (<.001)**
Total	.229 (.011)**	-.006 (.456)	.144 (.003)**	.062 (.133)	-.245 (.007)**	-.545 (<.001)**

*Approaching significance (p = 0.1 – 0.05)
**Significant (p < .05)
A positive difference indicates the simulation response was higher

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Table 4-8: Correlation Between Quiz Scores and Ratings

	Quiz Score	Effectiveness Rating	Engagement Rating
Quiz Score			
Effectiveness Rating	.111*		
Engagement Rating	.121*	.554*	

*p<.005
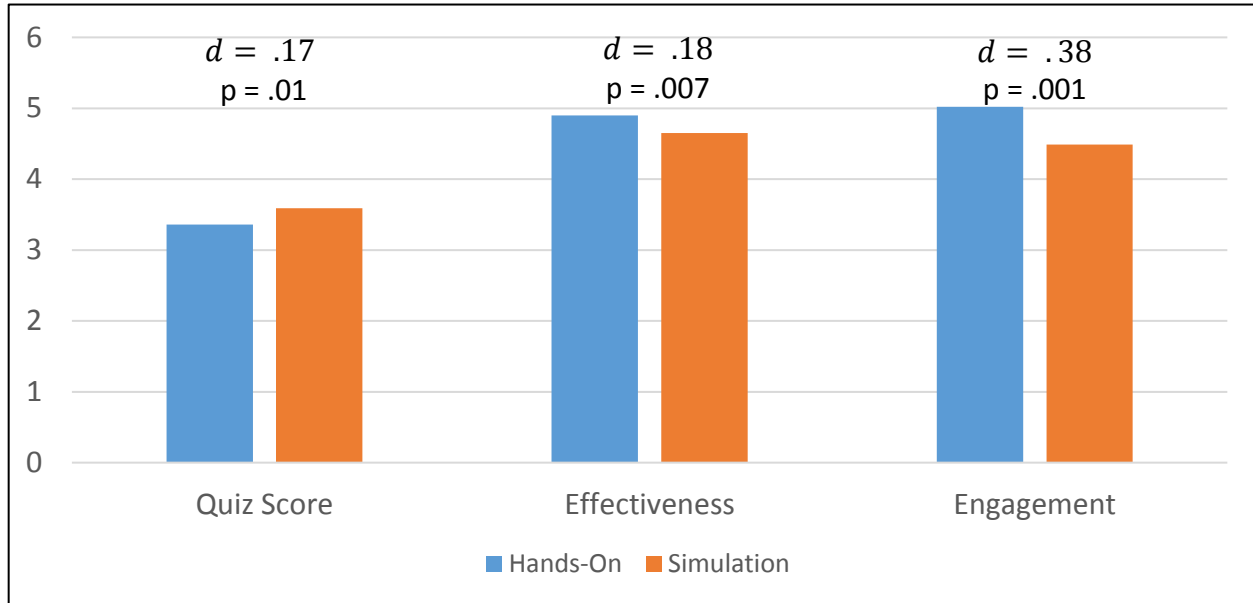
Figure 4-7: Combined Effects

4.8 Observational Data

An outside observer was brought in to watch all four periods of two labs: angular momentum and pendulums. The observer recorded the number of times the teacher interacted with students throughout the labs. No distinction was given to whether the teacher or student initiated the interaction, nor was the length of the interaction recorded. During the angular momentum lab, the observer counted 25 and 27 interactions during the hands-on lab periods and 25 and 28 interactions during the simulation lab periods. For the pendulum lab, 27 and 30

interactions were reported during the hands-on lab periods and 26 and 31 interactions were reported for the simulation lab periods.

5 CONCLUSION

The use of simulations has become more mainstream in both secondary and post-secondary education and industry. Although many of these simulations are true to the conditions of their physical counterparts and have the flexibility to account for many variables and factors, what can be done is ultimately limited and controlled by the creator of the simulation. The focus of this study is whether students are learning as well through simulations as they would through traditional lab experiences. This research had four sections of high school physics classes perform either simulation or hands-on versions of a lab to compare how the students learned and their attitudes toward the labs. This chapter will discuss the findings of the study, address the research questions, present delimitations of the study, and highlight future recommendations for study and application.

5.1 Research Questions Answered

The first question posed for this research was, "Do simulations lead to better understanding for students in high school physics classes?" This question was addressed through the students' performance on quizzes taken the day after they participated in a lab experience. Each lab showed that simulation labs were at least statistically equal with hands-on labs in helping students understand physics concepts. Looking at the combined quiz scores for all six labs there is a statistically significant difference between scores from students who had performed

simulation labs and those who had done a hands-on lab. Simulation labs did produce better quiz scores. Yet, the size of the difference, ($d = .17$) is very small. The raw difference in mean scores is only .23 points. For the size of the quiz, that is only about a 5% improvement in scores. While the general trend is that simulations do lead to slightly better outcomes, the practical significance is dubious. More accurately it can be said that simulation labs perform as well as their hands-on counterparts with the difference depending on the specific lab experience. It is interesting to note, however, that while for each individual lab the difference in means was not usually statistically significant, every simulation lab had better quiz scores than its hands-on version. For the purpose of extending this to a general population, the lack of significant difference is prohibitive, but the results are important and interesting to consider for the purpose of simple case study comparisons.

When examining the data by question type, further evidence of the benefits and relative parity are manifest. Quiz questions were grouped in pairs of recall questions, calculation questions, and transfer questions. When looking at the cumulative score of the total recall and transfer questions the difference between lab types essentially disappears. Almost all the difference in total quiz scores came from the calculation type questions. The reason why simulation labs may lead to better ability to use the equations that describe the relationships studied is an interesting one. There seems to be no predicted benefit in a simulation for this improvement in calculation score – in fact, perhaps we would predict the opposite, since much of the data collection and calculations are done by the computer. Perhaps it is that the cognitive load of manually collecting the data is reduced allowing students to focus on the relationships that derive the equations. The simulation labs may be providing scaffolding – providing students

the opportunity to gradually increase their zone of proximal development – in a way that the hands-on labs are not (Iris Center, 2016).

The second question addressed by the research was, "Do simulations lead to better perceptions of learning for high school physics students?". In other words, do students perceive one type of lab as more effective than the other? Do they feel more engaged and enjoy one type more than the other? Students answered these two questions before taking the quiz to prevent their performance on the quiz from introducing a potential bias on their responses. On a seven-point scale, they rated how effective and engaging they felt the lab was. Here the results were far more conclusive both on a macro level and in each case study. With the exception of one lab (angular momentum), each lab showed a significant difference in the mean rating in favor of the hands-on lab in one or both of those measures. The combined data again showed this statistically significant difference. The effect size for the difference in engagement was greater than the difference in perceived effectiveness, but both were significant. Clearly then, students enjoy hands-on experiences more, and also feel they learn better from them. It was common to hear that sentiment expressed directly by the students during labs. This is interesting as several studies have shown that students had positive impressions of simulation learning experiences (Smentana, 2012). In this study, while students still did have what could be termed a positive impression of simulations – the mean rating for effectiveness and engagement were both greater than four on a seven point Likert scale – they clearly preferred hands-on activities.

Despite students' perceptions that they learned better from hands-on lab experiences, the data does not support that conclusion. At best it can be said that students learn equally well from either type, and at worst (for the accuracy of their perspective) they actually learn better from simulation labs. When student responses on the survey were correlated to their quiz scores there

was a clear lack of correlation between how they rated the lab and how they scored. In other words, those who thought the lab was effective did not necessarily score well on the quiz and those who thought the lab was ineffective scored equally well on the quiz. The same can be said for how they rated the engagement. The only significant correlation was how they rated effectiveness and engagement. In other words, students who enjoyed the lab also usually thought the lab taught or showed the principles well. This seems to imply that students are very poor judges of how well they are learning or what learning experiences are actually effective. Instead, it seems that students equate having fun or enjoying the experience with actual learning.

5.2 Delimitations and Future Study

There are several limitations to the conclusions that can be drawn from this study. Each lab was effectively a separate quasi-experimental study. In that sense, it is difficult to combine the data from the labs and draw firm conclusions. Rather, only general trends can be noticed. Further, the exact reason for the trend in student performance and attitude is clouded by other factors. The cognitive load of data collection or the newness and inexperience with different types of equipment could lead to difficulty in focusing on the principles being studied. Simulation labs also tended to be more individual and perhaps students were thus less distracted. This may be an inherent advantage/disadvantage between the types of labs, but it does make it difficult to know the exact cause of the difference. The students may also interact less with the teacher in one type or the other. To address this an observer counted interactions between students and the teacher during two different labs (eight class periods, four for each lab) and the number of interactions was almost exactly the same every class period (25-30). Accordingly, this does not seem to be a factor, although perhaps the quality or duration of the interaction varied. Future study could focus on these interactions.

This idea of interaction also serves as a potential explanation in student attitudes. Students may have enjoyed the hands-on labs more because of the experience of manipulating things manually and using equipment. But, because of limitations of equipment and the number of tasks involved in collecting data, hands-on labs have to often be done as group activities, and the students may have simply enjoyed the increased interaction with their peers during hands-on labs. Addressing or separating this factor out would be enlightening. This could be done by controlling lab group sizes for hands-on labs and forcing students to work in small groups for simulation labs.

One of the more unusual findings occurred with the angular momentum lab. This lab was the only one where students rated the simulation lab higher in perceived effectiveness and engagement. One possible explanation for this is that this was the first lab after students switched which type of lab they were doing (the hands-on group started doing simulation, and the simulation group started doing hands-on), and where the newness of the type of lab may have led to confusion. However, during the time frame of the first three labs all students performed two simulation labs and one hands-on lab in addition to and outside of the labs being studied, so neither type was completely unfamiliar at the time of the switch. Further, while the angular momentum lab was unusual, the standard pattern reasserted itself for the final two labs indicating that there may have simply been something unique to that lab.

This does bring up the concern that the quiz scores and survey ratings reflect the efficacy of individual labs rather than truly comparing the two types. It should also be noted that in this study, it can only be stated that PhET simulations were compared to certain hands-on labs designed to mimic them. The degree to which the labs were similar in their objectives and tasks also has an effect on the validity of the comparison.

One final limitation is that the type of knowledge analyzed in this study was specific. The quizzes only measured content knowledge – knowledge of physics principles, ability to use the equations, and ability to apply the principles in new situations. Many would say, though, that this is not the only type of knowledge students should be gaining. The ability to collect data, problem solve when equipment or set-up is difficult, and instrumentation skills are also important learning outcomes to prepare students for careers. Hands-on labs would seem to have an inherent advantage here, but this was not addressed by the study and is an important consideration. Future studies could address whether some combination of these lab types could be even more effective. Having students perform both the hands-on and simulation versions of the lab could lead to greater gains in their understanding.

5.3 Recommendations

From the data collected in this study, it can be concluded that, in general, students enjoyed these hands-on lab experiences more than the PhET simulation counterparts. Student learning outcomes, however, are similar between lab types. Simulation labs are just as effective as hands-on labs for student learning. Some simulation labs even appear to have a slight advantage but the benefit may not outweigh other factors. In that light, it would seem that the question of which to use is up to the interpretation and needs of the instructor. Simulation labs are generally easier to run, less expensive, and faster than hands-on labs. Thus, if those are limitations an instructor must deal with, using simulation labs is a viable option that has demonstrated positive and equivalent outcomes for student learning. This also reflects well on the viability of online courses and learning experiences. However, if an instructor has sufficient time and resources, it may be beneficial to conduct hands-on labs - knowing that students will learn effectively and have a more enjoyable experience.

These considerations can be taken in light of the clear preference students showed for hands-on labs through their ratings on the survey questions. Further, their quiz scores demonstrated that student learning occurs in similar amounts from both types, but there is a slight advantage to simulation labs. A comment a student made after completing a simulation lab summarizes the findings succinctly: "It was super boring, but it showed the concept clearly." The use of simulations will likely only increase as society relies more heavily on digital communication and modeling. It appears that learning and productivity will likely suffer no ill effects from this transition, but it does seem that physical manipulation and interaction will always play an important role in students feeling connected to the learning experience.

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APPENDICES

APPENDIX A.   LAB WORKSHEETS AND SCREENSHOTS

The following pages contain copies of all lab handouts given for both hands-on labs and simulations. The simulations were all taken from the website phet.colorado.edu and screenshots of the simulations have been included for reference. For each set of labs, the hands-on version will come first followed by the simulation.

Collisions and Conservation of Momentum

Purpose:

Procedure:

Sketch of set-up:

Data:

Mass of cart 1 and 2	Velocity of cart 1 before collision	Velocity of cart 2 before collision	Velocity of cart 1 after collision	Velocity of cart 2 after collision	

P1 before	P2 before	P1 after	P2 after	Total P before	Total P after	Force on 1 and 2

Conclusion:

Collisions and Conservation of Momentum

Visit the website http://phet.colorado.edu/en/simulation/collision-lab & complete the following:

1. In the green box on the right side of the screen, select the following settings: 1 dimension, velocity vectors ON, momentum vectors ON, reflecting borders ON, momenta diagram ON, elasticity 0%. Look at the red and green balls on the screen and the vectors that represent their motion.
   a. Which ball has the greater velocity?

   b. Which has the greater momentum?

2. Explain why the green ball has more momentum but less velocity than the red ball (HINT: what is the definition of momentum?).

3. Push "play" and let the balls collide. After they collide and you see the vectors change, click "pause". Click "rewind" and watch the momenta box during the collision. Watch it more than once if needed by using "play", "rewind", and "pause". Zoom in on the vectors in the momenta box with the control on the right of the box to make it easier to see if necessary.
   a. What happens to the momentum of the red ball after the collision?

   b. What about the green ball?

c. What about the total momentum of both the red and green ball?

4. Change the mass of the red ball to match that of the green ball.
   a. Which ball has greater momentum now?

   b. How has the total momentum changed?

   c. Predict what will happen to the motion of the balls after they collide.

5. Watch the simulation, and then pause it once the vectors have changed.
   a. What happens to the momentum of the red ball after the collision?

   b. What about the green ball?

   c. What about the total momentum of both the red and green ball?

6. Now change the elasticity to 100%. Predict the motion of the balls after the collision.

7. Watch the simulation, and then pause it once the vectors have changed.
   a. What happens to the momentum of the red ball after the collision?

   b. What about the green ball?

   c. What about the total momentum of both the red and green ball?

8. Experiment a little by running additional simulations. Record the following data for at least 2 additional simulations (more simulations = extra credit):

Mass of Red Ball	Mass of Green Ball	% elasticity	Red and Green Momentum vectors before crash	Red and Green Momentum vectors after crash	Change in total momentum during simulation? (yes or no)	Force on the green and red balls (assume t = 0.01 s)	

9. What do you notice about the force on each ball? Why?

Screenshot of Simulation for Conservation of Momentum Lab

Name_____   Period_____   Date_____

Conservation of Energy

Purpose: Study relationship between gravitational, kinetic, and dissipated energy.

Procedure:

1.Using a ramp, give a ball gravitational energy and calculate the amount. Sketch set up.

2. Draw three energy graphs for the distribution of energy at the beginning, middle, and end.

3. Predict what the velocity at the bottom will be.

4. Allow the ball to roll down the ramp, and measure the velocity at the bottom. (How can you do this?)

5. Calculate the kinetic energy, and compare with the original gravitational. Find the amount of dissipated energy.

6. Do this for 3 different balls and 2 different steepness of ramp. Which combination has the least dissipated (do a percentage – dissipated/gravitational)?

Data: Construct a table for the gravitational energy, predicted velocity, measured velocity, calculated kinetic energy and dissipated energy for all six trials.

Trial	Eg	Predicted V	Actual V	Ek	Ed
1					
2					
3					
4					
5					
6					

Conclusion: What do you notice about your total energy at the beginning and your total energy at the end? What sources of error do you have?

Name: _____   **Period:** _____   **Date:** _____

Learning Goal: To examine the relationship between kinetic and potential energy.

Access: Go to Google and type in "phet energy skate park". Click on the top link, which should be http://phet.colorado.edu/simulations/sims.php?sim=Energy_Skate_Park

Play: Take a few minutes to play with the simulation and get to know how things work.

Then, your tasks are:

1. Start with the ramp on Earth. Bring up the graphs of Energy vs. position, Energy vs. time, and the bar graph. You may want to pull one up at a time so as to not overcrowd your screen.
    a. What do you notice about the total energy?

    b. How are kinetic and potential energy related to the total energy?

2. Replace the setting with the each of the other options (Moon, Space, and Jupiter) and bring up the graphs for each.
    a. What do you notice?

    b. Is the relationship between kinetic and potential energy the same at each location?

    c. Does gravity affect the total energy? Why?

3. Change the mass of the skater (by selecting a different skater) and return to Earth; examine the graphs again.
   a. Did anything change? What?

   b. Did that affect the velocity at the bottom? (look at the energy vs time graph and compare the period in the two cases)

4. Try altering the shape of the ramp by clicking on the blue circles and dragging. Describe how the change in track shape affects the energy levels on the bar graph. Draw the shape you made.

5. Now click on the "Track Friction >>" button to show a slider that will allow you to change the amount of friction. Drag the slider halfway to the first tick mark. Look back at the bar graph and notice what happens to the energy amounts.
   a. Does the Total change at all?

   b. Do the maximum values of the kinetic and potential energy change? How?

   c. Does the skater still reach the same height on both sides of the track?

      Explain why or why not in terms of energy transfer.

6. Remove all friction from the skater and click the "Moon" option from the "Location" menu. Now click the "Return Skater" button.
   a. Did his total energy change?

   b. Why?

   c. Now make a prediction for what will happen to his total energy if the gravity is changed to that of Jupiter. What will happen to the velocity at the bottom?

   d. Check your prediction. Were you right?

7. Summarize the relationship between potential and kinetic energy based on your observations of the Energy Skate Park.

8. Define:
   a. kinetic energy:

   b. potential energy:

   c. dissipated energy:

   d. total energy:

Screenshot of Simulation for Conservation of Energy Lab
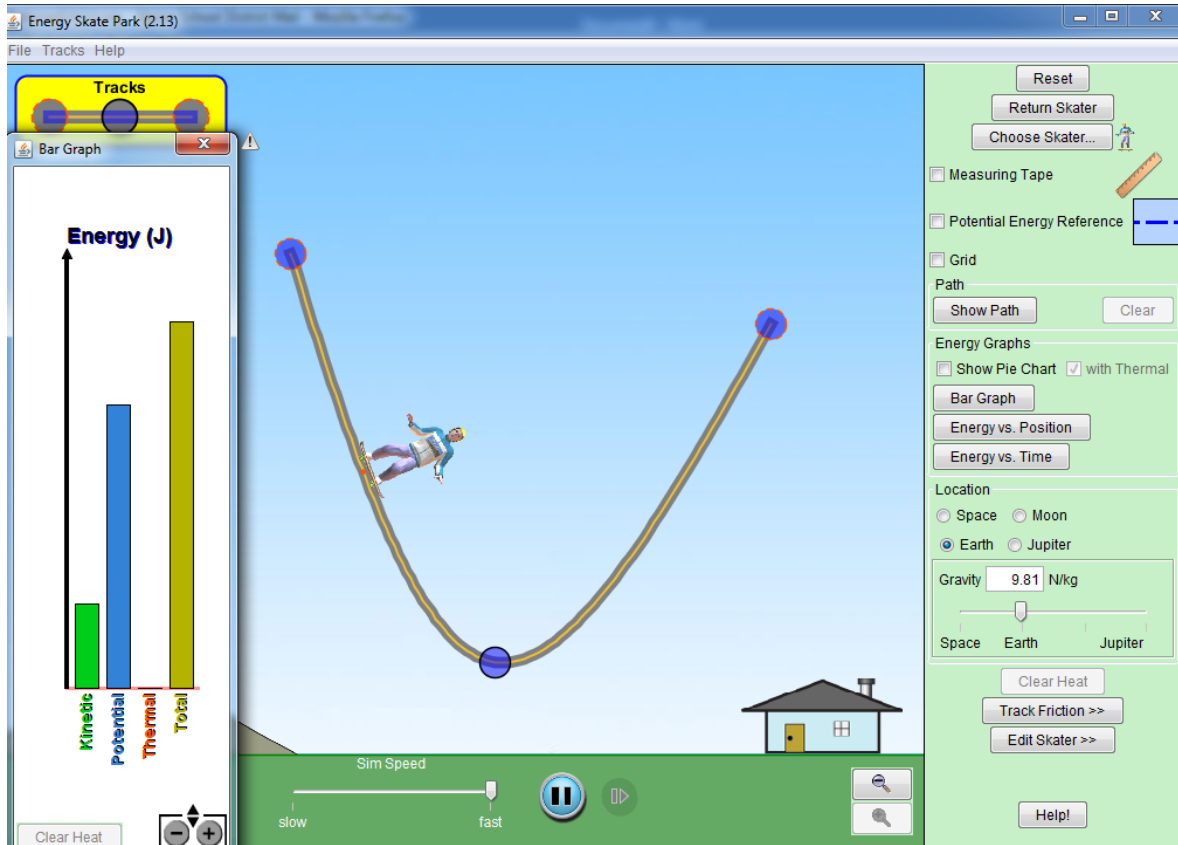
Name: _____   Period_____   Hour_____

Circuits Lab

Important Formulas: $\boxed{V = IR}$ Series: $\boxed{R_T = R_1 + R_2 + R_3 + ...}$ $\boxed{V_T = V_1 + V_2 + V_3 + ...}$

Parallel: $\boxed{\dfrac{1}{R_T} = \dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3} + ...}$ $\boxed{I_T = I_1 + I_2 + I_3 + ...}$

Procedure: *Use the snap kits to build both series and parallel circuits while looking at the patterns in voltage and current.*

Part I: DC Circuits in Series

- Build a simple circuit made of one battery and one resistor in a single loop.

Draw your circuit: Use proper symbols (not real life)
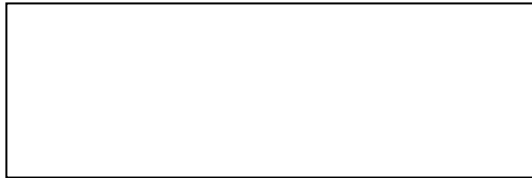
What is the **voltage** drop across the resistor?

_____ Volts

What is the resistance of the **circuit**?

_____ Ohms

Use Ohm's Law $\boxed{V = IR}$ to find the current of the resistor   _____ Amps   Meaures it _____

- Set both of the voltmeter's probes on the same side of the resistor. What is the voltage? _____   Why?
  _____

- Build a circuit made a battery and three resistors in *series*.

What are the **voltage** drops in the circuit?   *Draw your circuit: Use proper symbols.*

R 1: _____ Volts

R2: _____ Volts

R 3: _____ Volts

Battery: _____ Volts

What is the current in each part of the **circuit**?

Through R1: _____ Amps

 Through R2: _____ Amps

Through R3: _____ Amps

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Part II: DC Circuits in Parallel
Build a circuit made a battery pack and three resistors in *parallel* with the battery
What are the voltage drops in the circuit?   *Draw your circuit: Use proper*
symbols.
Resistor 1: _____ Volts
Resistor 2: _____ Volts
Resistor 3: _____ Volts
Battery: _____ Volts
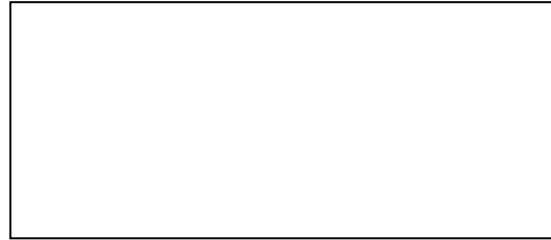
What is the current in each part of the circuit?
Resistor 1's path: _____ Amps
Resistor 2's path: _____ Amps
Resistor 3's path: _____ Amps
Battery: _____Amps
Remove a resistor from its path. What happens to the voltage of the other resistors?
_____
_____

For a parallel circuit, as resistors (with resistance) are added, the voltage

_____

Conclusion Questions and Calculations: ½ point each   USE YOUR FORMULA!!!!   **V = I R**

1. To assure the same voltage is available to all devices; my house is wired in *series / parallel*.

2. Safety features like GFI's and circuit breakers are wired in *series / parallel* to assure that when they are turned off, the whole circuit is turned off too.

3. In a **series** circuit, as resistors are added, the **voltage at the battery** *increases / decreases / remains the same*.

4. In a **series** circuit, as resistors are added, the **current at the battery** *increases / decreases / remains the same*.

5. In a **parallel** circuit, as resistors are added, the **voltage at the battery** *increases / decreases / remains the same*.

6. In a **parallel** circuit, as resistors are added, the **current at the battery** *increases / decreases / remains the same*.
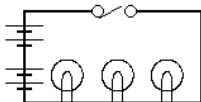
7.   With the switched closed, the bulb on the right will be *more bright / less bright / equally bright* than the resistor blub on the left.

8. In the above diagram, if the middle bulb burns out, the bulb on the right will *become brighter / dim / turn off*.

9. My TI calculator uses four 1.5 V AAA batteries. The effectual voltage needed by the calculator must be_____.

10. Two 10.0 Ω resistors in **series** produce an equivalent resistance of _____ Ω

11. Two 10.0 Ω resistors in **parallel** produce an equivalent resistance of _____ Ω

Circuits PhET Lab

Introduction: Wouldn't it be great to see inside wires and electrical devices, to actually watch the electrons flow? This simulation allows us to do this. In this sim, you will build simple and compound circuits and measure their potential (voltage), current, and resistance. Additionally, you will view the actions of electrons in an AC circuit.

Circuit Construction Kit (AC+DC)

Important Formulas: $\boxed{V = IR}$ Series: $\boxed{R_T = R_1 + R_2 + R_3 + ...}$

$\boxed{V_T = V_1 + V_2 + V_3 + ...}$

Parallel: $\boxed{\dfrac{1}{R_T} = \dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3} + ...}$ $\boxed{I_T = I_1 + I_2 + I_3 + ...}$

Procedure: *PheT Sims → Play → Electricity, Magnets, and Circuits → Circuit Construction Kit (AC+DCy)* **Run Now!**

To add elements to your circuits, simply drag an item into the work area.
To remove an item or change it, right-click the item you wish to change.
To uncouple two circuit elements, right click on the circular junction and choose "split junction."
To measure voltage and current, click on the boxes to the left.
Remember, voltage is read in parallel (outside of the circuit), while current is read in series (in the circuit)
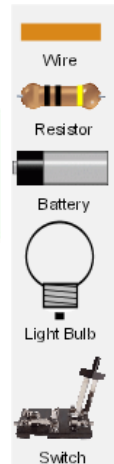
☑ **Voltmeter**

☑ **Ammeter(s)** 0.00 Amps

Wire

Resistor

Battery

Light Bulb

Switch

Part I: DC Circuits in Series
Build a simple circuit made of one battery and one light in a single loop.
Draw your circuit: Use proper symbols
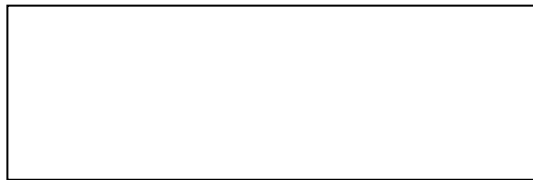
Light: _____ Amps

Use Ohm's Law $\boxed{V = IR}$ to find the resistance of the light   Light: _____ Ohms
Set both of the voltmeter's probes on the same side of a light. What is the voltage? _____
Why? _____
Reverse the battery. What happens to the flow of electrons?
_____
Build a circuit made a battery and three lights in **series**. *Draw your circuit: Use proper symbols.*
What are the **voltage** drops in the circuit?
Light 1: _____ Volts
Light 2: _____ Volts
Light 3: _____ Volts
Battery: _____ Volts
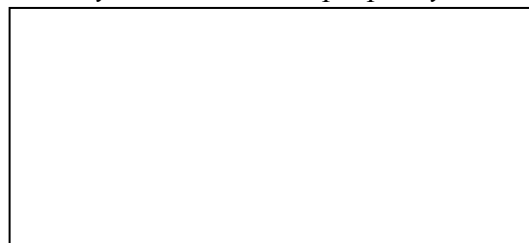
What is the current in each part of the **circuit**?

Between Bat and Light 1: _____ Amps   Use Ohm's Law to find the
resistance of the lights

Between Lights 1-2: _____ Amps   Light 1: _____ Ohms

Between Lights 2-3: _____ Amps   Light 2: _____ Ohms

Battery: _____Amps   Light 3: _____ Ohms

Are all the lights the same brightness? _____

Remove a light from the circuit and reclose the circuit. What happens to the brightness of the other lights?

_____

_____

For a series circuit, as lights (with resistance) are added, the voltage

_____

For a series circuit, as lights (with resistance) are added, the current

_____

Add additional batteries in series with the first battery.

What happens to the brightness? _____the voltages? _____the
currents? _____

Add a resistor to your series circuit.

What effect did the resistor have on the lights in the circuit?

_____

Create a wire path in your circuit that bypasses all the lights. This is a *short circuit*.

What happens to the battery in short circuit? _____ The lights?

_____

What happens to electrons that are not slowed by the resistance of lights?

_____

Part II: DC Circuits in Parallel

Build a circuit made a battery pack and three lights in ***parallel*** with the battery

What are the **voltage** drops in the circuit?   *Draw your circuit: Use proper symbols.*

Light 1: _____ Volts

Light 2: _____ Volts

Light 3: _____ Volts

Battery: _____ Volts
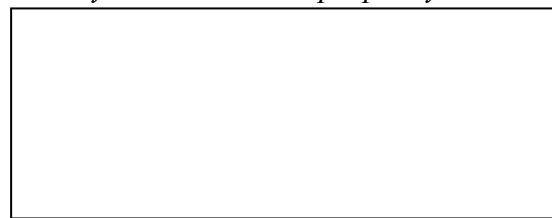
What is the current in each part of the **circuit**?

Light 1's path: _____ Amps   Use Ohm's Law to find the
resistance of the lights

Light 2's path: _____ Amps   Light 1: _____ Ohms

Light 3's path: _____ Amps   Light 2: _____ Ohms

Battery: _____Amps   Light 3: _____ Ohms

Are all the lights the same brightness? _____

Remove a light from its path. What happens to the brightness of the other lights?

_____

_____

For a parallel circuit, as lights (with resistance) are added, the voltage

_____

For a parallel circuit, as lights (with resistance) are added, the current

_____

Add additional batteries in series with the first battery.

What happens to the brightness? _____the voltages? _____the currents?_____

Add a resistor to one path in your parallel circuit.

What effect did the resistor have on the light in its path?

_____

What effect did the resistor have on the lights in the other two paths?

_____

Short circuit your parallel circuit.

How was the result similar or different to a shorted series circuit?

_____

Part III: Compound Circuits

Build the circuit illustrated on the right. Use two batteries in series.

Which light is the brightest? _____

Why?

_____
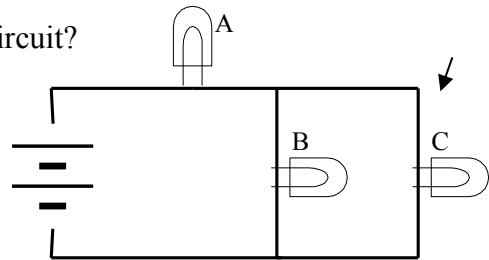
What is the voltage drop across?   What is the current through?   What is the resistance of?

Light A: _____ Volts   Light A: _____ Amps   Light A_____ Ohms

Light B: _____ Volts   Light B: _____ Amps   Light B_____ Ohms

Light C: _____ Volts   Light C: _____ Amps   Light C_____ Ohms

Battery: _____ Volts   Battery: _____ Amps   Battery_____ Ohms

Place a switch between B and C where the arrow indicates

What happens to light C when the switch is open? _____ Why?

_____

What happens to light B when the switch is open? _____

Why?_____

What happens to light A when the switch is open? _____ Why?

_____

Remove light A from the circuit and recluse the circuit.

How did B and C change? _____ Why?

_____

Conclusion Questions and Calculations: ½ point each   USE YOUR FORMULA!!!!   **V = I R**

To assure the same voltage is available to all devices; my house is wired in *series / parallel*.
Safety features like GFI's and circuit breakers are wired in *series / parallel* to assure that when they are turned off, the whole circuit is turned off too.

In a **series** circuit, as lights are added, the **voltage at the battery** *increases / decreases / remains the same*.

In a **series** circuit, as lights are added, the **current at the battery** *increases / decreases / remains the same*.

In a **parallel** circuit, as lights are added, the **voltage at the battery** *increases / decreases / remains the same*.

In a **parallel** circuit, as lights are added, the **current at the battery** *increases / decreases / remains the same*.
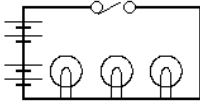
 With the switched closed, the bulb on the right will be *more bright / less bright / equally bright* than the light bulb on the left.

In the above diagram, if the middle bulb burns out, the bulb on the right will *become brighter / dim / turn off.*

My TI calculator uses four 1.5 V AAA batteries. The effectual voltage needed by the calculator must be_____.

Two 10.0 Ω lights in **series** produce an equivalent resistance of _____ Ω

Two 10.0 Ω lights in **parallel** produce an equivalent resistance of _____ Ω

Screenshot of Simulation for Circuits Lab
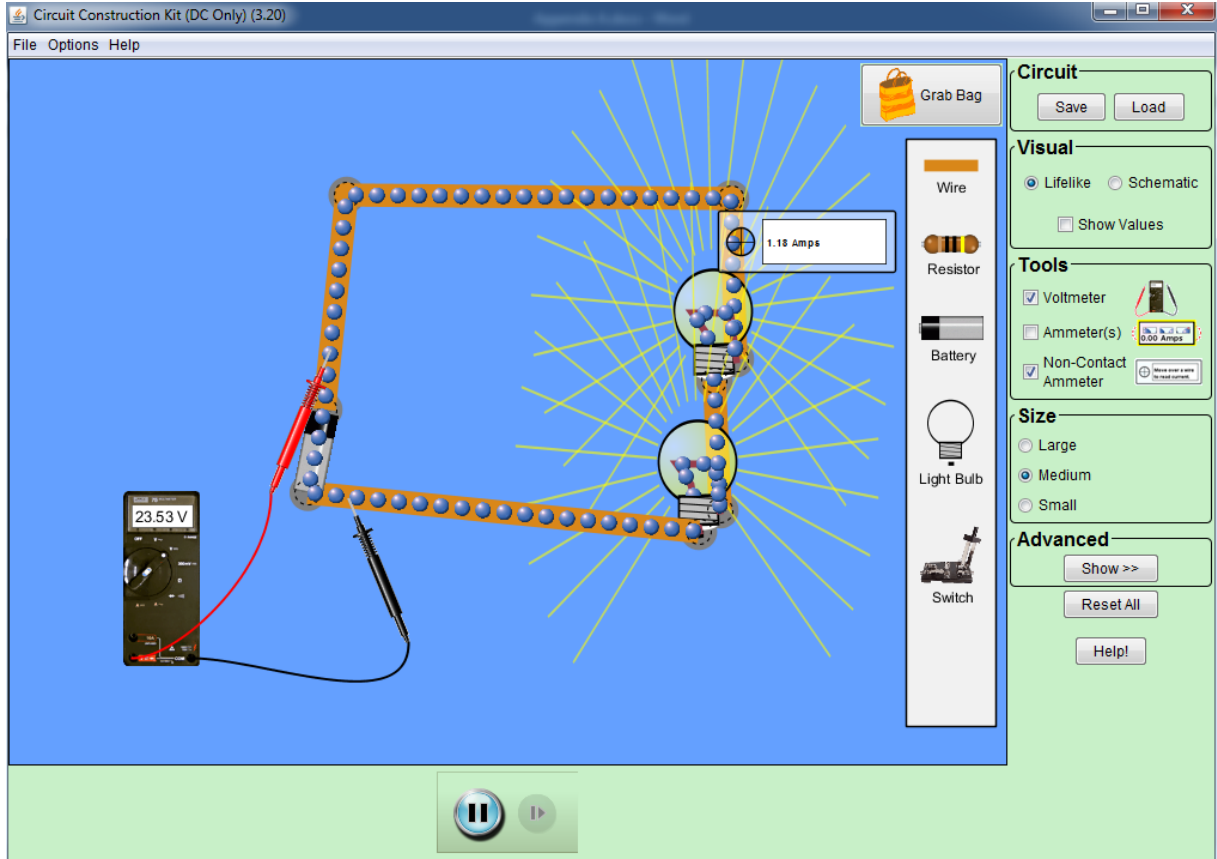
Name_____

Equipment Required

1. Ring stand   2. Long Screw   3. Electronic balance   4. RMS
5. Caliper   6. Disc   7. Ring

Purpose

A non-rotating ring is dropped onto a rotating disk, and the final angular speed of the system is compared with the value predicted using conservation of angular momentum.

Theory

When the ring is dropped onto the rotating disk, there is no net torque on the system since the torque on the ring is equal & opposite to the torque on the disk. Therefore, there is no change in angular momentum; angular momentum (L) is conserved.

$$L = I_i\omega_i = I_f\omega_f$$

where I_i is the initial rotational inertia & ω_i is the initial angular speed. The initial rotational inertia is that of a disk

$$I_i = \tfrac{1}{2} M_1 R^2$$

and the final rotational inertia of the combined disk & ring is

$$I_f = \tfrac{1}{2} M_1 R^2 + \tfrac{1}{2} M_2(r_1^2 + r_2^2)$$

where r_1 & r_2 are the inner & outer radii of the ring.

So the final rotational speed is given by

$$\omega_f = \frac{M_1 R^2}{M_1 R^2 + M_2(r_1^2 + r_2^2)}\omega_i$$
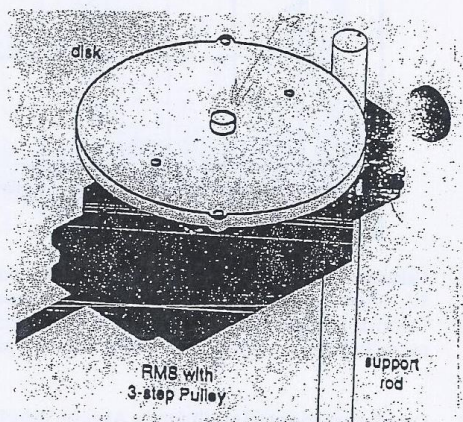
Figure 3.1: Setup for Dropping Ring Onto Disk

Setup

1. Mount the RMS to a support rod & connect it to a computer. Place the disk directly on the pulley as shown in Figure 3.1
2. Open Rotary Motion Sensor
3. Rotary Motion Angular.cmbl
4. Trouble shooting: if the collect button is not green go to experiment – connect interface – lab pro – com1

Procedure

1. Hold the ring with the pins up just above the center of the disk. Give the disk a spin using your hand & click the Record button – SPIN FAST

    After about 25 data points have been taken, drop the ring onto the spinning disk. See Fig 3.2

2. Click on the Stop button to end the data collection.

3. Click on the Cursor and move the cursor to the data point immediately before the collision. Record the Angular Velocity at the point in the Table 3.1. Move the cursor to the data point immediately after the collision. Record the Angular Velocity at this point in Table 3.1. Print graph, label the initial and final angular velocities on your graph & attach to your report.
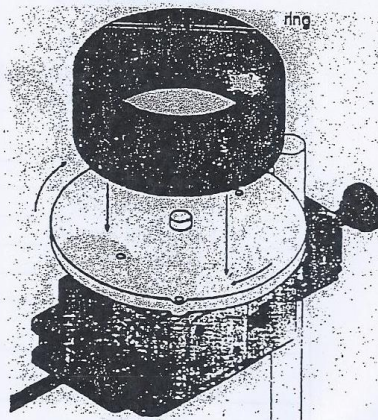
Figure 3.2: Drop Ring on Disk

4. Weigh the disk & ring & measure the radii. Record these values in Table 3.1
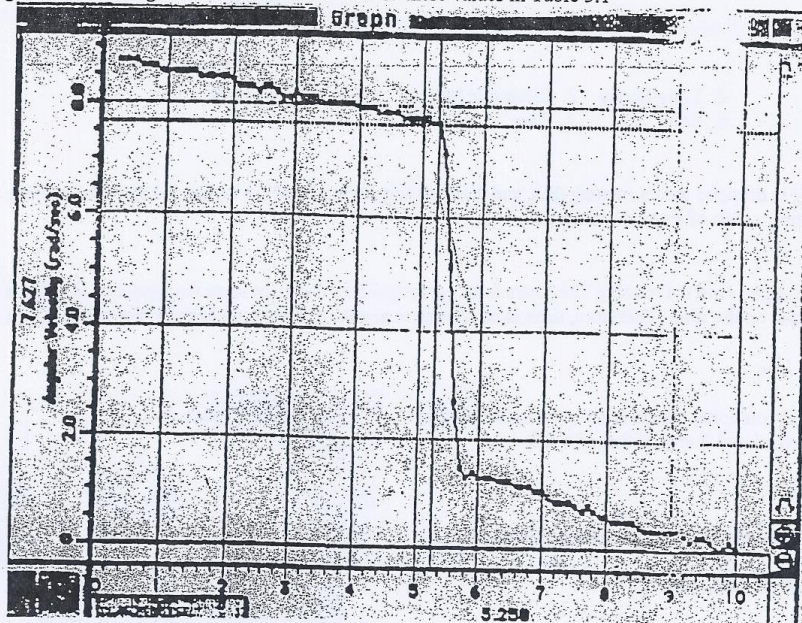
Analysis

1. Calculate the expected (theoretical) value for the final Angular Velocity using the equation & record this value in Table 3.1. Show all your work on a separate piece of paper.
2. Calculate the percent difference between the experimental & the theoretical values of the final Angular Velocity & record in Table 3.1. Show your work on separate piece of paper.

Questions

1. Does the experimental result for the Angular Velocity agree with the Theory?
2. What percentage of the rotational kinetic energy was lost during the collision? Calculate the energy lost & record the results in Table 3.1. Show your work on a separate piece of paper.

$$\%KE_{lost} = \frac{\frac{1}{2} I_i\omega_i^2 - \frac{1}{2} I_f\omega_f^2}{\frac{1}{2} I_i\omega_i^2}$$

Table 3.1: Data & Results

Initial Angular Velocity	
Final Angular Velocity (experimental value)	
Mass of Disk (M_1)	
Mass of Ring (M_2)	
Inner Radius of Ring (r_1)	
Outer Radius of Ring (r_2)	
Radius of Disk	
Final Angular Velocity (theoretical value)	
% Difference between Final Angular Velocities	
% KE lost	

Name_____ **Period**_____ **Date**_____

Moment of Inertia and Angular Momentum

Go to http://phet.colorado.edu/en/simulation/legacy/torque and open it.

Part I: Moment of Inertia

1. Click the Moment of Inertia Tab at the top.
2. Disregard any millimeter units. They should all be meters.
3. To best see the graphs, set the scale of the torque graph to show a range of 20 to   -20.
4. Set the Moment of Inertia Graph to show a range of 2 kg m^2 to – 2 kg m^2
5. Set the angular acceleration graph to show 1,000 degrees / s^2 to –1000 degrees / s^2
6. Calculate the moment of Inertia for the disk with the initial given information.

7. Hold the mouse over the disk so the mouse finger is pointing anywhere between the green and pink circles.
8. Hold down the left mouse button. Move your mouse to apply a force.
9. Look at the graph and try to apply a force that creates a torque of 10.
10. Use the ruler to determine the radius at any point between the green and pink circles. r = ____m
11. Calculate what the applied force must have been.

12. Calculate the angular acceleration of the disk. Work in SI units, and then convert to degrees / s^2. Compare to the graph to check your answer.

13. Predict what will happen to the moment of inertia if you keep the mass of the platform the same, but you create a hole in the middle (increase inner radius).
_____
14. Set the inner radius equal to 2. Calculate the moment of inertia for this shape. Set the disk in motion and check your answer by looking at the moment of inertia graph.

15. Even when the force on the platform changes, the moment of inertia graph remains constant. Why? _____

_____

16. Fill in the blanks: When the mass of an object increases, the moment of inertia
_____. When the distance of the mass from the axis of rotation increases,
the moment of inertia _____.

<u>Part II</u>

1. Click the Angular Momentum tab at the top.
2. Eliminate the moment of inertia tab. (click the red box)
3. Set the angular speed to be 45 degrees / s.
4. What is the SI unit for angular momentum? _____
5. Calculate the angular momentum in SI units (you should have already calculated the
moment of inertia in part II).

6. While the disk is moving, change the inner radius to 2.
7. Observe the graphs.
8. Changing the inner radius automatically changes the angular velocity to what? Why?
(mention moment of inertia and angular momentum in your answer).
9. Calculate the new moment of inertia.

10. Return the radius to 0 and instead (while the disk is still moving) change the mass to a
value of your choosing. What is the new velocity? What is the new moment of inertia?

11. What did you notice about the angular momentum graph through all this? This means
what?

Screenshot of Simulation for Angular Momentum Lab

Pendulum LAB

A pendulum is any mass that swings back and forth on a rope, string, or chain. Pendulums can be found in old clocks and other machinery. A playground swing is a pendulum. Many amusement park rides are pendulums.

If you pull the mass away from its rest position, so that the string is at an angle, and then let go, the mass will begin to swing back and forth. One trip back and forth is called a period. How fast the pendulum swings back and forth can change.

Problem: **What variables affect the PERIOD of a pendulum?**

For this lab you will investigate three possible factors that affect the Period of a pendulum. There are three separate experiments, graphs, data charts, & hypothesis.

Materials:

- Ring Stand
- Clamp
- String: 100 cm
- Masses
- Protractor
- Ruler or Meter Stick

Variable #1: **Does the length of string affect the PERIOD of a pendulum?**

Hypothesis: If the _____ of the string is increased, then

_____.

Procedure:

Attach a length of string (pivot point to center of mass should be appx. 80 cm) to the ring clamp and the mass (mass should be 100 g).

Raise the mass to a medium height and release and start timing the 10 complete swings (accurate to the *tenths* place).

Divide time by 10 to get the time it took to complete 1 cycle (period) (accurate to the *tenths* place)

Record your results in your data table.

Repeat this experiment for 5 more trials.

Shorten the string to 60 cm and repeat (hold mass constant at 100 g).

Repeat steps 1 – 5 for 60 cm, 40 cm, and 20 cm of string.

Data Chart for Variable #1

TIME (s) of one period	Length (cm) (hold mass constant at 100 grams)			
	80 cm	**60 cm**	**40 cm**	**20 cm**
Trial 1				
Trial 2				
Trial 3				
Trial 4				
Trial 5				
Average				

What is the independent variable?

_____

What is the dependent variable?

_____

Name two constants.

_____

_____

Graph of Variable #1: *Construct a **line graph** showing the **length of string** vs. the **Time** (to complete one period). Show Length on the **x axis** and time on the **y axis.***

Variable #2: How does changing the MASS of the pendulum affect the PERIOD of the pendulum?

Hypothesis: If the _____ of the pendulum increases, then _____

_____ .

Procedure:

1. Attach a length of string (pivot point to center of mass should be appx. 40 cm) to the ring clamp and the mass (mass should be 100 g).
2. Raise the mass to a medium height and release and start timing the 10 complete swings (tenths place)
3. Divide the time by 10 to get the time it took to complete one (1) cycle (period).(tenths place)
4. Record your results in your data table.
5. Repeat this experiment for 5 more trials.
6. Change the mass to 200 g and repeat (hold length of string constant at 40 cm.)
7. Repeat steps 1 – 5 for 200g, 300 g, and 400 g masses.

Data Chart for Variable #2

TIME (s) of one period	MASS (hold length constant at 40 cm)			
	100 g	200 g	300 g	400 g
Trial 1				
Trial 2				
Trial 3				
Trial 4				
Trial 5				
Average				

What is the independent variable?

_____

What is the dependent variable?

_____

Name two constants.

_____
_____
_____

Graph of Variable #2

*Construct a **line graph** showing the **MASS** vs. the **TIME** (to complete 1 period) for your data. Show Mass on the **x axis** and time on the **y axis**.*

Variable #3: How does changing the ANGLE of the pendulum affect the PERIOD of the pendulum?

Hypothesis: If the _____ of the pendulum increases, then _____

_____.

Procedure:

1. Attach a length of string (pivot point to center of mass should be appx. 40 cm) to the ring clamp and the mass (mass should be 100 g).

2. Raise the mass to a 5° height and release and start timing the 10 complete swings.

3. Divide the time by 10 to get the time it took to complete one (1) cycle

4. Record your results in your data table and repeat 4 more times

5. Change the ANGLE to 10° and repeat. (length of string constant at 40 cm, mass constant at 100g)

6. Repeat steps 1 – 5 for 10°, 15°, and 20° Angles.

Data Chart for Variable #3

TIME (s) of one period	ANGLE (hold length constant at 40 cm & mass at 100g)			
	5 °	10 °	15 °	20 °
Trial 1				
Trial 2				
Trial 3				
Trial 4				
Trial 5				
Average				

What is the independent variable?

_____

What is the dependent variable?

_____

Name two constants.

_____

_____

_____

Graph of Variable #3

*Construct a **line graph** showing the **ANGLE** vs. the **TIME** (to complete 1 period) for your data.*

*Show Angle on the **x** axis and Time on the **y** axis.*

Analysis

1. Does the data support your hypothesis #1? _____

2. Does the data support your hypothesis #2? _____

3. Does the data support your hypothesis #3? _____

4. Identify Relationships

   a) What is the relationship between LENGTH and PERIOD? Describe the relationship shown in graph 1: (circle the words so that it describes your graph.)

As **Length** (increased / deceased), **Period** (increased / decreased/stayed same / was random).

This is a (Direct / Inverse / No relationship) relationship.

   b) What is the relationship between MASS and PERIOD? Describe the relationship shown in graph 2: (circle the words so that it describes your graph.)

As **Mass** (increased / deceased), the **Period** (increased / decreased/stayed same / was random).

This is a (Direct / Inverse / No relationship) relationship.

   c) c) What is the relationship between ANGLE and PERIOD? Describe the relationship shown in graph 3: (circle the words so that it describes your graph.)

 As **Angle** (increased / deceased), the **Period** (increased / decreased/stayed same / was random).

This is a (Direct / Inverse / No relationship) relationship.

5. Explain any sources of error. _____

_____

_____

Pendulum LAB

A pendulum is any mass that swings back and forth on a rope, string, or chain. Pendulums can be found in old clocks and other machinery. A playground swing is a pendulum. Many amusement park rides are pendulums.

If you pull the mass away from its rest position, so that the string is at an angle, and then let go, the mass will begin to swing back and forth. One trip back and forth is called a period. How fast the pendulum swings back and forth can change.

Problem: **What variables affect the PERIOD of a pendulum?**

For this lab you will investigate three possible factors that affect the Period of a pendulum. There are three separate experiments, graphs, data charts, & hypothesis.

http://phet.colorado.edu/en/simulation/legacy/pendulum-lab

Variable #1: **Does the length of string affect the PERIOD of a pendulum?**

Hypothesis:

If the _____ of the string is increased, then _____

_____.

Procedure:

1. Raise the mass to a medium height and release. Use photogate to time the period of the swing.
2. This time to complete one cycle is known as the period (T).
3. Record your results in your data table.
4. Change the length and repeat (hold mass and angle constant).

Data Chart for Variable #1

TIME (s) of one period	Length (m) (hold mass constant at 1 kg)			
	0.5 m	**1 m**	**1.5 m**	**2 m**

What is the independent variable?

_____

What is the dependent variable?

_____

Name two constants.

Graph of Variable #1: *Construct a **line graph** showing the **length of string** vs. the* ***Time*** *(to complete one period). Show Length on the **x axis** and time on the **y axis.***
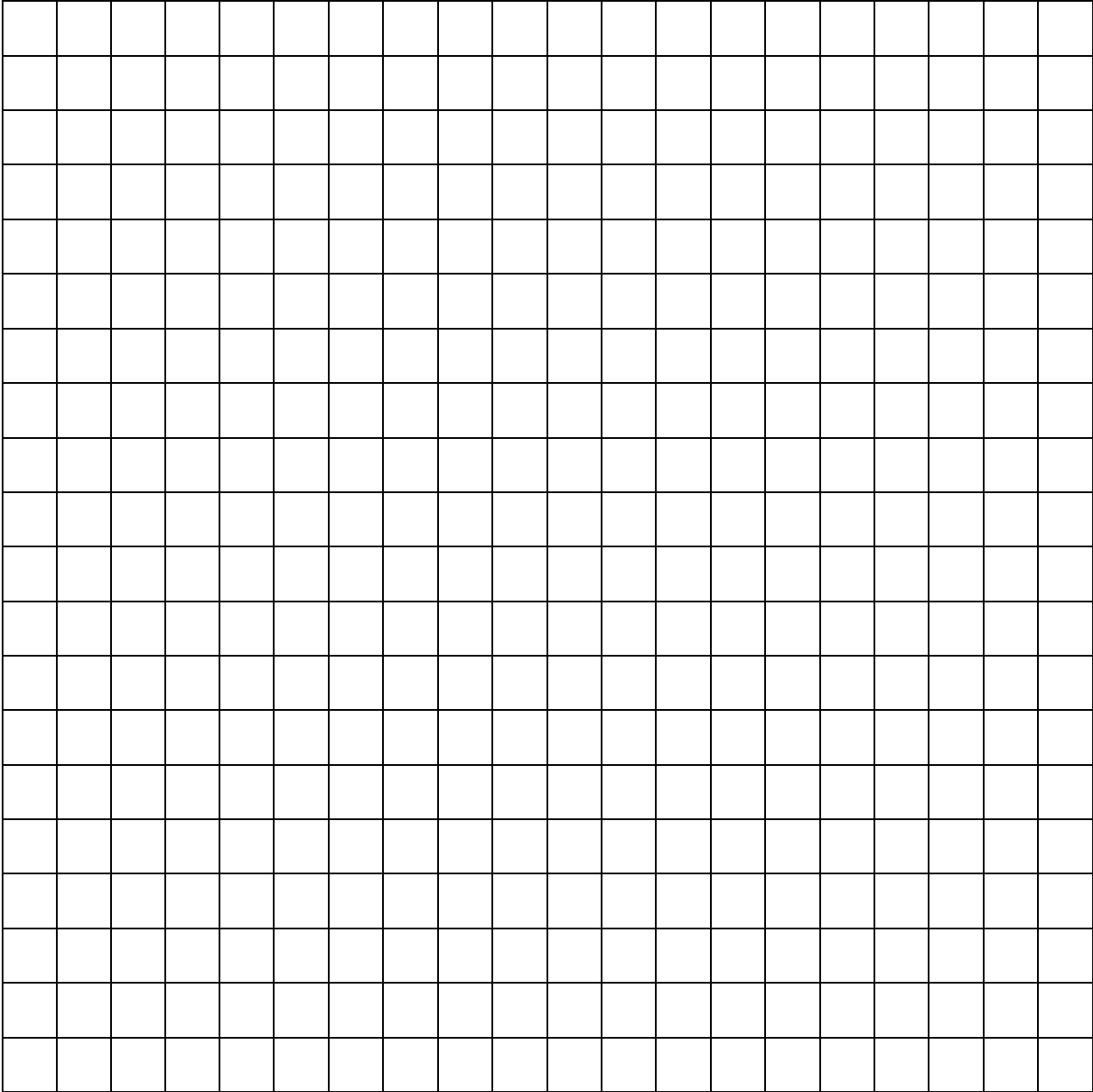
Variable #2: **How does changing the MASS of the pendulum affect the PERIOD of the pendulum?**

Hypothesis: If the _____ of the pendulum increases, then _____

_____.

Procedure:

1. Choose a length for the pendulum and set the mass at 0.5 kg.

3. Using the photogate timer measure the period of one cycle.

4. Record your results in your data table.

5. Change the mass and repeat.

Data Chart for Variable #2

TIME (s) of one period	MASS (hold length constant at 0.5 m)			
	0.5 kg	1 kg	1.5 kg	2 kg

What is the independent variable?

_____

What is the dependent variable?

_____

Name two constants.

_____
_____
_____

Graph of Variable #2

*Construct a **line graph** showing the **MASS** vs. the **TIME** (to complete 1 period) for your data. Show Mass on the **x axis** and time on the **y axis**.*
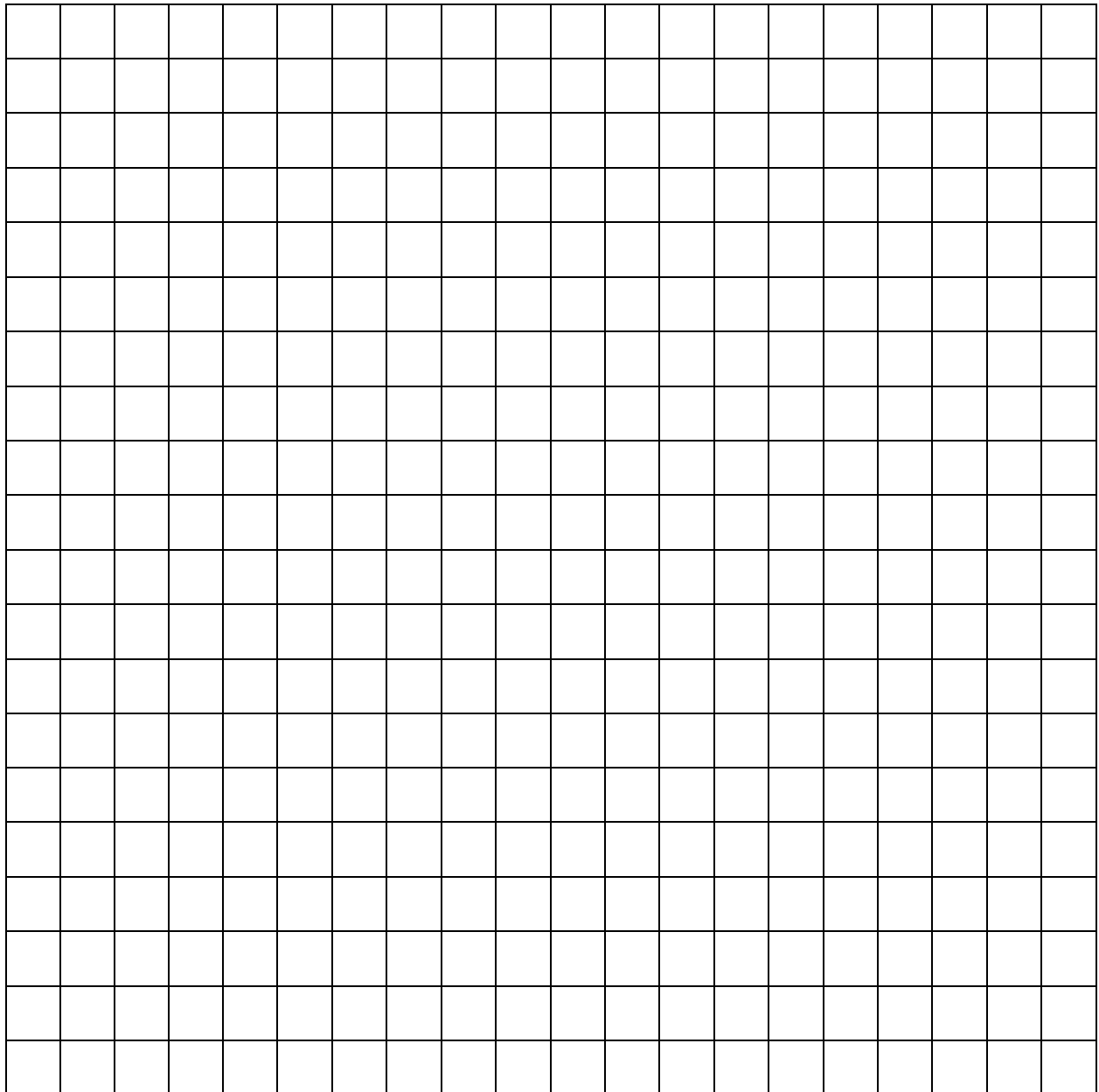
Variable #3: How does changing the ANGLE of the pendulum affect the PERIOD of the pendulum?

Hypothesis: If the _____ of the pendulum increases, then _____

_____.

Procedure:

1. Raise the mass to a 5º height and release and start timing swings.

2. Record your results in your data table.

3. Change the ANGLE to 10º and repeat. (length and mass constant).

Data Chart for Variable #3

TIME (s) of one period	ANGLE			
	5 º	10 º	15 º	20 º

What is the independent variable?

_____

What is the dependent variable?

_____

Name two constants.

_____
_____

Graph of Variable #3

*Construct a **line graph** showing the **ANGLE** vs. the **TIME** (to complete 1 period) for your data.*

*Show Angle on the **x** axis and Time on the **y** axis.*
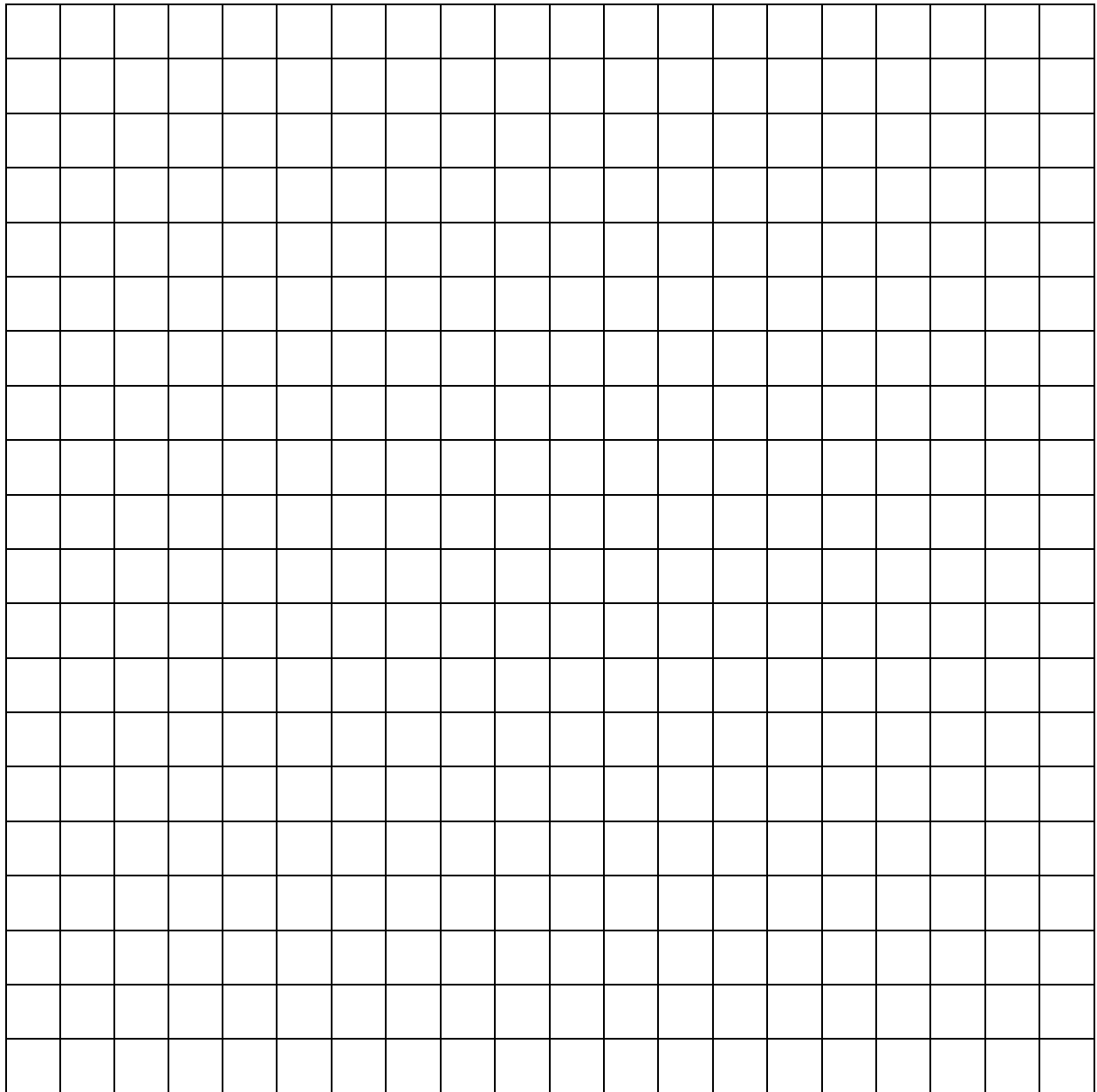
Analysis

6. Does the data support your hypothesis #1? _____

7. Does the data support your hypothesis #2? _____

8. Does the data support your hypothesis #3? _____

9. Identify Relationships

    d) What is the relationship between LENGTH and PERIOD? Describe the relationship shown in graph 1: (circle the words so that it describes your graph.)
    As **Length** (increased / deceased), **Period** (increased / decreased/stayed same / was random).

    This is a (Direct / Inverse / No relationship) relationship.

    e) What is the relationship between MASS and PERIOD? Describe the relationship shown in graph 2: (circle the words so that it describes your graph.)
    As **Mass** (increased / deceased), the **Period** (increased / decreased/stayed same / was random).

    This is a (Direct / Inverse / No relationship) relationship.

    f) c) What is the relationship between ANGLE and PERIOD? Describe the relationship shown in graph 3: (circle the words so that it describes your graph.)
    As **Angle** (increased / deceased), the **Period** (increased / decreased/stayed same / was random).

    This is a (Direct / Inverse / No relationship) relationship.

10. What happens to the period if you change the planet you are on?

Extra credit: Calculate 'g' for planet X.

Screenshot of Simulation for Pendulum Lab

Friction Lab

Students were provided the following instructions from a power point and the following lab report to complete their lab on.

And now… the Lab

- *Pass out lab report forms.*

- Purpose: "To find the relationship between the **Normal Force** and **Frictional Forces**."

- Remember to identify which is *independent* and which is *dependent*.

Comparing 2 Types of Friction on Two Different Surfaces

- Types of Friction
  - Fs and Fk
- Different Surfaces
  - Sandpaper and Tabletop

How to do it

- Zero out the sensor.
- Select mass (kg).
  - Convert to weight (Newtons)
  - Is this also Fg?
  - In this case Fg = Fn, right?
- *Remember, the purpose is to find the relationship between Fn and Friction.*
- Place mass on top of the lab notebook
- Drag across surfaces and measure forces.
  - Show on LoggerPro using "Examine" and "Statistics"

↑ Fn

↓ Fg

Graphing Tips

- *Write the following in the graphing section of your lab report form:*
- x-axis: Fn (N)
- y-axis: Frictional Force (N)
- The graph will have 4 lines
  - **Fs** for Tabletop; **Fk** for Tabletop
  - **Fs** for Sandpaper; **Fk** for Sandpaper
- Identify them clearly.
- Remember to do a "best fit" line (not dot-to-dot)

Mathematical Model Tips

- *Write the following in the graphing section of your lab report form:*
- Create 4 mathematical models
  - **Fs** for Tabletop; **Fk** for Tabletop
  - **Fs** for Sandpaper; **Fk** for Sandpaper
- Start with y=mx+b, then convert to what they represent.
- Identify them clearly.
- The slope is especially important in this lab.

Data Tables for the Raw Data Section

Remember to zero out the sensor.

Mass Conversion

200g = 2 N

400g = 4 N

600g = 6 N

800g = 8N

1000g = 10N

Tabletop		
Fn (N)	Fs (N)	Fk (N)
2		
4		
6		
8		
10		

Sandpaper		
Fn (N)	Fs (N)	Fk (N)
2		
4		
6		
8		
10		

PGHS Physics   *LAB REPORT*

Name: _____   **Period:** _____   **Date:** _____

Lab Name: _____

   Lab Partner Names:

   _____   _____   _____

   _____   _____   _____

Purpose

Independent and Dependent Variables

Apparatus
- Diagram drawn with all components labeled.

Procedure
- Clear and brief sequence of steps so someone could repeat it. Number them.

Raw Data

- Measurements organized into a neat table.
- Values are clearly labeled, with units included in the heading of the table or with each measured value.
- Multiple trials.

Graph

- Axes labeled, with units.
- Appropriate scale, accurate plotting.
- Best-fit line or curve (not dot-to-dot).
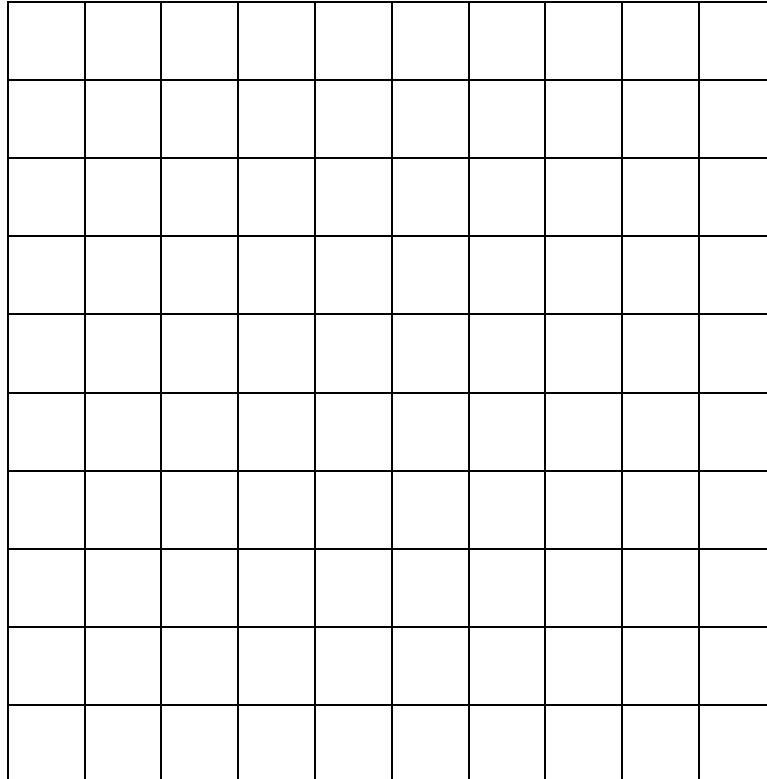
Mathematical Model

- Start with y = mx + b.
- Change to appropriate variables (replace y and x with what they represent).
- Correct numbers and units for slope (m) and y-intercept (b). Ready to use final equation.

Conclusion: please number your answers so they are easy to follow

1. Full sentence explanation of what the relationship is that was defined in the purpose section.
2. What does the slope of your graph and in your mathematical model represent?
3. Why is the y-intercept what it is?
4. Do you trust your results? Why or why not? Provide a reasonable explanation for sources of error. Avoid the phrase "human error."

Name_____ Period_____ Date_____

Friction Lab

Purpose:

Find the relationship between normal force and friction.

Go to phet.colorado.edu

Click on Play with sims

In the left menu choose Physics, then Motion; scroll down and find the icon for "Forces and Motion" and open it.

Lab Procedure:

Part A

1. Play around with the intro. Notice that you can change the object, the floor, etc. Try adding the "sum of forces" vector and notice when it appears.
2. Move to the next tab – "Friction"
3. The box should initially be 100 kg. Change gravity to 10. Increase the applied force until the box begins to move. Drop it back until you find the maximum force you can apply and the box doesn't move. Draw a force diagram.

4. So, what is the maximum static friction on the box?
5. Using this table, change the mass and/or gravity and find the static friction.

Trial	Mass (kg)	Gravity (m/s^2)	Friction (N)
1			
2			
3			
4			
5			
6			

6. Graph the Friction force vs. the Normal force

Friction Force (N) vs. Normal Force (N)
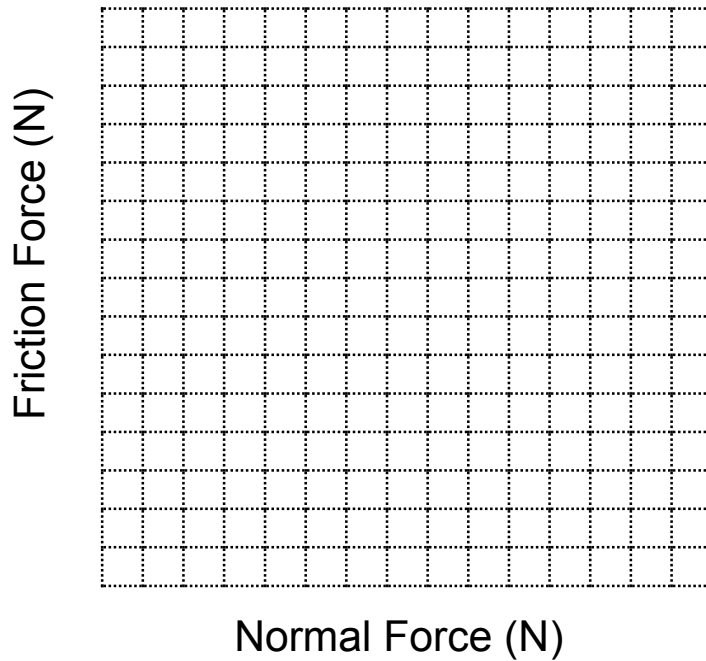
7. Find the slope.

8. Do you see this number appear anywhere else on the simulation screen? What does this number stand for?

9. Write an equation for calculating friction. Start with y = mx + b and customize it.

Part B

1. Go to the "Force Graphs" tab.
2. Click to show the Friction Force and Applied force on the graph.
3. Increase the applied force until the object begins to move. Then bring the applied force to 0 N.
4. Draw what the graph looks like. Indicate which line is which.

Force (N) ▲

(blank graph grid)

Time (Seconds)
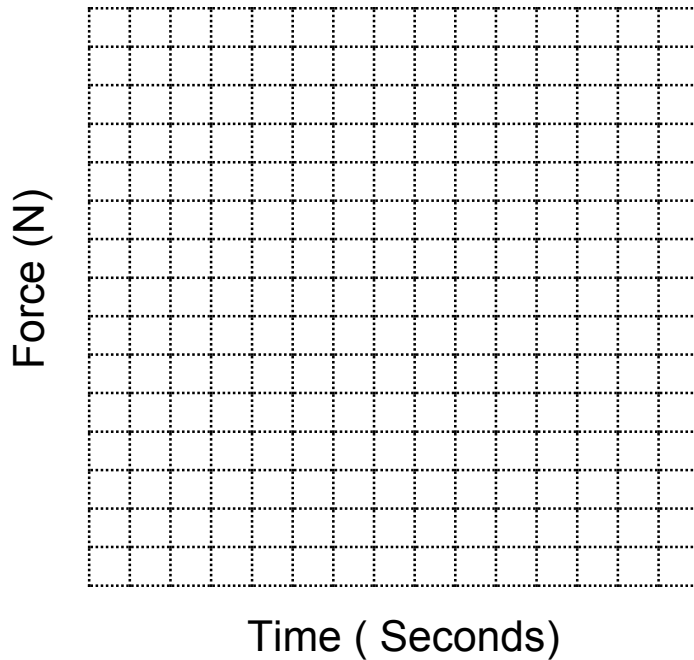
5. Record the maximum static friction.
   Friction - _____
6. What is the kinetic friction? _____
7. Describe how the static and kinetic frictions differ - both in relative strengths and in shape on the graph.

8. Using the equation you found in #9 of part A, pick 3 objects and using their mass and listed coefficient, find what friction should be. How does that compare to what the graph gave?

9. Why are they a little different?
10. Click the mystery object. Note that it doesn't give the mass or coefficients. So, assuming the mass of the object is 80 kg, calculate the static and kinetic coefficients.

Questions

1. Did the coefficients of friction change as you added more weight onto the block? (reference part 1) Explain why it did or didn't change.

2. How did the coefficient of static friction compare with the coefficient of kinetic friction? Was it greater, less or the same?

3. Explain a real life situation in which you use friction?

Screenshot of Simulation for Friction Lab

APPENDIX B.   **QUIZZES AND SURVEYS**

The following pages contain copies of all quizzes and surveys given to the students following the completion of the lab. Each lab group took the same quiz and survey. For each lab the survey will come first followed by the quiz which is the same order the students received them. The quizzes were given via PowerPoint.

Name_____ Period_____ Date_____

Momentum Lab Survey

How effective would you say the lab was at illustrating conservation of momentum?

                      1   2   3   4   5   6   7

         Not Effective   Very Effective

Comments?

How engaging was the lab?

                      1   2   3   4   5   6   7

         Very Boring   Very Engaging

Comments?

Momentum Quiz

▶ 1. What is the relationship between mass and momentum?

▶ 2. What is the relationship between velocity and momentum?

▶ 3. An object has a mass of 3 kg and velocity of 10 m/s. What is its momentum?

▶ 4. A 0.5 kg baseball travels at 40 m/s toward a 2 kg bat traveling 20 m/s the other direction. What is the total momentum of the system?

▶ 5. The cue ball strikes another stationary pool ball. How does the momentum of the cue ball before the collision compare to the momentum of both balls after?

▶ 6. A 70 kg running back collides with a 140 kg linesman. If they were both running at each other with a speed 5 m/s, who experiences the larger force?

Name_____ Period_____ Date_____

Energy Lab Survey

How effective would you say the lab was at illustrating the concept of conservation of energy?

                      1   2   3   4   5   6   7

          Not Effective   Very Effective

Comments?

How engaging was the lab?

                      1   2   3   4   5   6   7

          Very Boring   Very Engaging

Comments?

Energy Quiz

1. As energy is changed from one form to another the total energy stays the same.

    A. Sometimes true

    B. Always false

    C. Always true

2. A ball is thrown into the air with 100 J of kinetic energy, which is transformed to gravitational potential energy at the top of its trajectory. When it returns to its original level after encountering **air resistance**, its kinetic energy is

    A. less than 100 J   B. more than 100 J   C. 100 J

    A **2.0 kg** block is allowed to slide from rest down a hill that is **10 m** high. It reaches the bottom with a speed of **5.0 m/s**. Consider Friction.

3. What type(s) of energy makes up the total initial energy?

    A. E_k B. E_g C. $E_g + E_k$ D. E_{el} E. E_{diss}

4. What type(s) of energy makes up the total final energy?

    A. $E_k + E_{diss}$ B. E_k C. E_{diss} D. $E_g + E_k$

5. How much energy was dissipated by friction?

    A. 20 J   B. 200 J   C. 100 J   D. 175 J   E. 50 J

6. If the hill was 25 m long, what was the force of friction?

    A. 1 N   B. 7 N   C. 20 N   D. 25 N

Name_____ Period_____ Date_____

Circuit Lab Survey

How effective would you say the lab was at illustrating the relationships between voltage, current, and resistance?

                    1   2   3   4   5   6   7

            Not Effective   Very Effective

Comments?

How engaging was the lab?

                    1   2   3   4   5   6   7

            Very Boring   Very Engaging

Comments?

Circuits Quiz

▶ 1. What are the two ways resistors can be combined in a circuit?

▶ 2. What is true about resistors connected in parallel?

    ▶ a. the current through each is the same

    ▶ b. the voltage through each is the same

    ▶ c. the total resistance is more than either of them

    ▶ d. the power used by each is the same

▶ 3. Two 10 ohm resistors are connected in series. What is the total voltage drop across them if each has a current of 3 amps through them?

    ▶ A. 60 V

    ▶ B. 30 V

    ▶ C. 0.3 V

    ▶ D. 0.6 V

    ▶ 4. What is the resistance if an element has 13 V and 0.5 amps passing through it?

▶ 5. A 5 ohm, 10 ohm, and 15 ohm resistor are connected in series. Which bulb would shine the brightest?

▶ 6. What is the total resistance of this circuit?

Name_____ Period_____ Date_____

Angular Momentum Lab Survey

How effective would you say the lab was at illustrating the relationship between inertia and momemtum?

                 1   2   3   4   5   6   7

         Not Effective   Very Effective

Comments?

How engaging was the lab?

                 1   2   3   4   5   6   7

         Very Boring   Very Engaging

Comments?
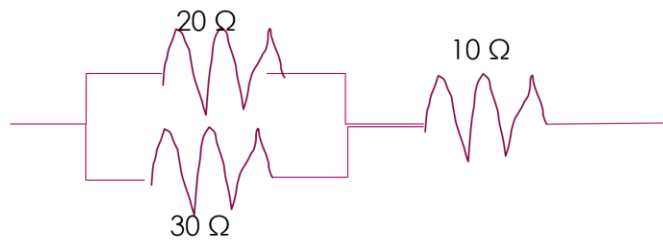
Angular Momentum Quiz

1. Having a large moment of inertia makes it:

    A. easier for an object to go fast
    B. easier for an object to go faster
    C. harder for an object to go fast
    D. harder for an object to go faster

2. Increasing the moment of inertia for an object while it is spinning has what effect on the angular momentum?

    A. Increases it
    B. Decreases it
    C. Has no effect
    D. Increases it by the square (exponential)

3. Calculate the moment of inertia for a ring with an inner radius of 0.5 m and outer radius of 1 m and a mass of 3 kg.

4. An object initially spins with an angular velocity of 8 rad/s. If the object's inertia is initially 3 kgm^2 and becomes 12 kgm^2, what is the new velocity?

5. An ice skater wants to slow their spin. What should they do?

    A. Raise their arm up

    B. Put their arms out

    C. Pull their arms in

    D. Keep their arms by their side

6. You want to create a tire that has the most angular momentum for a given speed. You can only make one change and cannot change its shape. Which should you do?

    A. Double its mass

    B. Half its mass

    C. Double its radius

    D. Half its radius

Name_____ Period_____ Date_____

Pendulum Lab survey

How effective would you say the lab was at illustrating which variables affect period?

                              1   2   3   4   5   6   7

               Not Effective   Very Effective

Comments?

How engaging was the lab?

                              1   2   3   4   5   6   7

               Very Boring   Very Engaging

Comments?

Pendulum Quiz

1. A full period for a pendulum is the time between:

▶ A. when the position repeats

▶ B. when velocity repeats

▶ C. when both the velocity and position repeat

▶ D. when the pendulum reverses direction

2. What has the greatest effect on a pendulum?

▶ A. its length

▶ B. its mass

▶ C. its weight

▶ D. the angle it swings

3. What would be the period of a pendulum on earth that has a mass of 2 kg and a length of 0.5 m?

4. What would happen to the period of the pendulum if you made the pendulum four times longer?

5. Imagine you could take a pendulum to different planets. Which planet would it have the longest period?

▶ A. Earth

▶ B. Mars

▶ C. Venus

▶ D. Saturn

6. If you are swinging on a swing, what happens to the period of your swing as you let it slow down/ come to a stop?

Name_____ Period_____ Date_____

Friction Lab Survey

How effective would you say the lab was at illustrating the relationship between friction and normal force?

                   1   2   3   4   5   6   7

    Not Effective   Very Effective

Comments?

How engaging was the lab?

                   1   2   3   4   5   6   7

    Very Boring   Very Engaging

Comments?

Friction Quiz

1. What is the relationship between the force of friction and the normal force?

   ▶ A. The force of friction is directly proportional to the normal force.

   ▶ B. The force of friction is inversely proportional to the normal force.

   ▶ C. The force of friction is proportional to the square of the normal force.

   ▶ D. The normal force is proportional to the square of the friction.

2. In general, how does the coefficient of static friction compare to the coefficient of kinetic friction for the same two materials?

   ▶ A. The coefficient of static friction is equal to the coefficient of kinetic friction.

   ▶ B. The coefficient of static friction is less than the coefficient of kinetic friction.

   ▶ C. The coefficient of static friction is greater than the coefficient of kinetic friction.

   ▶ D. It depends on the material which coefficient is greater.

3. When you push a 2-kg book resting on a tabletop, you have to exert a force of 3 N to start the book sliding. Once it is sliding, however, you can use a force of only 1 N to keep the book moving with constant speed. What is the coefficient of kinetic friction?

4. A car weighs 9000 N. If the coefficient of static friction between the tires and the road is 0.85, what amount of friction can the car generate to make it accelerate?

5. A packing crate is sitting at rest on an inclined loading ramp. How does the magnitude of the force of static friction compare to the other forces acting on the crate?

   ▶ A. The magnitude of the force of static friction is equal to the magnitude of the weight of the crate.

   ▶ B. The magnitude of the force of static friction is equal to the magnitude of the normal force acting on the crate.

   ▶ C. The force of static friction is the only force acting on the crate, and it is responsible for keeping the crate at rest.

   ▶ D. The magnitude of the force of static friction is equal to the magnitude of the component of the weight of the crate parallel to the inclined ramp.

6. Two drivers traveling side by side at the same speed suddenly see a deer in the road ahead of them and begin braking. Driver 1 stops by locking up his brakes and screeching to a halt; driver 2 stops by applying her brakes just to the verge of locking, so that the wheels continue to turn until her car comes to a complete stop. All other factors being equal, is the stopping distance of driver 1 greater than, less than, or equal to the stopping distance of driver 2?

   a. less than   b. equal to   c. greater than

APPENDIX C.   RAW QUIZ AND SURVEY DATA

Momentum Lab Data

Lab Type	Quiz Score	Recall	Calculation	Transfer	Survey Response on Effectiveness	Survey Response on Engagement
Hands-on	4	1	1	2	6	7
Hands-on	5	2	2	1	5	4
Hands-on	5	2	1	2	5	5
Hands-on	3	1	1	1	5	5
Hands-on	4	1	2	1	5	3
Hands-on	3	1	1	1	5	5
Hands-on	5	1	2	2	5	4
Hands-on	3	1	1	1	6	3
Hands-on	3	1	1	1	4	6
Hands-on	5	2	2	1	4	5
Hands-on	3	1	1	1	5	5
Hands-on	3	1	1	1	6	5
Hands-on	4	1	2	1	6	7
Hands-on	5	2	2	1	6	4
Hands-on	1	0	1	0	5	5
Hands-on	4	1	2	1	5	4
Hands-on	4	1	2	1	6	6
Hands-on	3	1	2	0	6	6
Hands-on	5	2	2	1	7	5
Hands-on	3	0	2	1	4	3
Hands-on	3	1	1	1	3	5
Hands-on	4	1	1	2	4	6
Hands-on	4	1	1	2	5	7
Hands-on	6	2	2	2	4	5
Hands-on	5	2	1	2	2	4
Hands-on	4	1	1	2	7	7

Lab Type	Quiz Score	Recall	Calculation	Transfer	Survey Response on Effectiveness	Survey Response on Engagement
Simulation	5	2	1	2	4	7
Simulation	3	2	0	1	6	6
Simulation	6	2	2	2	6	5
Simulation	5	2	2	1	5	5
Simulation	4	1	2	1	5	5
Simulation	5	2	1	2	6	6
Simulation	5	2	2	1	5	4
Simulation	5	2	2	1	5	6
Simulation	5	1	2	2	5	6
Simulation	6	2	2	2	5	7
Simulation	4	2	1	1	7	7
Simulation	5	2	2	1	5	6
Simulation	4	0	2	2	2	3
Simulation	5	2	2	1	2	3
Simulation	3	0	2	1	4	5
Simulation	6	2	2	2	5	4
Simulation	5	2	2	1	5	6
Simulation	6	2	2	2	5	3
Simulation	4	2	1	1	6	6
Simulation	4	2	2	0	5	6
Simulation	6	2	2	2	7	7
Simulation	1	0	1	0	5	4
Simulation	6	2	2	2	5	4
Simulation	5	2	1	2	3	3
Simulation	2	0	1	1	4	1
Simulation	5	2	1	2	6	4
Simulation	5	2	2	1	6	6
Simulation	4	1	2	1	5	6

Lab Type	Quiz Score	Recall	Calculation	Transfer	Survey Response on Effectiveness	Survey Response on Engagement
Hands-on	5	2	2	1	6	7
Hands-on	6	2	2	2	5	5
Hands-on	5	2	2	1	5	6
Hands-on	3	2	1	0	6	5
Hands-on	4	2	2	0	6	7
Hands-on	4	2	2	0	6	4
Hands-on	4	2	1	1	5	5
Hands-on	2	0	1	1	5	4
Hands-on	4	2	1	1	6	6
Hands-on	5	2	1	2	6	6
Hands-on	5	2	2	1	7	5
Hands-on	6	2	2	2	4	3
Hands-on	6	2	2	2	3	5
Hands-on	3	1	1	1	4	6
Hands-on	4	2	2	0	5	7
Hands-on	3	1	1	1	4	5
Hands-on	4	2	1	1	2	4
Hands-on	4	2	1	1	7	7
Hands-on	5	2	2	1	4	7
Hands-on	5	2	2	1	6	6
Hands-on	0	0	0	0	6	5
Hands-on	6	2	2	2	6	6
Hands-on	4	2	2	0	4	6
Hands-on	2	0	1	1	4	5
Hands-on	5	2	2	1	5	5

Lab Type	Quiz Score	Recall	Calculation	Transfer	Survey Response on Effectiveness	Survey Response on Engagement
Simulation	3	1	1	1	4	3
Simulation	5	1	2	2	5	6
Simulation	6	2	2	2	4	4
Simulation	5	2	2	1	6	5
Simulation	4	2	2	0	5	5
Simulation	2	0	1	1	5	3
Simulation	2	1	0	1	4	5
Simulation	4	1	2	1	4	6
Simulation	5	2	1	2	3	3
Simulation	3	2	1	0	1	1
Simulation	2	1	1	0	4	4
Simulation	4	2	1	1	5	5
Simulation	5	2	2	1	4	4
Simulation	5	1	2	2	4	
Simulation	6	2	2	2	1	1
Simulation	3	2	1	0	5	6
Simulation	6	2	2	2	5	4
Simulation	4	1	1	2	6	5
Simulation	4	2	2	0	2	2
Simulation	4	1	1	2	5	3
Simulation	4	2	1	1	1	1
Simulation	5	2	2	1	4	2
Simulation	5	2	2	1	6	5
Simulation	5	2	2	1	5	6
Simulation	3	1	1	1	4	2
Simulation	4	2	1	1	3	3
Simulation	2	0	1	1	6	7
Simulation	4	2	1	1	4	5
Simulation	6	2	2	2	5	6
Simulation	4	2	1	1	3	4
Simulation	4	1	1	2	4	5
Simulation	3	1	1	1	5	6

Energy Lab Data

Lab Type	Quiz Score	Recall	Calculation	Transfer	Survey Response on Effectiveness	Survey Response on Engagement
Hands-on	3	1	2	0	6	7
Hands-on	4	2	0	2	5	4
Hands-on	2	1	1	0	5	5
Hands-on	6	2	2	2	5	5
Hands-on	4	1	2	1	5	3
Hands-on	1	1	2	2	5	5
Hands-on	3	2	0	1	5	4
Hands-on	1	0	1	0	6	3
Hands-on	3	2	1	0	4	6
Hands-on	5	1	2	2	4	5
Hands-on	5	1	2	2	5	5
Hands-on	6	2	2	2	6	5
Hands-on	3	1	1	1	6	7
Hands-on	4	2	2	0	6	4
Hands-on	4	2	2	0	5	5
Hands-on	2	2	0	0	5	4
Hands-on	3	2	1	0	6	6
Hands-on	4	1	1	2	6	6
Hands-on	4	1	2	1	7	5
Hands-on	6	2	2	2	4	3
Hands-on	2	2	0	0	3	5
Hands-on	5	1	2	2	4	6
Hands-on	4	2	1	1	5	7
Hands-on	2	1	1	0	4	5
Hands-on	5	2	2	1	2	4
Hands-on	5	2	1	2	7	7
Hands-on	5	2	2	1	4	7
Hands-on	5	2	2	1	6	6
Hands-on	6	2	2	2	6	5
Hands-on	4	2	1	1	6	6

Lab Type	Quiz Score	Recall	Calculation	Transfer	Survey Response on Effectiveness	Survey Response on Engagement
Simulation	6	2	2	2	6	5
Simulation	3	2	1	0	7	7
Simulation	5	2	2	1	5	4
Simulation	5	2	2	1	1	2
Simulation	5	2	2	1	6	3
Simulation	4	2	2	0	5	5
Simulation	4	2	2	0	6	5
Simulation	4	2	2	0	6	5
Simulation	2	2	0	0	4	4
Simulation	2	1	1	0	4	5
Simulation	6	2	2	2	5	5
Simulation	6	2	2	2	5	6
Simulation	3	2	1	0	5	6
Simulation	4	2	2	0	4	4
Simulation	1	0	1	0	3	2
Simulation	3	2	1	0	5	4
Simulation	3	2	1	0	5	4
Simulation	4	2	2	0	6	5
Simulation	5	2	2	1	4	4
Simulation	4	2	2	0	5	6
Simulation	4	2	2	0	6	6
Simulation	4	2	2	0	6	4
Simulation	6	2	2	2	5	6
Simulation	4	2	2	0	6	7
Simulation	6	2	2	2	4	5
Simulation	4	2	2	0	5	6
Simulation	6	2	2	2	3	4
Simulation	4	1	2	1	3	5

Lab Type	Quiz Score	Recall	Calculation	Transfer	Survey Response on Effectiveness	Survey Response on Engagement
Hands-on	2	1	1	0	6	7
Hands-on	6	2	2	2	6	4
Hands-on	4	2	2	0	6	6
Hands-on	2	1	1	0	6	6
Hands-on	4	1	2	1	5	6
Hands-on	5	1	2	2	4	4
Hands-on	0	2	0	0	6	6
Hands-on	4	1	1	0	3	4
Hands-on	5	2	2	1	5	5
Hands-on	5	2	2	1	5	6
Hands-on	5	2	2	1	3	6
Hands-on	2	1	1	0	6	3
Hands-on	4	2	2	0	2	2
Hands-on	4	2	2	0	3	5
Hands-on	4	1	2	1	6	6
Hands-on	2	1	0	1	7	7
Hands-on	2	2	0	0	6	7
Hands-on	3	0	2	1	5	5
Hands-on	6	2	2	2	5	5
Hands-on	5	2	2	1	7	7
Hands-on	6	2	2	2	6	4
Hands-on	4	2	1	1	6	3
Hands-on	5	2	2	1	6	4.5
Hands-on	3	1	2	0	5	5
Hands-on	3	2	1	0	7	6
Hands-on	3	2	1	0	6	6
Hands-on	4	1	2	1	6	4
Hands-on	5	1	2	2	6	5
Hands-on	4	1	2	1	7	7

Lab Type	Quiz Score	Recall	Calculation	Transfer	Survey Response on Effectiveness	Survey Response on Engagement
Simulation	4	2	2	0	6	5
Simulation	4	2	2	0	7	7
Simulation	6	2	2	2	5	4
Simulation	3	1	2	0	1	2
Simulation	5	2	2	1	6	3
Simulation	3	1	2	0	5	5
Simulation	2	1	1	0	6	5
Simulation	2	1	1	0	6	5
Simulation	2	1	1	0	4	4
Simulation	4	1	2	1	4	5
Simulation	2	2	0	0	5	5
Simulation	4	2	2	0	5	6
Simulation	6	2	2	2	5	6
Simulation	5	1	2	2	4	4
Simulation	1	1	0	0	3	2
Simulation	5	2	2	1	5	4
Simulation	5	2	2	1	5	4
Simulation	4	2	2	0	6	5
Simulation	2	0	2	0	4	4
Simulation	3	2	1	0	5	6
Simulation	3	2	1	0	6	6
Simulation	4	2	2	0	6	4
Simulation	4	2	2	0	5	6
Simulation	5	2	2	1	6	7
Simulation	1	0	1	0	4	5

Circuits Lab Data

Lab Type	Quiz Score	Recall	Calculation	Transfer	Survey Response on Effectiveness	Survey Response on Engagement
Hands-on	2	1	0	1	3	5
Hands-on	2	1	1	0	6	6
Hands-on	3	2	1	0	5	6
Hands-on	5	2	2	1	5	7
Hands-on	1	0	0	1	3	3
Hands-on	1	0	0	1	6	6
Hands-on	2	2	0	0	5	6
Hands-on	2	0	2	0	3	4
Hands-on	4	1	2	1	4	3
Hands-on	3	2	0	1	4	4
Hands-on	2	1	1	0	3	4
Hands-on	4	2	2	0	2	4
Hands-on	4	1	2	1	4	5
Hands-on	5	1	2	2	4	6
Hands-on	3	1	1	1	3	4
Hands-on	3	1	1	1	2	5
Hands-on	2	0	1	1	3	4
Hands-on	6	2	2	2	6	4
Hands-on	2	1	1	0	3	4
Hands-on	3	2	1	1	3	3
Hands-on	1	1	0	0	6	5
Hands-on	3	1	1	1	5	6
Hands-on	1	0	1	0	5	6
Hands-on	3	2	1	0	5	5
Hands-on	3	2	1	0	5	6
Hands-on	2	1	1	0	5	4
Hands-on	3	2	1	0	7	5
Hands-on	3	2	1	0	5	7

Lab Type	Quiz Score	Recall	Calculation	Transfer	Survey Response on Effectiveness	Survey Response on Engagement
Simulation	3	2	1	0	5	4
Simulation	5	1	2	2	5	6
Simulation	4	2	1	1	5	6
Simulation	3	2	1	0	5	7
Simulation	2	1	1	0	7	7
Simulation	3	1	1	1	5	6
Simulation	4	2	2	0	2	3
Simulation	3	1	1	1	2	3
Simulation	2	1	1	0	4	5
Simulation	3	2	1	0	5	4
Simulation	2	1	1	0	5	6
Simulation	1	0	0	1	5	3
Simulation	4	2	1	1	6	6
Simulation	3	1	1	1	5	6
Simulation	4	2	1	1	7	7
Simulation	5	2	2	1	5	4
Simulation	3	2	1	0	5	4
Simulation	4	2	1	1	3	3
Simulation	4	2	1	1	4	1
Simulation	6	2	2	2	6	4
Simulation	3	2	1	0	6	6
Simulation	6	2	2	2	5	6
Simulation	5	1	2	2	5	5
Simulation	3	1	1	1	5	5
Simulation	2	1	1	0	6	7
Simulation	3	2	1	0	5	5
Simulation	4	2	1	1	5	6

Lab Type	Quiz Score	Recall	Calculation	Transfer	Survey Response on Effectiveness	Survey Response on Engagement
Hands-on	2	1	1	0	6	3
Hands-on	3	2	1	0	6	5
Hands-on	3	2	1	0	5	4
Hands-on	3	1	2	0	6	5
Hands-on	2	1	1	0	5	5
Hands-on	4	2	1	1	3	5
Hands-on	4	2	1	1	4	6
Hands-on	2	1	1	0	5	7
Hands-on	4	2	1	1	2	5
Hands-on	4	0	1	1	4	4
Hands-on	4	2	1	1	5	4
Hands-on	5	2	1	2	6	7
Hands-on	5	2	2	1	5	5
Hands-on	4	2	1	1	6	7
Hands-on	4	2	1	1	5	5
Hands-on	2	1	1	0	5	7
Hands-on	4	2	1	1	5	5
Hands-on	3	2	1	0	5	5
Hands-on	3	2	1	0	6	7
Hands-on	1	1	0	0	6	7
Hands-on	2	1	1	0	4	5
Hands-on	1	1	0	0	6	6
Hands-on	3	2	1	0	5	3
Hands-on	3	2	1	0	3	6
Hands-on	5	2	2	1	5	6
Hands-on	4	2	1	1	5	6
Hands-on	2	1	1	0	4	3
Hands-on	4	2	2	0	7	7
Hands-on	5	2	2	1	7	7
Hands-on	3	2	0	1	5	6
Hands-on	3	1	1	1	4	6
Hands-on	5	2	2	1	5	5
Hands-on	3	1	2	0	6	5
Hands-on	3	2	1	0	6	6

Lab Type	Quiz Score	Recall	Calculation	Transfer	Survey Response on Effectiveness	Survey Response on Engagement
Simulation	4	2	1	1	4	3
Simulation	4	1	2	1	5	6
Simulation	2	1	0	1	4	4
Simulation	3	2	1	0	6	5
Simulation	4	2	2	0	5	5
Simulation	4	2	1	1	5	3
Simulation	4	2	1	1	4	5
Simulation	3	0	2	1	4	6
Simulation	3	1	2	0	3	3
Simulation	4	1	1	1	1	1
Simulation	2	1	1	0	4	4
Simulation	2	1	1	0	5	5
Simulation	2	1	1	0	4	4
Simulation	3	1	1	1	4	
Simulation	1	0	1	0	1	1
Simulation	3	1	1	1	5	6
Simulation	3	2	1	0	5	4
Simulation	3	2	1	0	6	5
Simulation	2	1	1	0	2	2
Simulation	3	2	1	0	5	3
Simulation	1	0	0	1	1	1
Simulation	4	1	1	2	4	2
Simulation	4	1	2	1	6	5
Simulation	4	2	2	0	5	6
Simulation	3	1	1	1	4	2
Simulation	3	2	1	0	3	3

Angular Momentum Lab Data

Lab Type	Quiz Score	Recall	Calculation	Transfer	Survey Response on Effectiveness	Survey Response on Engagement
Simulation	5	1	2	2	2	4
Simulation	4	1	1	2	3	4
Simulation	2	0	1	1	2	2
Simulation	4	1	1	2	4	6
Simulation	3	0	1	2	4	3
Simulation	6	2	2	2		
Simulation	2	1	1	0	3	2
Simulation	3	1	1	1	2	2
Simulation	5	1	2	2	6	6
Simulation	5	1	2	2	6	5
Simulation	5	1	2	2	5	4
Simulation	1	0	0	1	4	3
Simulation	0	0	0	0	6	4
Simulation	2	1	0	1	3	5
Simulation	2	0	1	1	2	3
Simulation	2	0	1	1	4	2
Simulation	3	0	1	2	4	4
Simulation	2	0	1	1	6	5
Simulation	4	2	1	1	5	6
Simulation	4	2	1	1	4	5
Simulation	4	2	1	1	3	5
Simulation	6	2	2	2	6	5
Simulation	4	1	1	1	4	2
Simulation	4	2	1	1	6	6
Simulation	4	1	1	2	5	6
Simulation	3	1	1	1	5	4
Simulation	4	1	1	2	4	4
Simulation	2	0	1	1	5	6
Simulation	2	0	0	2	3	3
Simulation	5	1	2	2	5	6
Simulation	4	1	0.5	2	4	6
Simulation	5	1	2	2	5	5
Simulation	3	1	1	1	5	4

Lab Type	Quiz Score	Recall	Calculation	Transfer	Survey Response on Effectiveness	Survey Response on Engagement
Hands-on	2	0	1	1	5	4
Hands-on	3	1	1	1	4	5
Hands-on	3	1	1	1	3	1
Hands-on	5	2	1	2	3	4
Hands-on	2	0	0	2	5	3
Hands-on	3	0	2	1	5	3
Hands-on	5	1	2	2	5	5
Hands-on	4	1	2	1	5	6
Hands-on	2	0	1	1	4	4
Hands-on	5	2	1	2	2	3
Hands-on	4	1	1	2	4	4
Hands-on	3	0	1	2	3	4
Hands-on	3	1	1	1	3	5
Hands-on	3	0	1	2	4	5
Hands-on	3	1	1	1	1	1
Hands-on	3	1	1	1	4	5
Hands-on	4	1	2	1	4	3
Hands-on	5	1	2	2	6	4
Hands-on	4	2	1	1	3	3
Hands-on	5	2	2	1	3	3
Hands-on	2	0	1	1	4	2
Hands-on	4	0	1	1	4	4
Hands-on	3	0	1	2	3	4
Hands-on	3	0	1	2	3	5
Hands-on	3	1	1	1	4	5
Hands-on	3	1	1	1	3	4
Hands-on	4	1	1	2	4	5
Hands-on	5	2	1	2	4	3

Lab Type	Quiz Score	Recall	Calculation	Transfer	Survey Response on Effectiveness	Survey Response on Engagement
Simulation	4	1	1	2	3	4
Simulation	4	1	1	2	5	5
Simulation	3	0	1	2	6	6
Simulation	3	1	1	1	5	5
Simulation	3	0	1	2	5	7
Simulation	3	0	1	1	4	5
Simulation	2	0	1	1	4	5
Simulation	5	1	2	2	4	5
Simulation	3	0	2	1	3	3
Simulation	5	2	1	2	3	4
Simulation	5	2	1	2	5	6
Simulation	2	1	0	1	3	1
Simulation	4	1	1	2	3	2
Simulation	4	2	0	2	5	5
Simulation	5	2	1	2	6	5
Simulation	4	1	1	0	6	-
Simulation	4	1	1	2	3	3
Simulation	5	1	2	2	4	6
Simulation	3	0	1	2	2	2
Simulation	4	1	1	2	5	3
Simulation	3	1	1	1	4	5
Simulation	4	0	2	2	4	4
Simulation	4	0	2	1	5	5
Simulation	4	0	2	1	7	7
Simulation	4	1	2	1	5	5
Simulation	5	2	2	1	5	4
Simulation	5	1	2	2	5	3
Simulation	4	1	1	2	1	1
Simulation	3	1	1	1	4	4
Simulation	2	0	1	1	3	1
Simulation	6	2	2	2	5	6
Simulation	0	0	0	0	3	4
Simulation	4	1	1	2	5	5
Simulation	4	1	1	2	5	4
Simulation	1	0	1	0	5	4

Lab Type	Quiz Score	Recall	Calculation	Transfer	Survey Response on Effectiveness	Survey Response on Engagement
Hands-on	4	1	1	2	2	6
Hands-on	2	0	0	2	3	5
Hands-on	3	1	1	1	4	5
Hands-on	4	1	2	1	4	4
Hands-on	4	1	1	2	6	6
Hands-on	3	1	1	1	2	2
Hands-on	3	1	0	2	2	2
Hands-on	3	1	0	2	5	6
Hands-on	1	0	0	1	5	4
Hands-on	2	0	1	1	6	5
Hands-on	3	1	2	0	4	4
Hands-on	3	0	1	2	2	3
Hands-on	4	2	1	1	3	5
Hands-on	3	0	1	2	2	5
Hands-on	3	1	1	1	2	4
Hands-on	3	1	1	1	5	5
Hands-on	5	1	2	2	2	7
Hands-on	4	1	1	2	1	4
Hands-on	4	1	1	2	1	4
Hands-on	4	1	1	2	3	5
Hands-on	2	0	0	2	4	2
Hands-on	2	0	0	2	4	4
Hands-on	4	2	1	1	6	3
Hands-on	4	1	1	2	4	3
Hands-on	3	0	1	2	4	3
Hands-on	3	1	1	1	3	5
Hands-on	2	0	1	1	1	2
Hands-on	4	1	2	1	4	6
Hands-on	3	1	1	1	3	5
Hands-on	4	1	1	2	4	4

Pendulum Lab Data

Lab Type	Quiz Score	Recall	Calculation	Transfer	Survey Response on Effectiveness	Survey Response on Engagement
Simulation	3	2	0	1	4	3
Simulation	5	2	2	1	5	5
Simulation	5	2	2	1	7	7
Simulation	5	2	2	1	6	6
Simulation	3	1	1	1	6	5
Simulation	3	2	1	0	5	5
Simulation	2	0	1	1	6	6
Simulation	3	2	0	1	4	3
Simulation	4	1	2	1	5	7
Simulation	4	2	1	1	3	2
Simulation	3	1	1	1	6	6
Simulation	4	2	1	1	5	5
Simulation	2	2	0	0	6	6
Simulation	3	2	1	0	5	5
Simulation	4	2	2	0	5	4
Simulation	4	2	2	0	6	5
Simulation	5	2	2	1	7	2
Simulation	3	2	1	0	6	3
Simulation	5	2	2	1	6	5
Simulation	5	2	1	2	7	7
Simulation	5	2	1	2	6	7
Simulation	4	2	1	1	7	3
Simulation	2	1	1	0	6	5
Simulation	4	2	1	1	4	5
Simulation	2	0	1	1	7	5
Simulation	3	1	1	1	6	5
Simulation	5	2	2	1	7	6
Simulation	4	2	1	1	6	6

Lab Type	Quiz Score	Recall	Calculation	Transfer	Survey Response on Effectiveness	Survey Response on Engagement
Hands-on	2	1	1	0	6	4
Hands-on	1	1	0	0	5	4
Hands-on	2	1	1	0	6	5
Hands-on	4	2	1	1	5	6
Hands-on	4	2	2	0	6	5
Hands-on	3	1	0	2	5	6
Hands-on	4	2	2	0	5	6
Hands-on	5	2	2	1	6	7
Hands-on	6	2	2	2	7	2
Hands-on	5	1	2	2	7	2
Hands-on	1	0	0	1	6	6
Hands-on	4	1	2	1	7	7
Hands-on	5	2	2	1	7	7
Hands-on	5	2	2	1	6	6
Hands-on	4	1	2	1	7	6
Hands-on	4	1	2	1	5	6
Hands-on	1	1	0	0	5	5
Hands-on	1	1	0	0	7	5
Hands-on	3	1	0	2	7	4
Hands-on	3	1	0	2	6	4
Hands-on	5	2	1	2	5	4
Hands-on	2	1	1	0	7	7
Hands-on	2	1	1	0	7	5
Hands-on	6	2	2	2	5	6
Hands-on	4	2	1	1	4	4
Hands-on	1	1	0	0	4	6
Hands-on	5	1	2	2	6	4
Hands-on	3	2	1	0	6	6
Hands-on	2	2	0	0	5	4

Lab Type	Quiz Score	Recall	Calculation	Transfer	Survey Response on Effectiveness	Survey Response on Engagement
Simulation	5	2	1	2	5	6
Simulation	2	2	0	0	6	4
Simulation	5	2	1	2	5	5
Simulation	2	1	0	1	5	5
Simulation	3	1	1	1	6	6
Simulation	5	1	2	2	6	4
Simulation	2	1	1	0	6	5
Simulation	4	2	2	0	6	5
Simulation	4	1	2	1	5	6
Simulation	6	2	2	2	6	7
Simulation	5	2	1	2	5	6
Simulation	6	2	2	2	6	7
Simulation	5	2	1	2	4	3
Simulation	5	2	2	1	6	5
Simulation	3	1	1	1	5	4
Simulation	3	1	1	1	3	4
Simulation	1	1	0	0	5	3
Simulation	4	2	1	1	5	7
Simulation	5	2	1	2	6	5
Simulation	2	1	0	1	6	5
Simulation	6	2	2	2	7	6
Simulation	3	2	0	1	6	5
Simulation	4	1	2	1	6	4
Simulation	1	1	0	0	6	5
Simulation	1	1	0	0	5	4
Simulation	4	1	1	2	6	4
Simulation	3	1	1	1	6	6
Simulation	5	2	1	2	5	5
Simulation	2	1	1	0	4	7
Simulation	4	1	2	1	6	6
Simulation	2	2	0	0	6	5
Simulation	5	2	1	2	7	5
Simulation	2	2	0	0	3	2

Lab Type	Quiz Score	Recall	Calculation	Transfer	Survey Response on Effectiveness	Survey Response on Engagement
Hands-on	3	2	1	0	7	7
Hands-on	3	1	2	0	7	7
Hands-on	3	1	1	1	7	7
Hands-on	3	1	2	0	5	7
Hands-on	5	2	1	2	7	6
Hands-on	4	2	2	0	5	7
Hands-on	3	1	1	1	5	7
Hands-on	3	2	1	0	7	5
Hands-on	3	1	1	1	6	7
Hands-on	4	2	1	1	6	6
Hands-on	4	1	2	1	5	6
Hands-on	3	2	1	0	6	7
Hands-on	0	0	0	0	7	7
Hands-on	4	2	2	0	5	4
Hands-on	3	2	1	0	6	6
Hands-on	3	1	1	1	6	5
Hands-on	2	1	1	0	6	6
Hands-on	2	2	0	0	6	6
Hands-on	2	1	0	1	6	6
Hands-on	2	0	1	1	5	5
Hands-on	3	1	1	1	5	6
Hands-on	3	1	1	1	6	5
Hands-on	1	1	0	0	3	
Hands-on	4	2	1	1	5	7
Hands-on	5	1	2	2	6	5
Hands-on	5	1	2	2	6	5
Hands-on	4	1	1	2	6	4

Friction Lab Data

Lab Type	Quiz Score	Recall	Calculation	Transfer	Survey Response on Effectiveness	Survey Response on Engagement
Hands-on	3	1	1	1	5	4
Hands-on	5	2	1	2	3	3
Hands-on	5	2	1	2	6	5
Hands-on	3	1	1	1	3	2
Hands-on	2	0	0	2	5	6
Hands-on	2	0	1	1	5	3
Hands-on	4	2	1	1	4	5
Hands-on	4	2	1	1	5	4
Hands-on	4	2	1	1	4	3
Hands-on	3	1	1	1	5	6
Hands-on	2	2	0	0	5	6
Hands-on	1	1	0	0	4	4
Hands-on	1	1	0	0	5	5
Hands-on	4	2	2	0	5	6
Hands-on	3	1	1	1	6	6
Hands-on	2	1	0	1	5	6
Hands-on	3	1	0	2	4	3
Hands-on	1	1	0	0	6	4
Hands-on	4	2	1	1	5	5
Hands-on	3	1	1	1	6	6
Hands-on	2	1	0	1	4	2
Hands-on	4	2	0	2	5	6
Hands-on	3	2	0	1	6	4
Hands-on	3	2	0	1	3	3
Hands-on	4	2	0	2	5	6
Hands-on	3	2	1	0	5	5
Hands-on	4	2	1	1	6	5
Hands-on	4	2	1	1	6	5
Hands-on	5	2	2	1	7	5
Hands-on	3	2	0	1	4	6
Hands-on	3	2	0	1	5	5
Hands-on	3	2	1	0	6	5
Hands-on	2	1	0	1	5	6

Lab Type	Quiz Score	Recall	Calculation	Transfer	Survey Response on Effectiveness	Survey Response on Engagement
Hands-on	2	1	0	1	6	5
Hands-on	3	2	0	1	5	5
Hands-on	2	2	0	0	6	6
Hands-on	1	1	0	0	5	6
Hands-on	2	2	0	0	6	6
Hands-on	4	2	1	1	5	7
Hands-on	3	2	0	1	5	6
Hands-on	2	1	0	1	5	6
Hands-on	1	0	1	0	5	5
Hands-on	3	2	1	0	5	6
Hands-on	2	1	1	0	5	5
Hands-on	3	2	0	1	6	3
Hands-on	1	1	0	0	4	5
Hands-on	3	2	0	1	5	5
Hands-on	2	2	0	0	6	6
Hands-on	2	1	0	1	6	6
Hands-on	3	2	0	1	5	6
Hands-on	1	1	0	0	5	6
Hands-on	2	2	0	0	5	5
Hands-on	4	2	0	2	4	6
Hands-on	5	2	2	1	6	5
Hands-on	2	1	0	1	5	5
Hands-on	1	1	0	0	5	6
Hands-on	2	1	0	1	4	4
Hands-on	3	1	0	2	3	4
Hands-on	2	1	0	1	6	4
Hands-on	4	2	0	2	7	6
Hands-on	4	1	1	2	6	6
Hands-on	3	2	0	1	5	4
Hands-on	4	2	0	2	3	6
Hands-on	4	2	0	2	6	7
Hands-on	4	2	0	2	6	5
Hands-on	1	0	0	1	3	4
Hands-on	3	2	0	1	4	5
Hands-on	5	2	1	2	6	5

Lab Type	Quiz Score	Recall	Calculation	Transfer	Survey Response on Effectiveness	Survey Response on Engagement
Simulation	5	2	1	2	5	3
Simulation	5	2	1	2	6	5
Simulation	3	1	0	2	6	7
Simulation	4	1	1	2	2	2
Simulation	3	1	1	1	6	5
Simulation	2	0	0	2	1	2
Simulation	3	1	0	2	1	0
Simulation	4	2	1	1	6	5
Simulation	4	2	1	1	4	3
Simulation	4	2	1	1	5	4
Simulation	5	2	2	1	6	4
Simulation	4	2	2	0	5	7
Simulation	4	2	1	1	6	6
Simulation	2	1	0	1	5	6
Simulation	2	1	0	1	4	5
Simulation	3	2	0	1	5	3
Simulation	4	1	0	1	4	3
Simulation	3	2	1	0	5	4
Simulation	2	2	0	0	5	5
Simulation	2	0	1	1	3	3
Simulation	2	0	0	2	4	3
Simulation	4	1	2	1	3	3
Simulation	2	0	1	1	4	3
Simulation	5	2	2	1	6	4
Simulation	3	0	1	2	5	4
Simulation	3	0	1	2	5	6
Simulation	3	0	1	2	5	4
Simulation	4	1	1	2	5	5
Simulation	3	0	2	1	3	3
Simulation	3	1	1	1	3	4
Simulation	3	2	1	0	4	6
Simulation	3	1	1	1	6	6

Lab Type	Quiz Score	Recall	Calculation	Transfer	Survey Response on Effectiveness	Survey Response on Engagement
Simulation	6	2	2	2	5	7
Simulation	1	0	0	1	7	7
Simulation	4	1	1	2	3	4
Simulation	2	1	1	0	4	4
Simulation	5	2	1	2	3	4
Simulation	2	0	0	2	5	4
Simulation	0	0	0	0	3	3
Simulation	2	1	1	0	6	6
Simulation	1	1	0	0	4	5
Simulation	1	0	0	1	3	1
Simulation	2	1	0	1	3	4
Simulation	1	1	0	0	2.5	2
Simulation	3	1	1	1	5	6
Simulation	2	2	0	0	3	4
Simulation	0	0	0	0	4	3
Simulation	2	0	1	1	3	2
Simulation	4	1	1	2	3	3
Simulation	5	2	2	1	6	2
Simulation	3	2	1	0	3	4
Simulation	3	1	1	1	5	3
Simulation	1	0	1	0	3	3
Simulation	3	1	1	1	5	6
Simulation	3	1	1	1	4	4
Simulation	2	1	0	1	5	4
Simulation	4	1	2	1	5	4
Simulation	2	0	1	1	3	3
Simulation	1	0	0	1	4	2
Simulation	2	1	0	1	5	5
Simulation	4	2	1	1	4	2
Simulation	4	2	1	1	4	6

APPENDIX D.   STATISTICAL ANALYSIS PRODUCED USING JMP

The following pages contain the statistical analysis outputs produced by the JMP

program. These include individual outputs for each lab, the combined data, and the correlation

data.

Output for Momentum Lab Analysis

Oneway Analysis of Score By Type
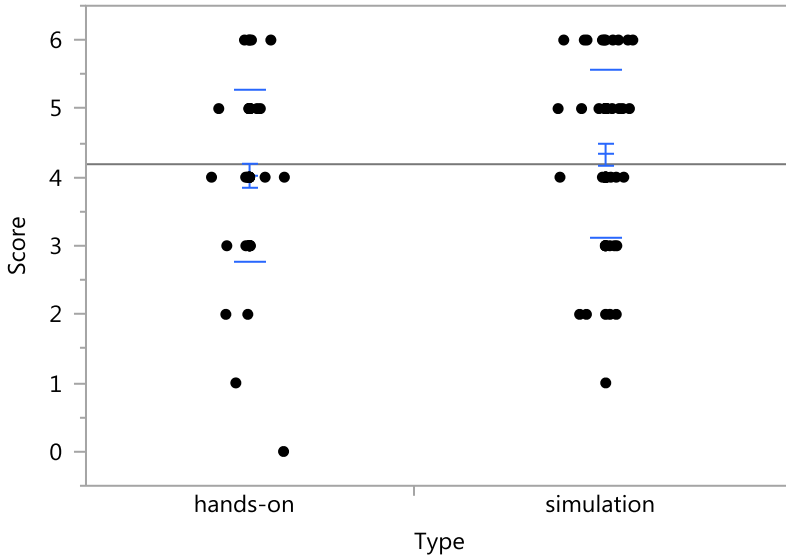
Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
hands-on	51	4.01961	1.25682	0.17599	3.6661	4.3731
simulation	60	4.33333	1.23050	0.15886	4.0155	4.6512

t Test
simulation-hands-on
Assuming unequal variances

Difference	0.31373	t Ratio	1.323276
Std Err Dif	0.23708	DF	105.3826
Upper CL Dif	0.78380	Prob > |t|	0.1886
Lower CL Dif	-0.15635	Prob > t	0.0943
Confidence	0.95	Prob < t	0.9057
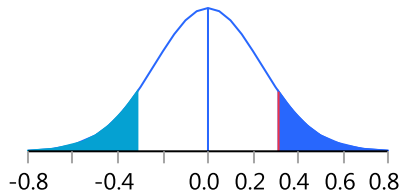
Oneway Analysis of Recall By Type
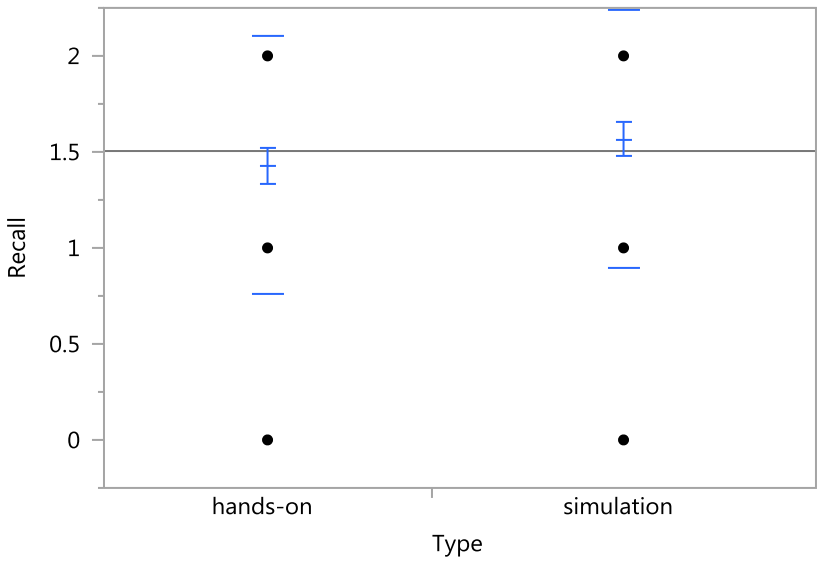
Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
hands-on	51	1.43137	0.670967	0.09395	1.2427	1.6201
simulation	60	1.56667	0.673132	0.08690	1.3928	1.7406

t Test
simulation-hands-on
Assuming unequal variances

Difference	0.13529	t Ratio	1.057141
Std Err Dif	0.12798	DF	106.2461
Upper CL Dif	0.38902	Prob > |t|	0.2928
Lower CL Dif	-0.11843	Prob > t	0.1464
Confidence	0.95	Prob < t	0.8536
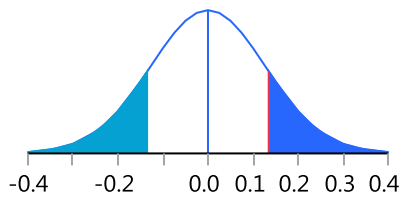
Oneway Analysis of Calculation By Type
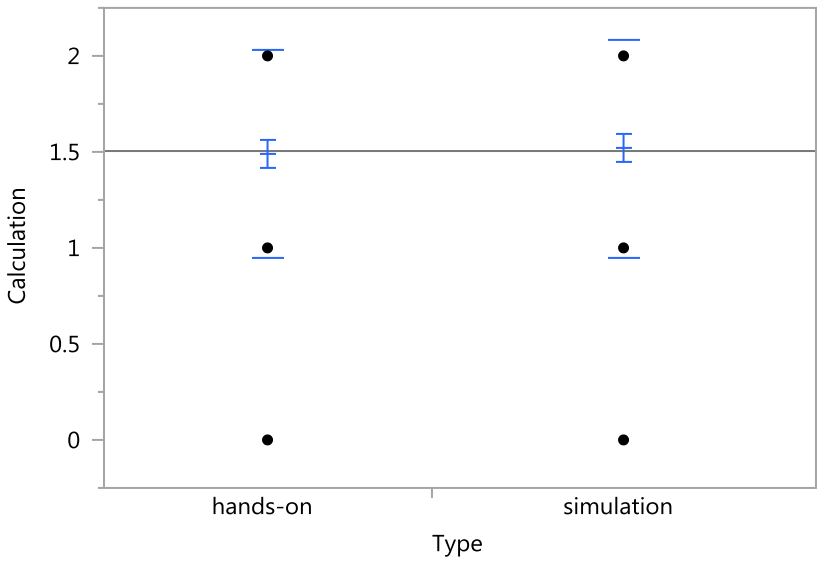
Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
hands-on	51	1.49020	0.543049	0.07604	1.3375	1.6429
simulation	60	1.51667	0.567231	0.07323	1.3701	1.6632

t Test

simulation-hands-on

Assuming unequal variances

Difference	0.02647	t Ratio	0.250741
Std Err Dif	0.10557	DF	107.436
Upper CL Dif	0.23574	Prob > |t|	0.8025
Lower CL Dif	-0.18280	Prob > t	0.4012
Confidence	0.95	Prob < t	0.5988
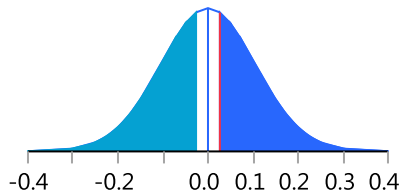
Oneway Analysis of Transfer By Type
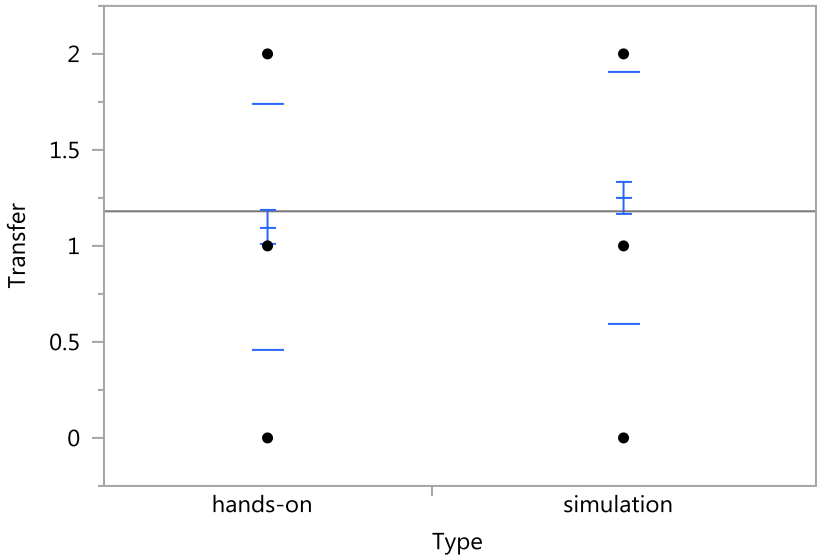
Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
hands-on	51	1.09804	0.640466	0.08968	0.9179	1.2782
simulation	60	1.25000	0.654191	0.08446	1.0810	1.4190

t Test
simulation-hands-on
Assuming unequal variances

Difference	0.15196	t Ratio	1.233546
Std Err Dif	0.12319	DF	106.8145
Upper CL Dif	0.39618	Prob > |t|	0.2201
Lower CL Dif	-0.09225	Prob > t	0.1100
Confidence	0.95	Prob < t	0.8900
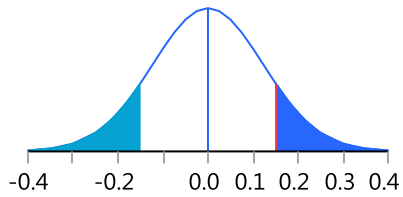
Oneway Analysis of Effective By Type
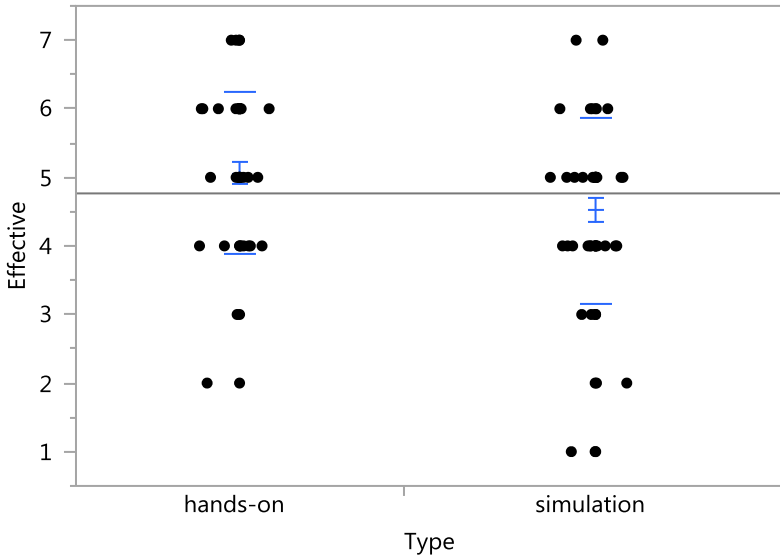
Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
hands-on	51	5.05882	1.17323	0.16429	4.7288	5.3888
simulation	60	4.51667	1.35911	0.17546	4.1656	4.8678

t Test
simulation-hands-on
Assuming unequal variances

Difference	-0.5422	t Ratio	-2.25555
Std Err Dif	0.2404	DF	108.9688
Upper CL Dif	-0.0658	Prob > |t|	0.0261*
Lower CL Dif	-1.0186	Prob > t	0.9870
Confidence	0.95	Prob < t	0.0130*
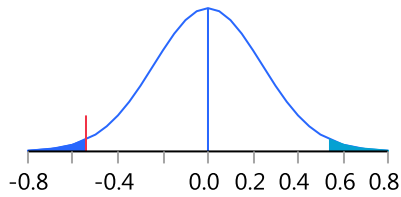
Oneway Analysis of Engagement By Type
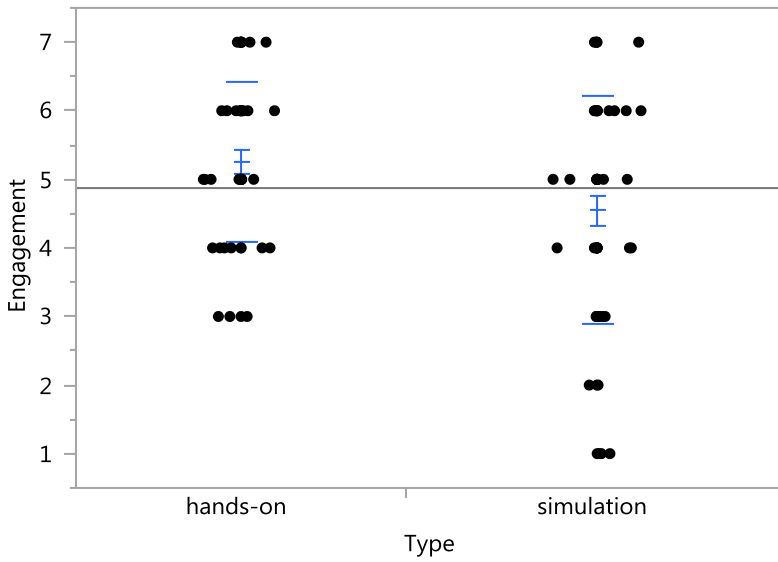
Missing Rows   1

Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
hands-on	51	5.25490	1.16350	0.16292	4.9277	5.5821
simulation	59	4.54237	1.66425	0.21667	4.1087	4.9761

t Test
simulation-hands-on
Assuming unequal variances

Difference	-0.7125	t Ratio	-2.62842
Std Err Dif	0.2711	DF	103.6812
Upper CL Dif	-0.1749	Prob > |t|	0.0099*
Lower CL Dif	-1.2501	Prob > t	0.9951
Confidence	0.95	Prob < t	0.0049*
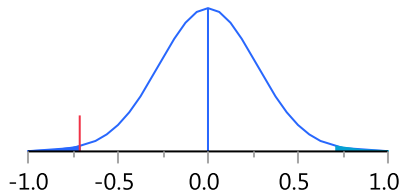
Output for Energy Lab

Oneway Analysis of raw score By lab type
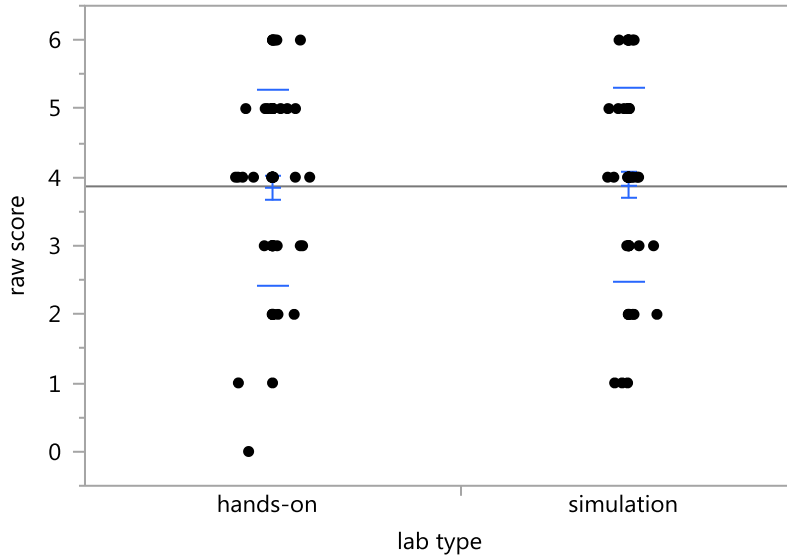
Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
hands-on	59	3.84746	1.43615	0.18697	3.4732	4.2217
simulation	53	3.88679	1.40959	0.19362	3.4983	4.2753

t Test
simulation-hands-on
Assuming unequal variances

Difference	0.03933	t Ratio	0.146139
Std Err Dif	0.26916	DF	109.1236
Upper CL Dif	0.57280	Prob > |t|	0.8841
Lower CL Dif	-0.49413	Prob > t	0.4420
Confidence	0.95	Prob < t	0.5580
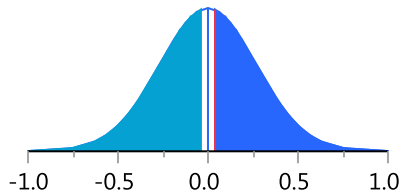
Oneway Analysis of Recall By lab type
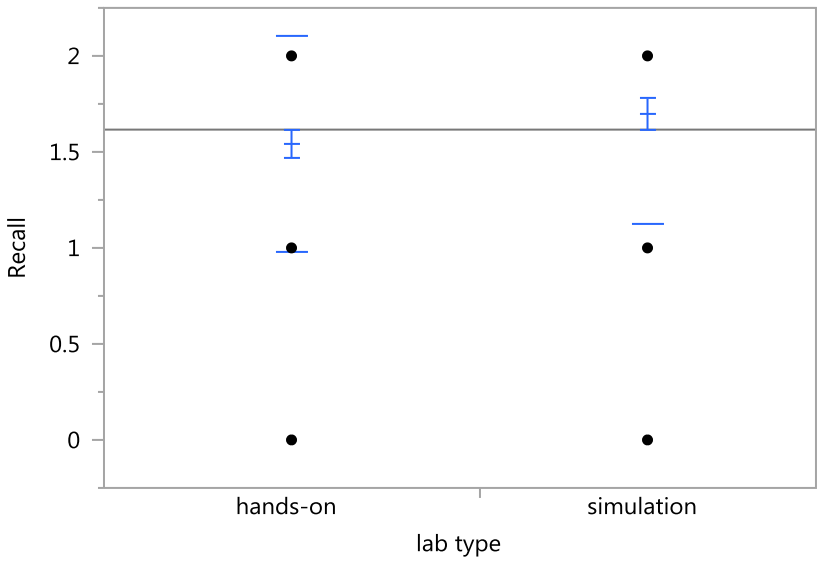
Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
hands-on	59	1.54237	0.566965	0.07381	1.3946	1.6901
simulation	53	1.69811	0.574620	0.07893	1.5397	1.8565

t Test
simulation-hands-on
Assuming unequal variances

Difference	0.15574	t Ratio	1.441159
Std Err Dif	0.10807	DF	108.3956
Upper CL Dif	0.36994	Prob > |t|	0.1524
Lower CL Dif	-0.05846	Prob > t	0.0762
Confidence	0.95	Prob < t	0.9238
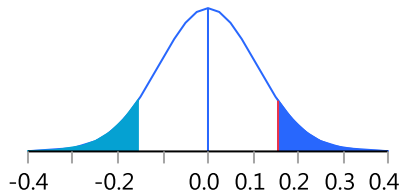
Oneway Analysis of Calculation By lab type
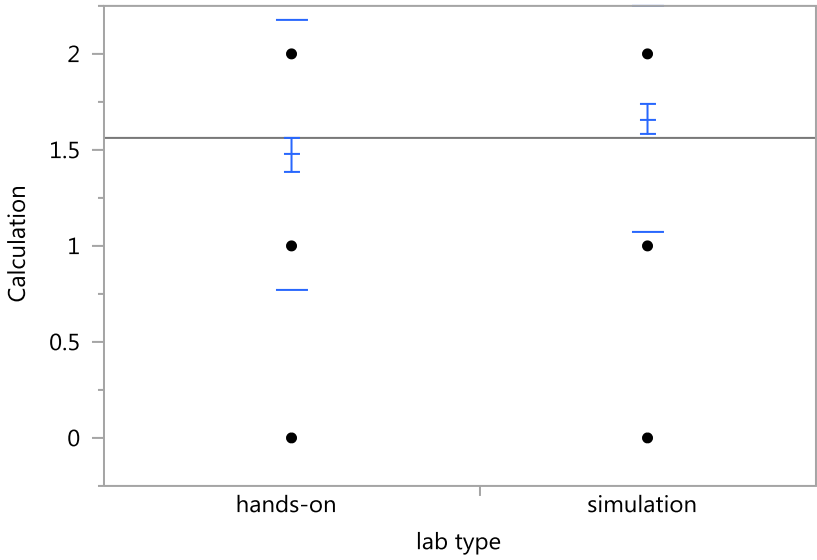
Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
hands-on	59	1.47458	0.703585	0.09160	1.2912	1.6579
simulation	53	1.66038	0.586495	0.08056	1.4987	1.8220

t Test
simulation-hands-on
Assuming unequal variances

Difference	0.18580	t Ratio	1.523139
Std Err Dif	0.12199	DF	109.4127
Upper CL Dif	0.42756	Prob > |t|	0.1306
Lower CL Dif	-0.05596	Prob > t	0.0653
Confidence	0.95	Prob < t	0.9347
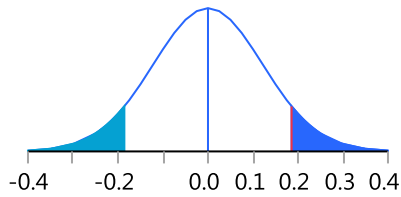
Oneway Analysis of Transfer By lab type
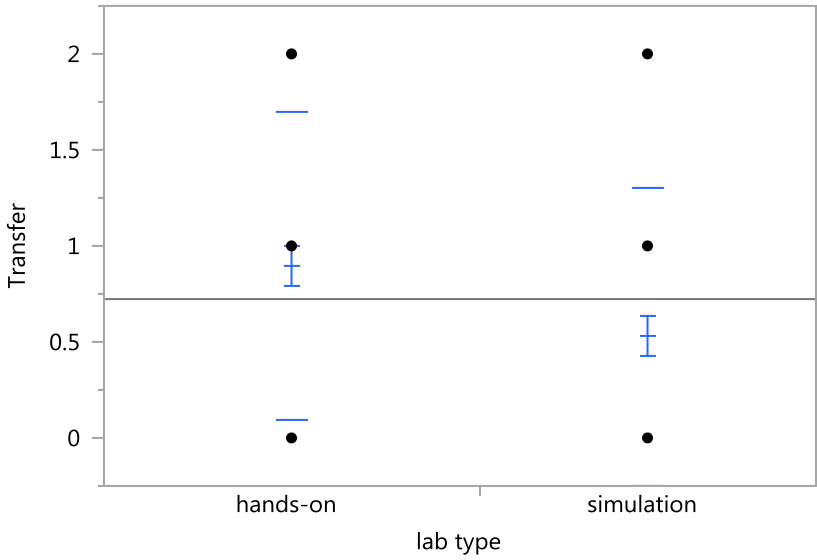
Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
hands-on	59	0.898305	0.802902	0.10453	0.68907	1.1075
simulation	53	0.528302	0.774690	0.10641	0.31477	0.7418

t Test
simulation-hands-on
Assuming unequal variances

Difference	-0.37000	t Ratio	-2.48052
Std Err Dif	0.14916	DF	109.4248
Upper CL Dif	-0.07438	Prob > |t|	0.0146*
Lower CL Dif	-0.66563	Prob > t	0.9927
Confidence	0.95	Prob < t	0.0073*
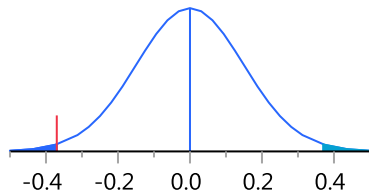
Oneway Analysis of Effective By lab type
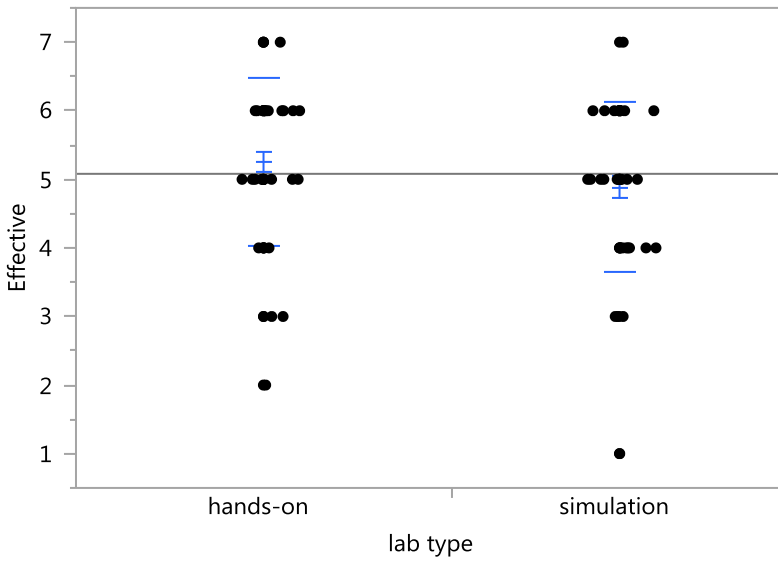
Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
hands-on	59	5.25424	1.21191	0.15778	4.9384	5.5701
simulation	53	4.88679	1.25054	0.17178	4.5421	5.2315

t Test
simulation-hands-on
Assuming unequal variances

Difference	-0.36744	t Ratio	-1.5754
Std Err Dif	0.23324	DF	107.8987
Upper CL Dif	0.09488	Prob > |t|	0.1181
Lower CL Dif	-0.82977	Prob > t	0.9410
Confidence	0.95	Prob < t	0.0590
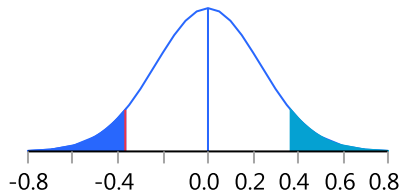
Oneway Analysis of Engagement By lab type
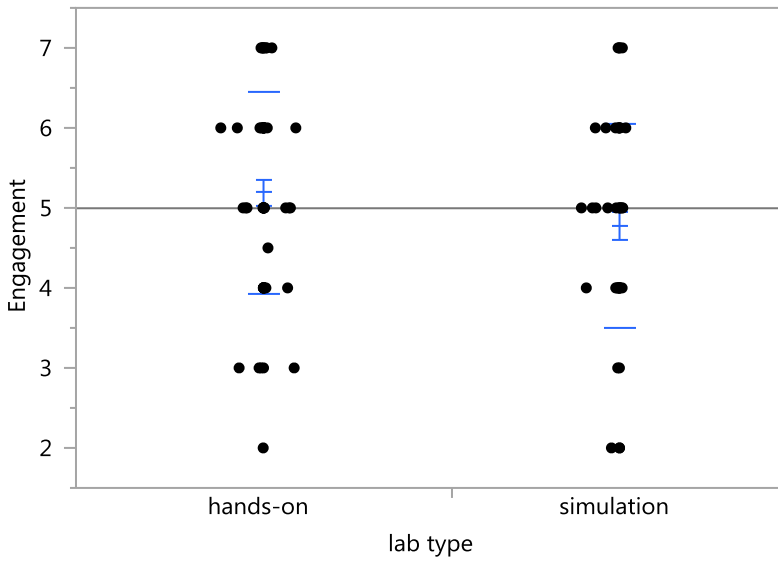
Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
hands-on	59	5.19492	1.25951	0.16397	4.8667	5.5231
simulation	53	4.77358	1.26554	0.17384	4.4248	5.1224

t Test
simulation-hands-on
Assuming unequal variances

Difference	-0.42133	t Ratio	-1.76312
Std Err Dif	0.23897	DF	108.6119
Upper CL Dif	0.05232	Prob > |t|	0.0807
Lower CL Dif	-0.89498	Prob > t	0.9597
Confidence	0.95	Prob < t	0.0403*

-0.8   -0.4   0.0 0.2 0.4 0.6 0.8

148
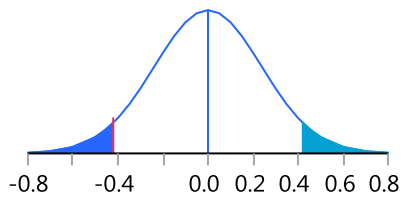
Output for Circuits Lab

Output for Quiz Score by Lab type
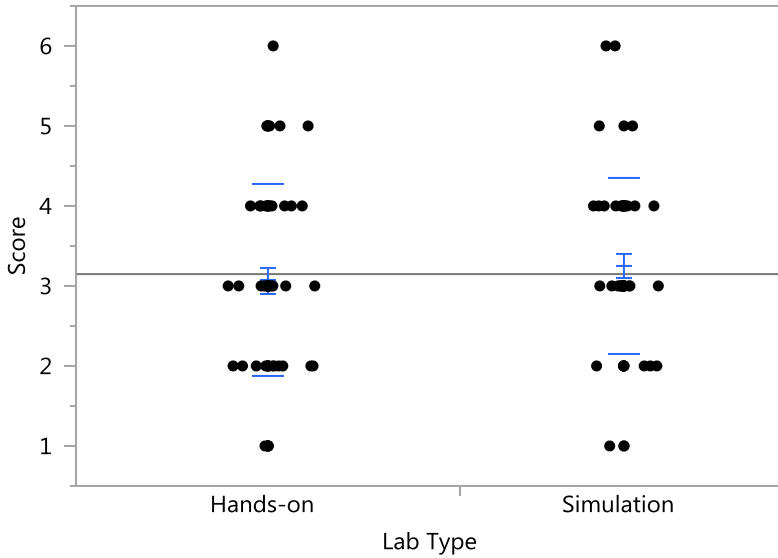
Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
Hands-on	62	3.06452	1.19933	0.15232	2.7599	3.3691
Simulation	53	3.24528	1.10776	0.15216	2.9399	3.5506

t Test
Simulation-Hands-on
Assuming unequal variances

Difference	0.18077	t Ratio	0.83961
Std Err Dif	0.21530	DF	112.3009
Upper CL Dif	0.60734	Prob > |t|	0.4029
Lower CL Dif	-0.24581	Prob > t	0.2015
Confidence	0.95	Prob < t	0.7985

Oneway Analysis of Recall By Lab Type
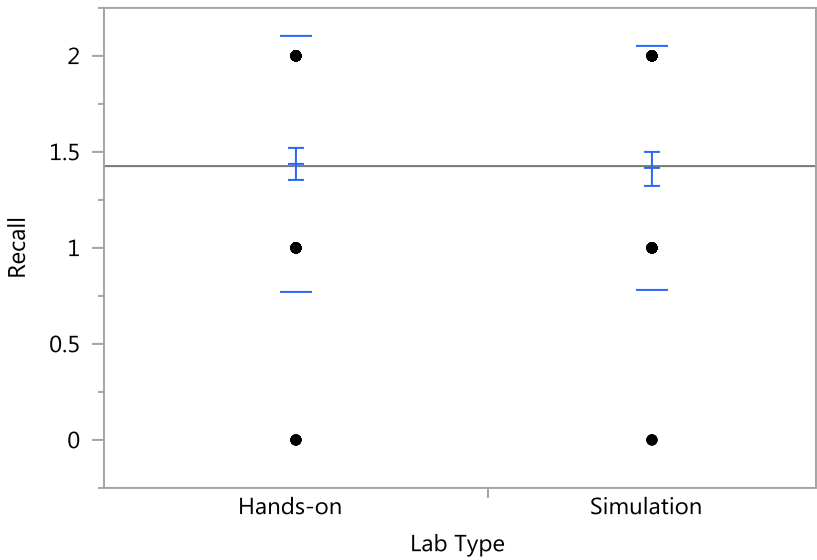
Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
Hands-on	62	1.43548	0.668273	0.08487	1.2658	1.6052
Simulation	53	1.41509	0.633487	0.08702	1.2405	1.5897

t Test
Simulation-Hands-on
Assuming unequal variances

Difference	-0.02039	t Ratio	-0.16774
Std Err Dif	0.12155	DF	111.7692
Upper CL Dif	0.22046	Prob > |t|	0.8671
Lower CL Dif	-0.26123	Prob > t	0.5665
Confidence	0.95	Prob < t	0.4335
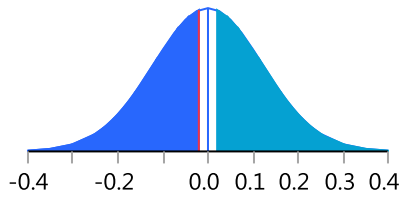
Oneway Analysis of Calculation By Lab Type
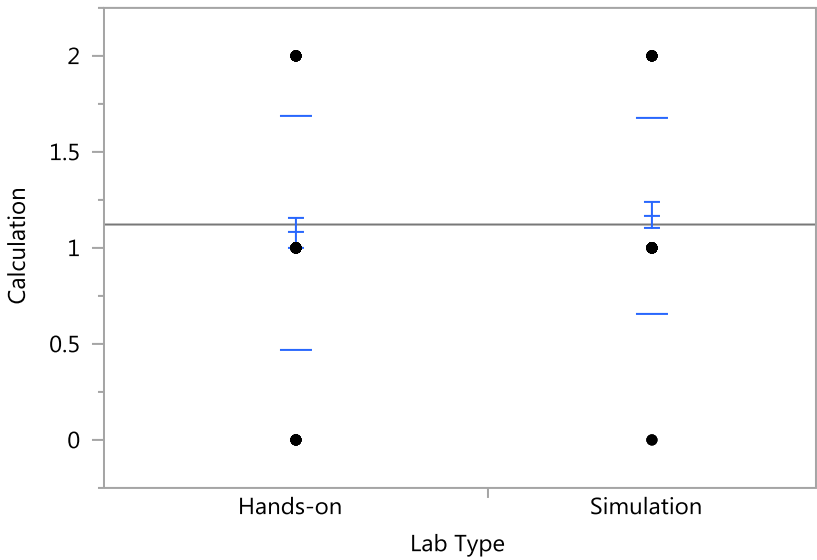
Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
Hands-on	62	1.08065	0.608637	0.07730	0.9261	1.2352
Simulation	53	1.16981	0.508990	0.06992	1.0295	1.3101

t Test
Simulation-Hands-on
Assuming unequal variances

Difference	0.08917	t Ratio	0.855512
Std Err Dif	0.10423	DF	112.9527
Upper CL Dif	0.29566	Prob > |t|	0.3941
Lower CL Dif	-0.11732	Prob > t	0.1970
Confidence	0.95	Prob < t	0.8030
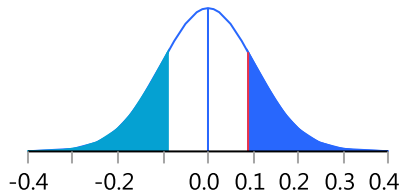
Oneway Analysis of Transfer By Lab Type
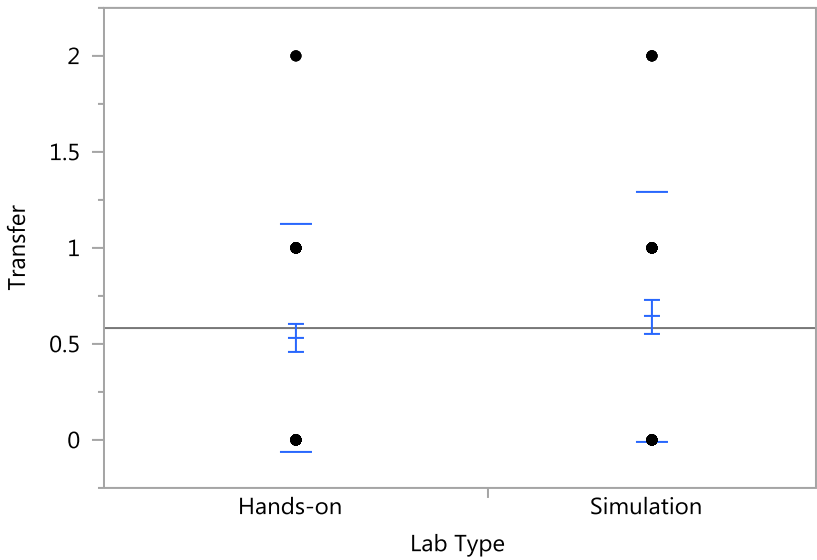
Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
Hands-on	62	0.532258	0.592791	0.07528	0.38172	0.68280
Simulation	53	0.641509	0.653227	0.08973	0.46146	0.82156

t Test
Simulation-Hands-on
Assuming unequal variances

Difference	0.10925	t Ratio	0.932757
Std Err Dif	0.11713	DF	106.1426
Upper CL Dif	0.34146	Prob > |t|	0.3531
Lower CL Dif	-0.12296	Prob > t	0.1765
Confidence	0.95	Prob < t	0.8235
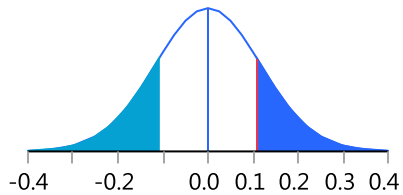
Oneway Analysis of Effective By Lab Type
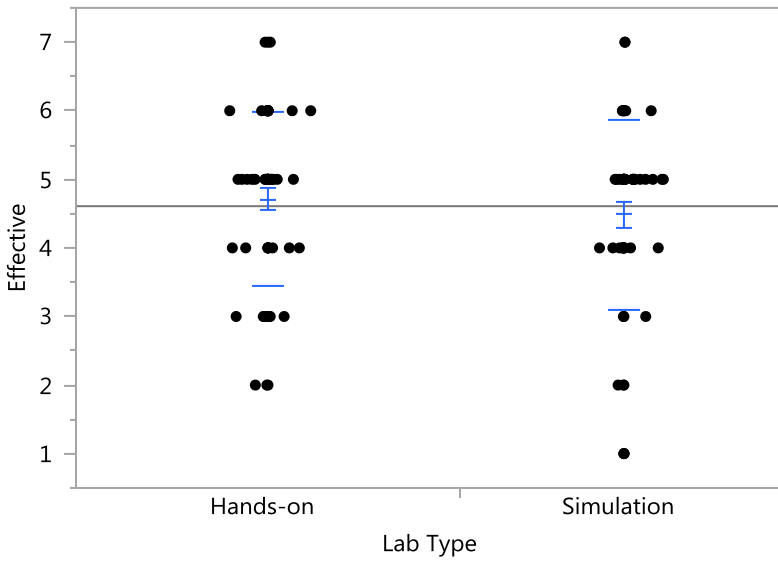
Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
Hands-on	62	4.70968	1.25955	0.15996	4.3898	5.0295
Simulation	53	4.49057	1.38151	0.18976	4.1098	4.8714

t Test
Simulation-Hands-on
Assuming unequal variances

Difference	-0.21911	t Ratio	-0.88283
Std Err Dif	0.24819	DF	106.371
Upper CL Dif	0.27293	Prob > |t|	0.3793
Lower CL Dif	-0.71115	Prob > t	0.8103
Confidence	0.95	Prob < t	0.1897
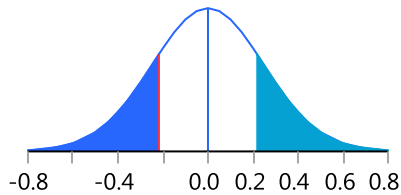
Oneway Analysis of Engagement By Lab Type
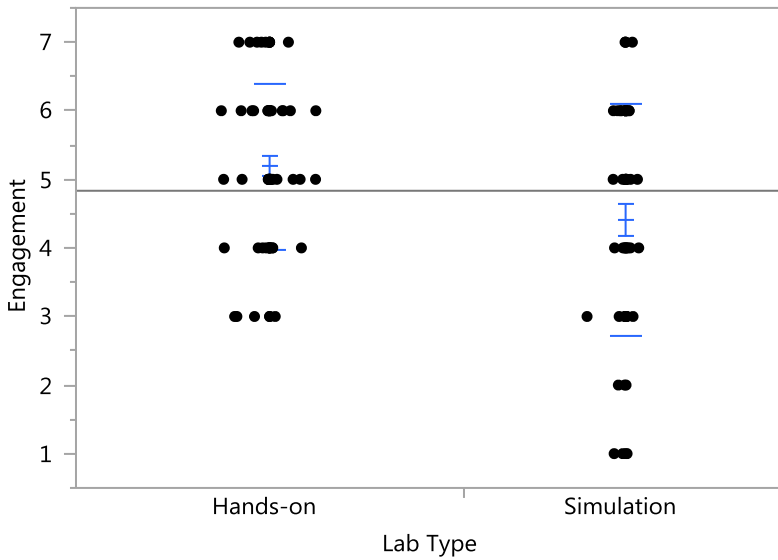
Missing Rows   1

Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
Hands-on	62	5.19355	1.21249	0.15399	4.8856	5.5015
Simulation	52	4.40385	1.69497	0.23505	3.9320	4.8757

t Test
Simulation-Hands-on
Assuming unequal variances

Difference	-0.7897	t Ratio	-2.81034
Std Err Dif	0.2810	DF	90.26902
Upper CL Dif	-0.2315	Prob > |t|	0.0061*
Lower CL Dif	-1.3479	Prob > t	0.9970
Confidence	0.95	Prob < t	0.0030*

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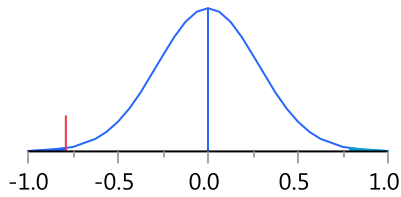
Output for Angular Momentum Lab

Oneway Analysis of Score By Lab Type
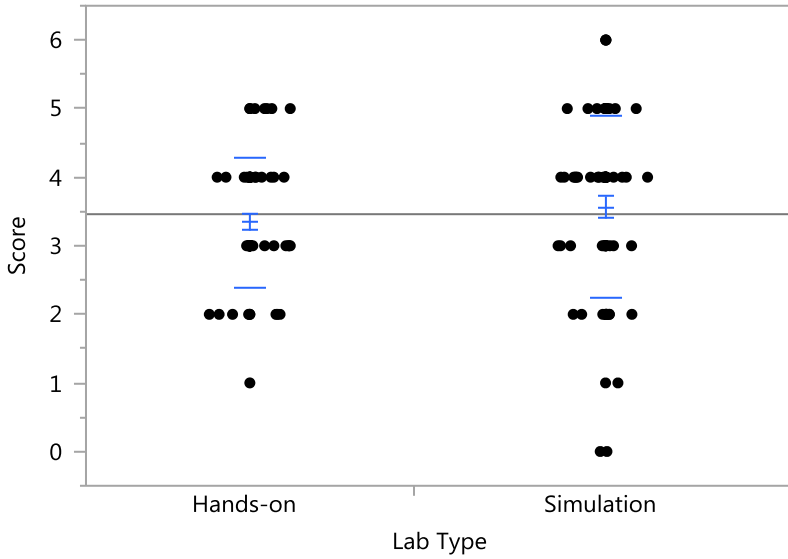
Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
Hands-on	58	3.34483	0.94686	0.12433	3.0959	3.5938
Simulation	68	3.55882	1.33139	0.16146	3.2366	3.8811

t Test
Simulation-Hands-on
Assuming unequal variances

Difference	0.21400	t Ratio	1.050142
Std Err Dif	0.20378	DF	120.2977
Upper CL Dif	0.61745	Prob > |t|	0.2958
Lower CL Dif	-0.18946	Prob > t	0.1479
Confidence	0.95	Prob < t	0.8521
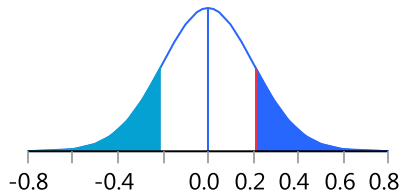
Oneway Analysis of Recall By Lab Type
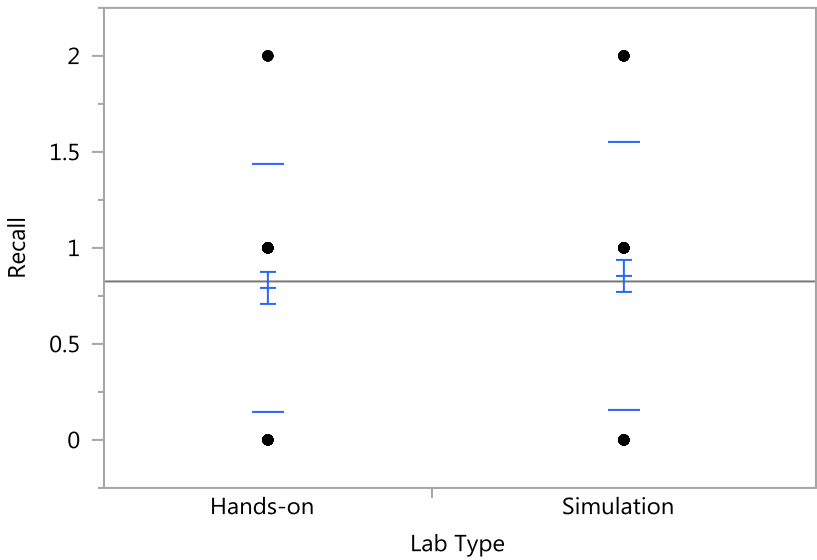
Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
Hands-on	58	0.793103	0.642326	0.08434	0.62421	0.9620
Simulation	68	0.852941	0.696788	0.08450	0.68428	1.0216

t Test
Simulation-Hands-on
Assuming unequal variances

Difference	0.05984	t Ratio	0.501205
Std Err Dif	0.11939	DF	123.2299
Upper CL Dif	0.29615	Prob > |t|	0.6171
Lower CL Dif	-0.17648	Prob > t	0.3086
Confidence	0.95	Prob < t	0.6914
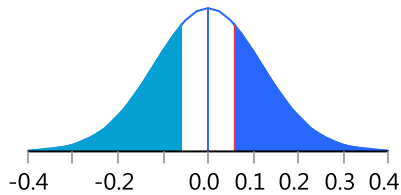
Oneway Analysis of Calculation By Lab Type
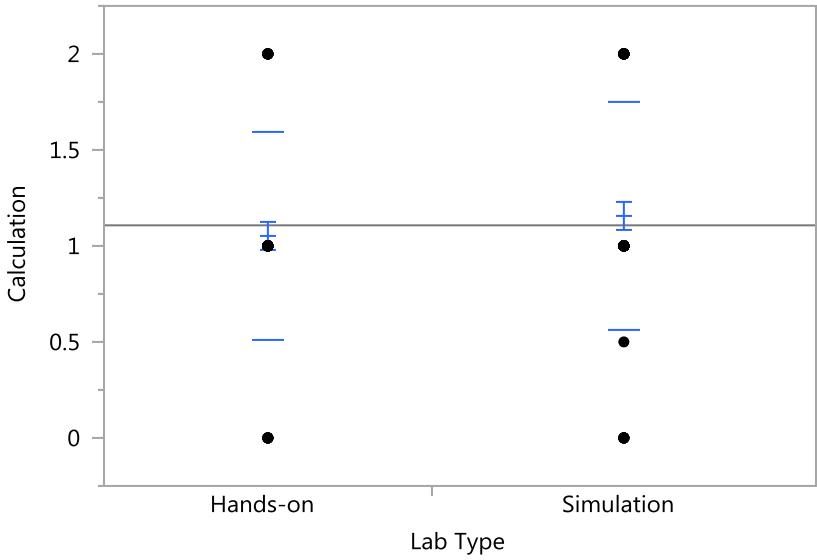
Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
Hands-on	58	1.05172	0.543621	0.07138	0.9088	1.1947
Simulation	68	1.15441	0.593858	0.07202	1.0107	1.2982

t Test
Simulation-Hands-on
Assuming unequal variances

Difference	0.10269	t Ratio	1.012721
Std Err Dif	0.10140	DF	123.3601
Upper CL Dif	0.30339	Prob > |t|	0.3132
Lower CL Dif	-0.09802	Prob > t	0.1566
Confidence	0.95	Prob < t	0.8434
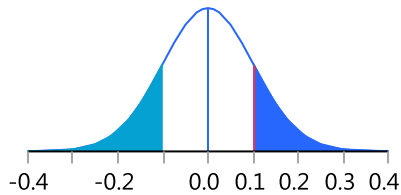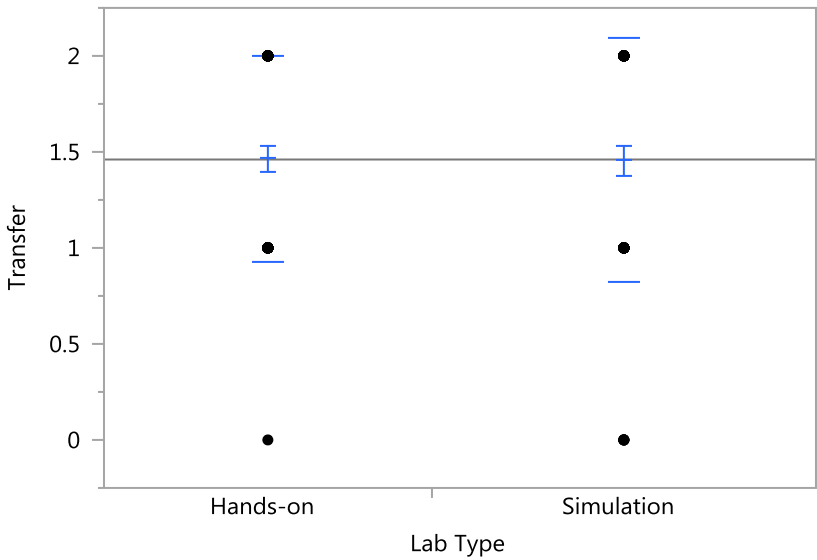
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Oneway Analysis of Transfer By Lab Type

Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
Hands-on	58	1.46552	0.536902	0.07050	1.3243	1.6067
Simulation	68	1.45588	0.633253	0.07679	1.3026	1.6092

t Test
Simulation-Hands-on
Assuming unequal variances

Difference	-0.00963	t Ratio	-0.09242
Std Err Dif	0.10425	DF	123.9973
Upper CL Dif	0.19670	Prob > |t|	0.9265
Lower CL Dif	-0.21597	Prob > t	0.5367
Confidence	0.95	Prob < t	0.4633
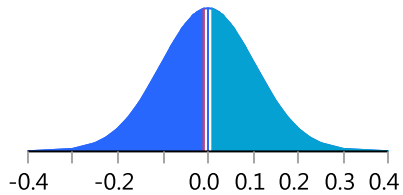
Oneway Analysis of Effective By Lab Type
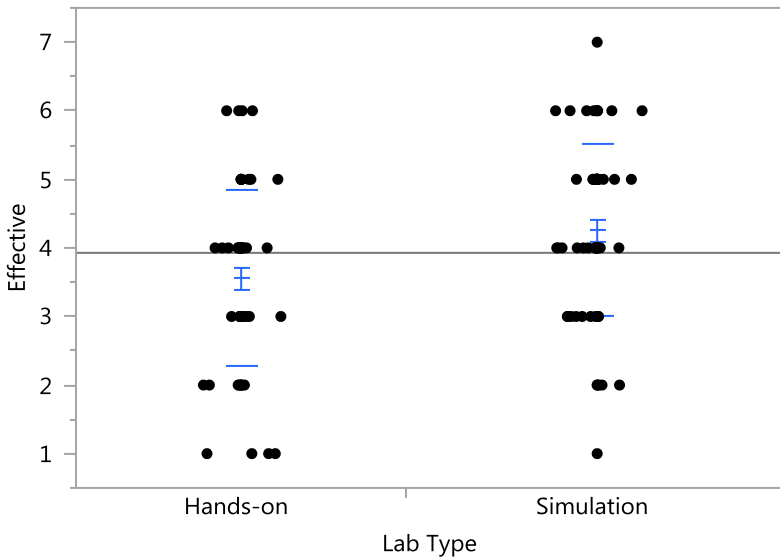
Missing Rows   1

Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
Hands-on	58	3.55172	1.28654	0.16893	3.2134	3.8900
Simulation	67	4.25373	1.25943	0.15386	3.9465	4.5609

t Test
Simulation-Hands-on
Assuming unequal variances

Difference	0.70201	t Ratio	3.072264
Std Err Dif	0.22850	DF	119.6718
Upper CL Dif	1.15443	Prob > |t|	0.0026*
Lower CL Dif	0.24958	Prob > t	0.0013*
Confidence	0.95	Prob < t	0.9987

159
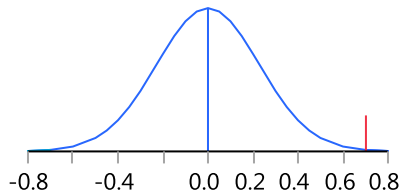
Oneway Analysis of Engagement By Lab Type
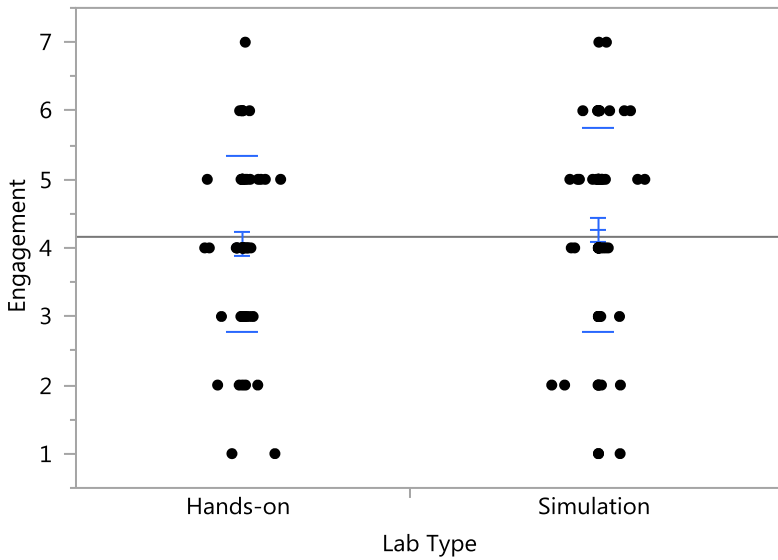
Missing Rows   2

Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
Hands-on	58	4.05172	1.28994	0.16938	3.7126	4.3909
Simulation	66	4.25758	1.48127	0.18233	3.8934	4.6217

t Test
Simulation-Hands-on
Assuming unequal variances

Difference	0.20585	t Ratio	0.827162
Std Err Dif	0.24886	DF	121.9922
Upper CL Dif	0.69850	Prob > |t|	0.4098
Lower CL Dif	-0.28680	Prob > t	0.2049
Confidence	0.95	Prob < t	0.7951

160
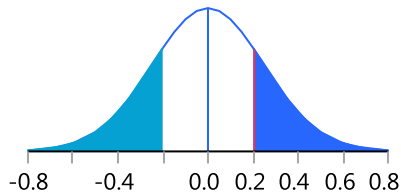
Output for Pendulum Lab

Oneway Analysis of Score By Lab Type
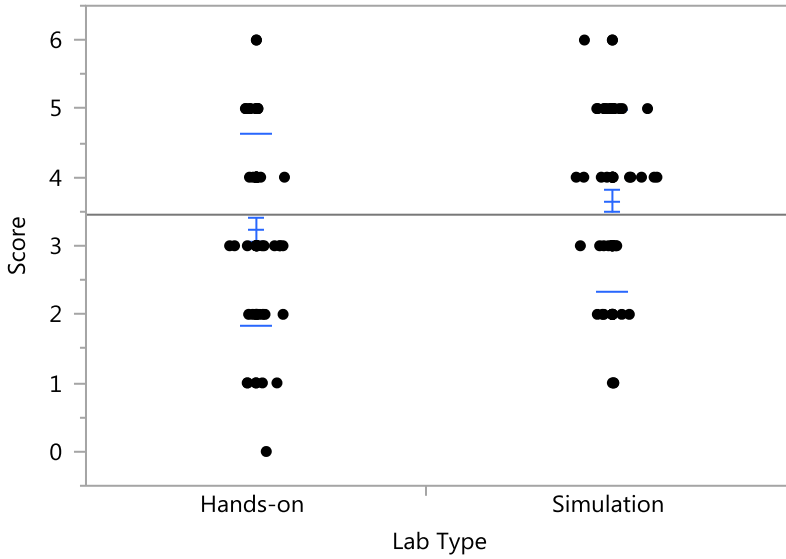
Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
Hands-on	56	3.23214	1.38815	0.18550	2.8604	3.6039
Simulation	61	3.65574	1.32772	0.17000	3.3157	3.9958

t Test
Simulation-Hands-on
Assuming unequal variances

Difference	0.42359	t Ratio	1.683521
Std Err Dif	0.25161	DF	113.07
Upper CL Dif	0.92208	Prob > |t|	0.0950
Lower CL Dif	-0.07489	Prob > t	0.0475*
Confidence	0.95	Prob < t	0.9525
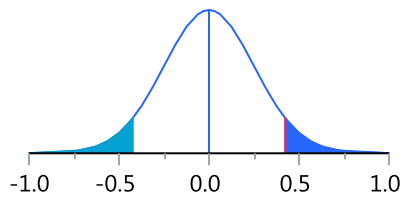
Oneway Analysis of Recall By Lab Type
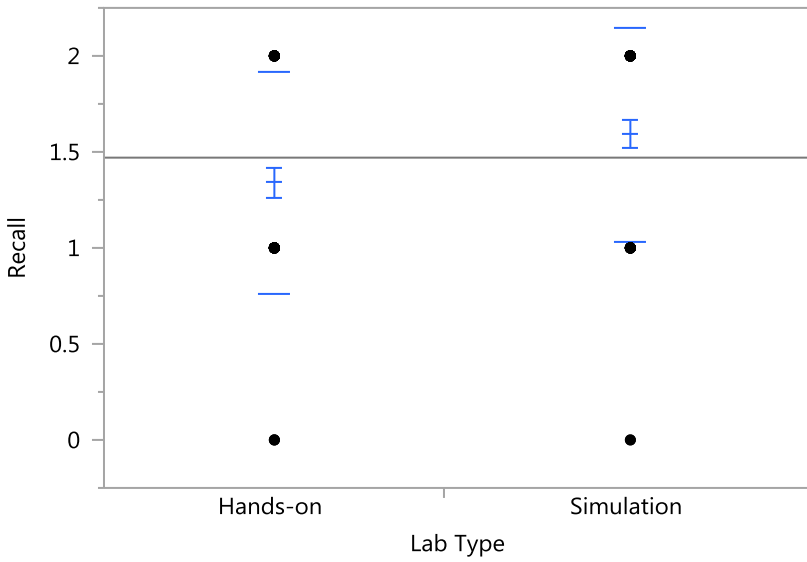
Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
Hands-on	56	1.33929	0.580808	0.07761	1.1837	1.4948
Simulation	61	1.59016	0.559078	0.07158	1.4470	1.7334

t Test
Simulation-Hands-on
Assuming unequal variances

Difference	0.250878	t Ratio	2.376103
Std Err Dif	0.105584	DF	113.2499
Upper CL Dif	0.460054	Prob > |t|	0.0192*
Lower CL Dif	0.041702	Prob > t	0.0096*
Confidence	0.95	Prob < t	0.9904
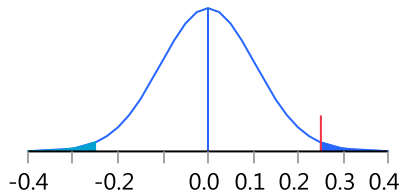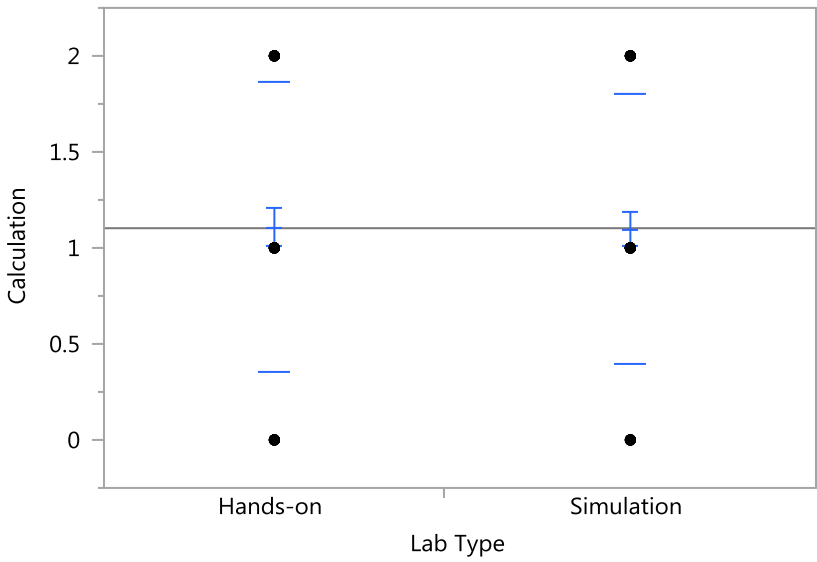
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Oneway Analysis of Calculation By Lab Type

Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
Hands-on	56	1.10714	0.755069	0.10090	0.90493	1.3094
Simulation	61	1.09836	0.700117	0.08964	0.91905	1.2777

t Test
Simulation-Hands-on
Assuming unequal variances

Difference	-0.00878	t Ratio	-0.06507
Std Err Dif	0.13497	DF	112.0801
Upper CL Dif	0.25864	Prob > |t|	0.9482
Lower CL Dif	-0.27620	Prob > t	0.5259
Confidence	0.95	Prob < t	0.4741
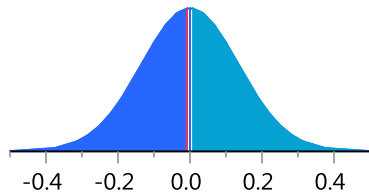
163

Oneway Analysis of Transfer By Lab Type
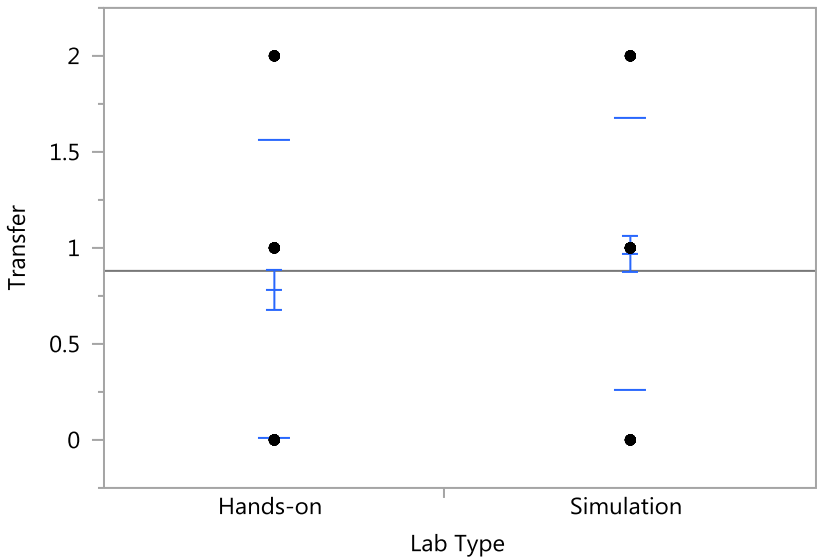
Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
Hands-on	56	0.785714	0.779610	0.10418	0.57693	0.9945
Simulation	61	0.967213	0.706334	0.09044	0.78631	1.1481

t Test
Simulation-Hands-on
Assuming unequal variances

Difference	0.18150	t Ratio	1.315615
Std Err Dif	0.13796	DF	111.2268
Upper CL Dif	0.45486	Prob > |t|	0.1910
Lower CL Dif	-0.09187	Prob > t	0.0955
Confidence	0.95	Prob < t	0.9045
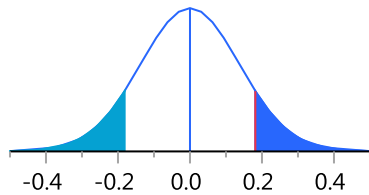
Oneway Analysis of Effective By Lab Type
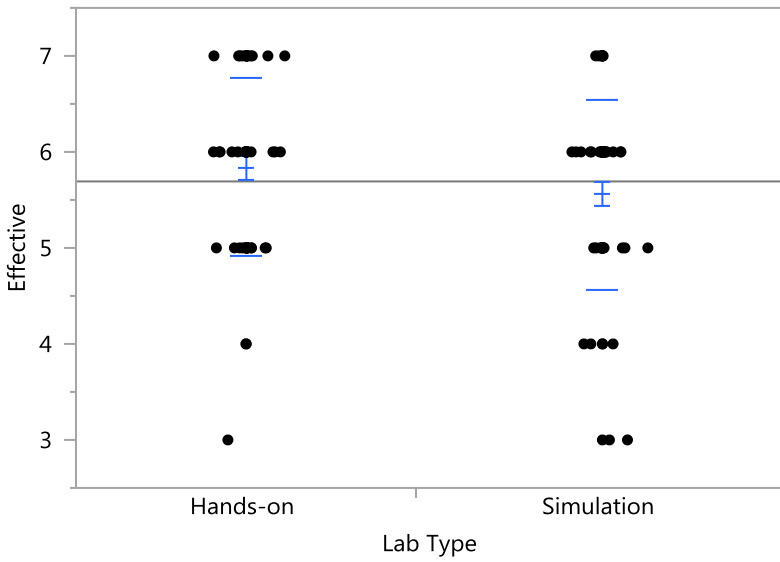
Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
Hands-on	56	5.83929	0.929844	0.12426	5.5903	6.0883
Simulation	61	5.55738	0.992045	0.12702	5.3033	5.8115

t Test
Simulation-Hands-on
Assuming unequal variances

Difference	-0.28191	t Ratio	-1.58653
Std Err Dif	0.17769	DF	114.9468
Upper CL Dif	0.07006	Prob > |t|	0.1154
Lower CL Dif	-0.63388	Prob > t	0.9423
Confidence	0.95	Prob < t	0.0577

165

Oneway Analysis of Engagement By Lab Type

Missing Rows   1

Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
Hands-on	55	5.54545	1.25931	0.16981	5.2050	5.8859
Simulation	61	5.00000	1.31656	0.16857	4.6628	5.3372

t Test
Simulation-Hands-on
Assuming unequal variances

Difference	-0.5455	t Ratio	-2.27968
Std Err Dif	0.2393	DF	113.5907
Upper CL Dif	-0.0714	Prob > |t|	0.0245*
Lower CL Dif	-1.0195	Prob > t	0.9878
Confidence	0.95	Prob < t	0.0122*

-0.8   -0.4   0.0 0.2 0.4 0.6 0.8

Output for Friction Lab

Oneway Analysis of Score By Lab Type
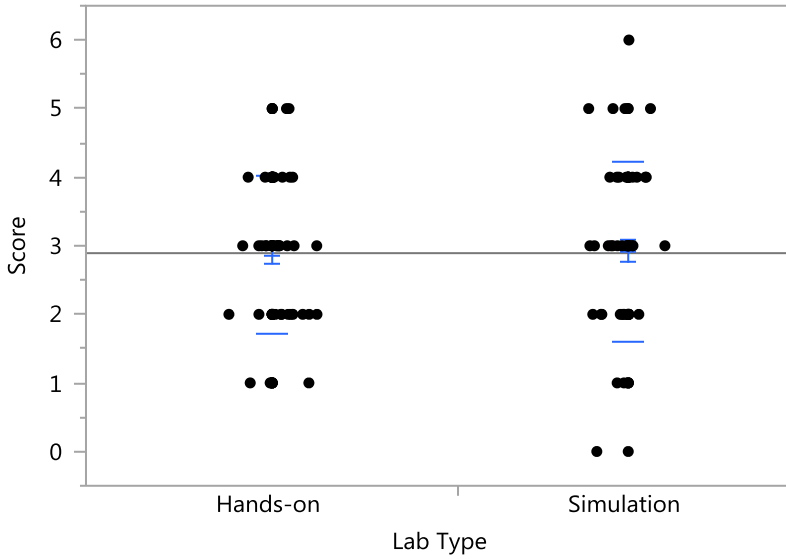
Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
Hands-on	68	2.86765	1.14481	0.13883	2.5905	3.1447
Simulation	62	2.91935	1.30947	0.16630	2.5868	3.2519

t Test
Simulation-Hands-on
Assuming unequal variances

Difference	0.05171	t Ratio	0.238689
Std Err Dif	0.21663	DF	121.7927
Upper CL Dif	0.48056	Prob > |t|	0.8117
Lower CL Dif	-0.37715	Prob > t	0.4059
Confidence	0.95	Prob < t	0.5941
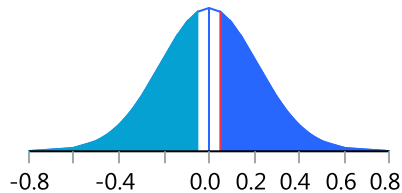
Oneway Analysis of Recall By Lab Type
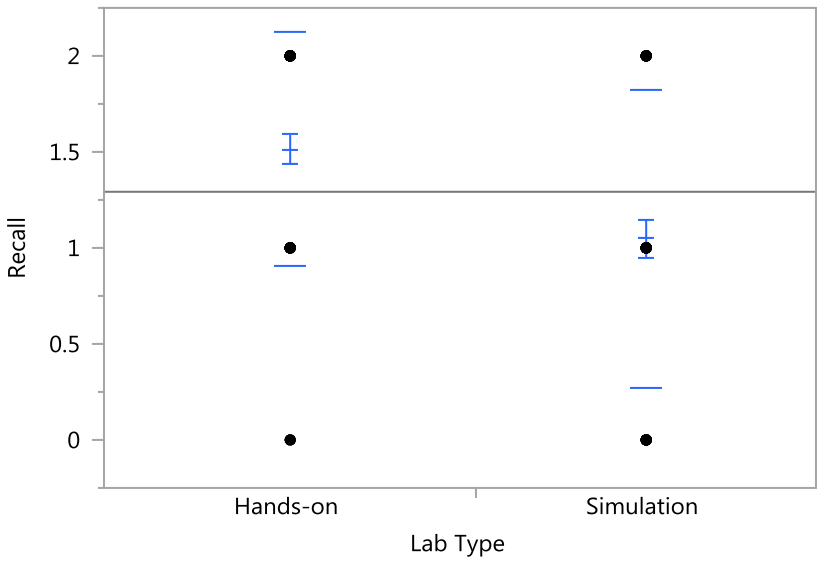
Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
Hands-on	68	1.51471	0.610668	0.07405	1.3669	1.6625
Simulation	62	1.04839	0.777289	0.09872	0.8510	1.2458

t Test
Simulation-Hands-on
Assuming unequal variances

Difference	-0.46632	t Ratio	-3.77876
Std Err Dif	0.12341	DF	115.6341
Upper CL Dif	-0.22189	Prob > |t|	0.0003*
Lower CL Dif	-0.71075	Prob > t	0.9999
Confidence	0.95	Prob < t	0.0001*
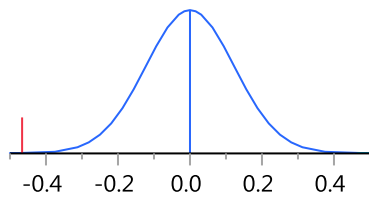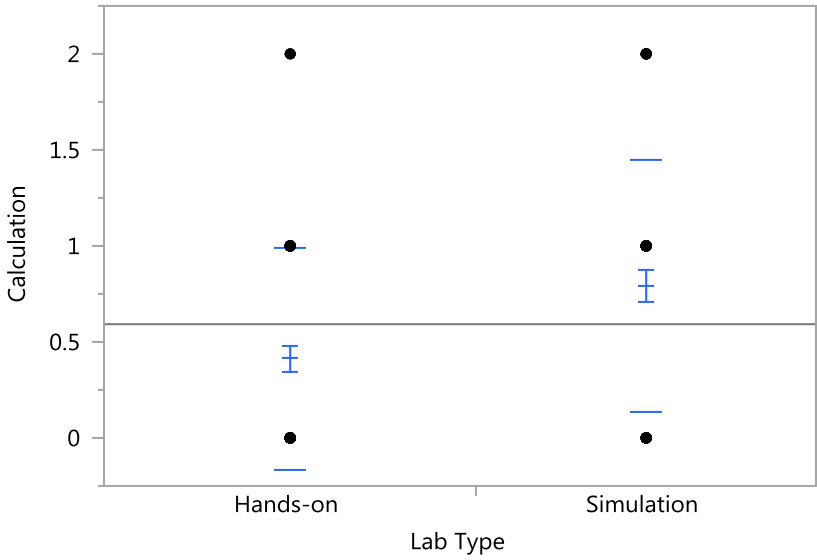
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Oneway Analysis of Calculation By Lab Type

Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
Hands-on	68	0.411765	0.579122	0.07023	0.27159	0.55194
Simulation	62	0.790323	0.656296	0.08335	0.62365	0.95699

t Test
Simulation-Hands-on
Assuming unequal variances

Difference	0.378558	t Ratio	3.473263
Std Err Dif	0.108992	DF	122.2567
Upper CL Dif	0.594314	Prob > |t|	0.0007*
Lower CL Dif	0.162802	Prob > t	0.0004*
Confidence	0.95	Prob < t	0.9996
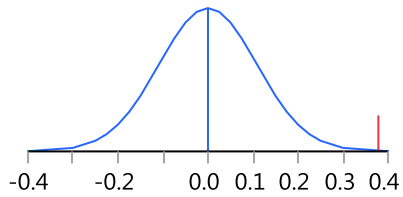
Oneway Analysis of Transfer By Lab Type
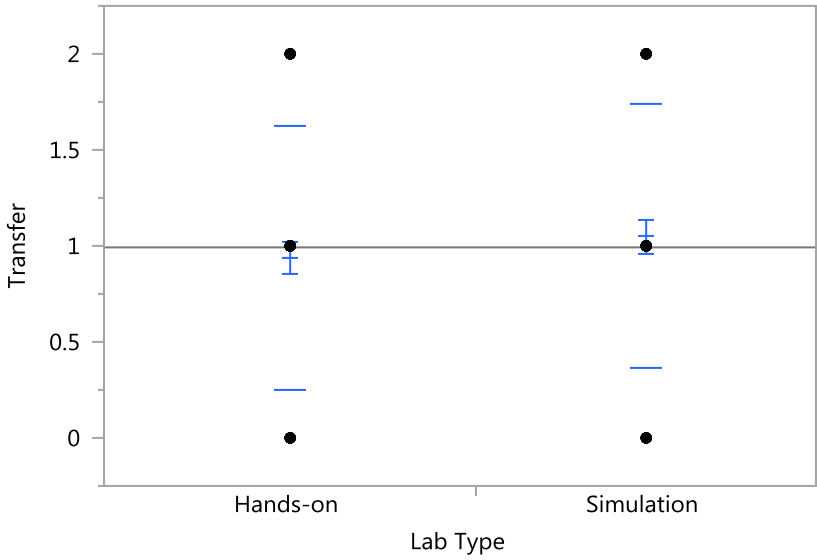
Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
Hands-on	68	0.94118	0.688549	0.08350	0.77451	1.1078
Simulation	62	1.04839	0.687772	0.08735	0.87373	1.2230

t Test
Simulation-Hands-on
Assuming unequal variances

Difference	0.10721	t Ratio	0.887233
Std Err Dif	0.12084	DF	126.9256
Upper CL Dif	0.34633	Prob > |t|	0.3766
Lower CL Dif	-0.13191	Prob > t	0.1883
Confidence	0.95	Prob < t	0.8117
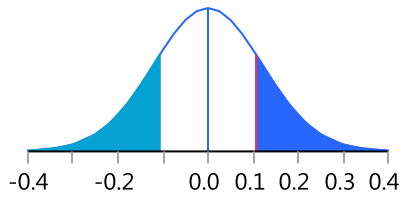
Oneway Analysis of Effective By Lab Type
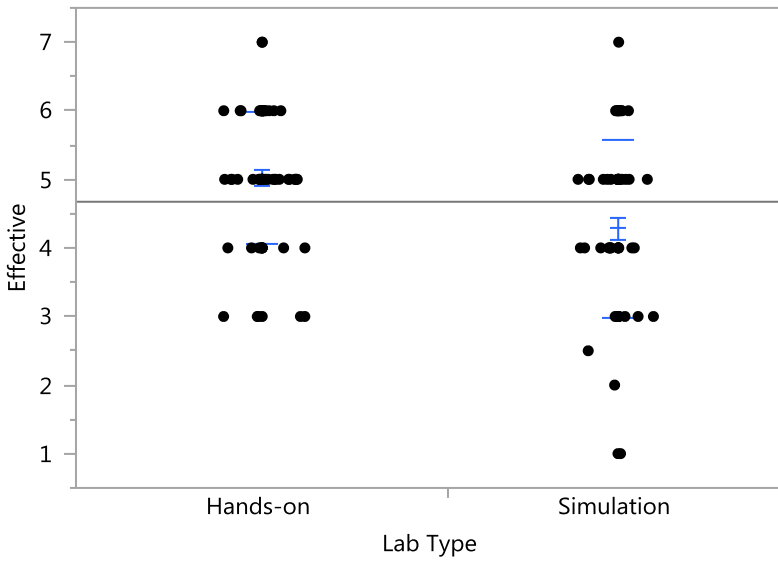
Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
Hands-on	68	5.02941	0.96151	0.11660	4.7967	5.2621
Simulation	62	4.28226	1.29508	0.16447	3.9534	4.6111

t Test
Simulation-Hands-on
Assuming unequal variances

Difference	-0.7472	t Ratio	-3.7059
Std Err Dif	0.2016	DF	111.9719
Upper CL Dif	-0.3477	Prob > |t|	0.0003*
Lower CL Dif	-1.1466	Prob > t	0.9998
Confidence	0.95	Prob < t	0.0002*
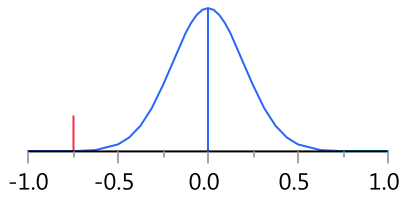
Oneway Analysis of Engagement By Lab Type
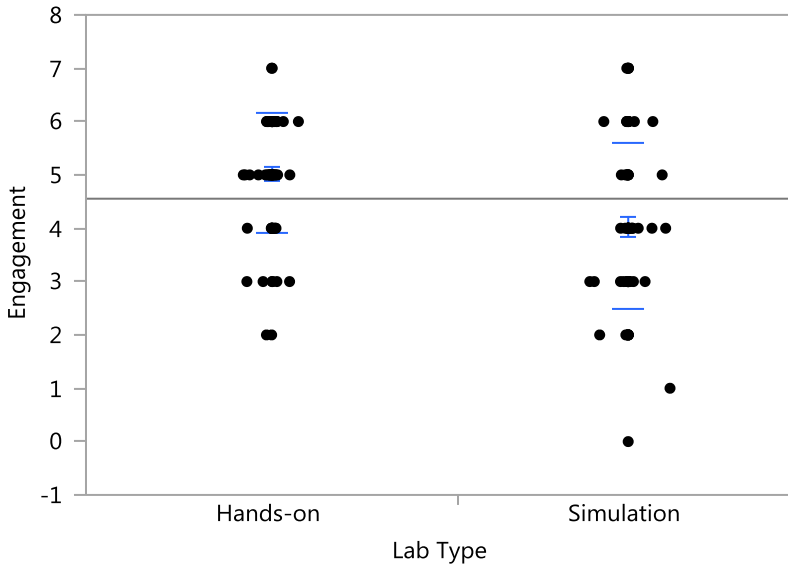
Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
Hands-on	68	5.02941	1.13257	0.13734	4.7553	5.3036
Simulation	62	4.03226	1.55730	0.19778	3.6368	4.4277

t Test
Simulation-Hands-on
Assuming unequal variances

Difference	-0.9972	t Ratio	-4.14121
Std Err Dif	0.2408	DF	110.6018
Upper CL Dif	-0.5200	Prob > |t|	<.0001*
Lower CL Dif	-1.4743	Prob > t	1.0000
Confidence	0.95	Prob < t	<.0001*
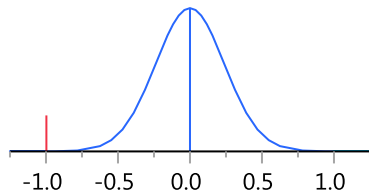
Output for Combined Data

One way analysis of Quiz Score by lab type
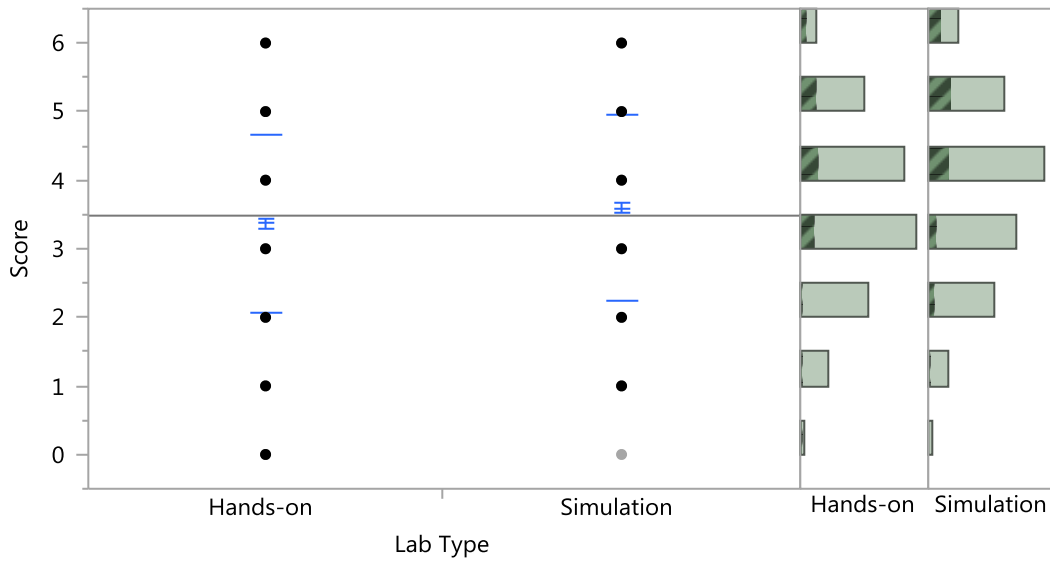
Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
Hands-on	354	3.36723	1.29311	0.06873	3.2321	3.5024
Simulation	357	3.59664	1.35944	0.07195	3.4551	3.7381

t Test
Simulation-Hands-on
Assuming unequal variances

Difference	0.229407	t Ratio	2.305603
Std Err Dif	0.099500	DF	707.7785
Upper CL Dif	0.424757	Prob > |t|	0.0214*
Lower CL Dif	0.034057	Prob > t	0.0107*
Confidence	0.95	Prob < t	0.9893
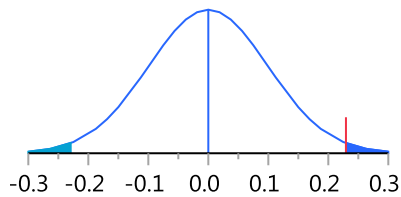
Oneway Analysis of Recall By Lab Type
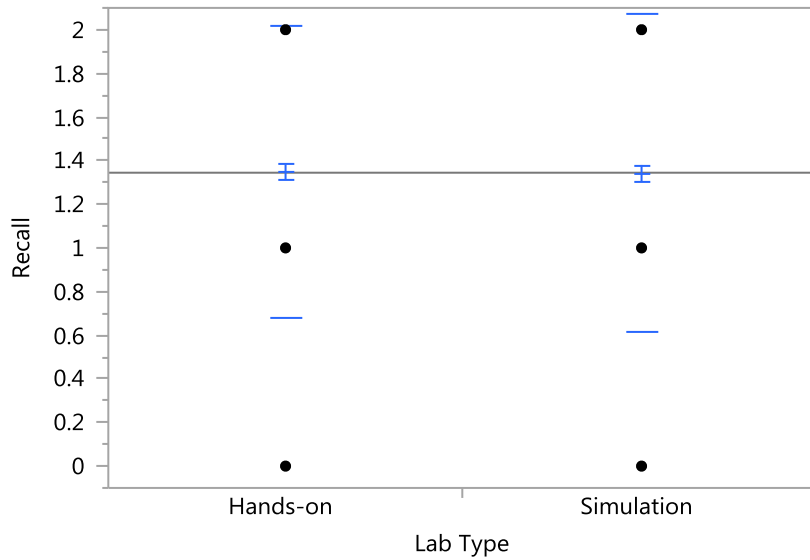
Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
Hands-on	354	1.34746	0.669579	0.03559	1.2775	1.4174
Simulation	357	1.34174	0.727293	0.03849	1.2660	1.4174

t Test
Simulation-Hands-on
Assuming unequal variances

Difference	-0.00572	t Ratio	-0.10913
Std Err Dif	0.05242	DF	705.1314
Upper CL Dif	0.09720	Prob > |t|	0.9131
Lower CL Dif	-0.10864	Prob > t	0.5434
Confidence	0.95	Prob < t	0.4566
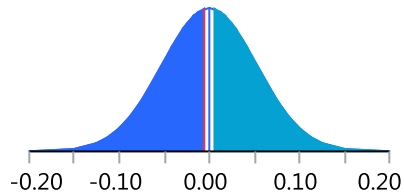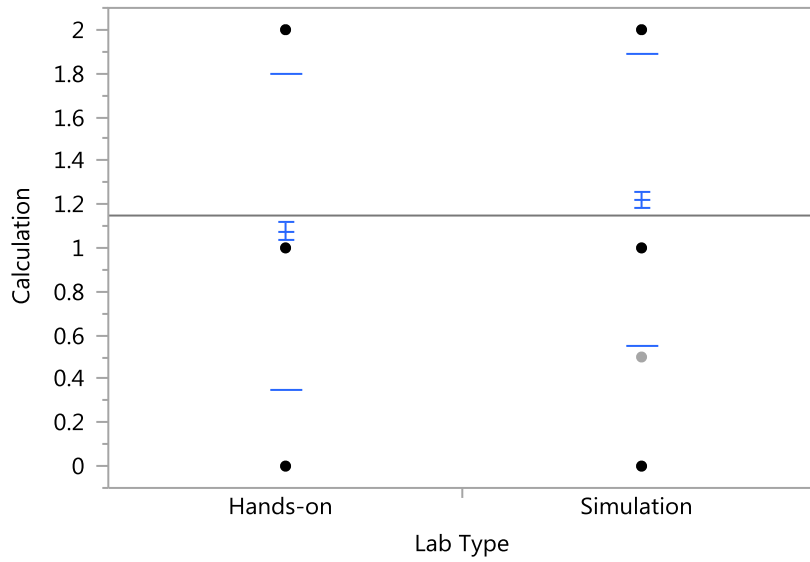
-0.20   -0.10   0.00   0.10   0.20

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Oneway Analysis of Calculation By Lab Type

Means and Std Deviations

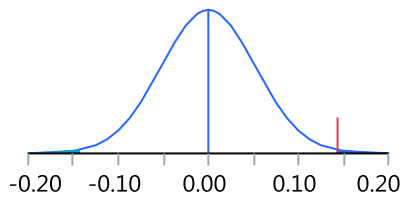| Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
Hands-on	354	1.07627	0.723817	0.03847	1.0006	1.1519
Simulation	357	1.21989	0.666175	0.03526	1.1505	1.2892

t Test
Simulation-Hands-on
Assuming unequal variances

Difference	0.143617	t Ratio	2.752168
Std Err Dif	0.052183	DF	703.1493
Upper CL Dif	0.246070	Prob > |t|	0.0061*
Lower CL Dif	0.041163	Prob > t	0.0030*
Confidence	0.95	Prob < t	0.9970

Oneway Analysis of Transfer By Lab Type
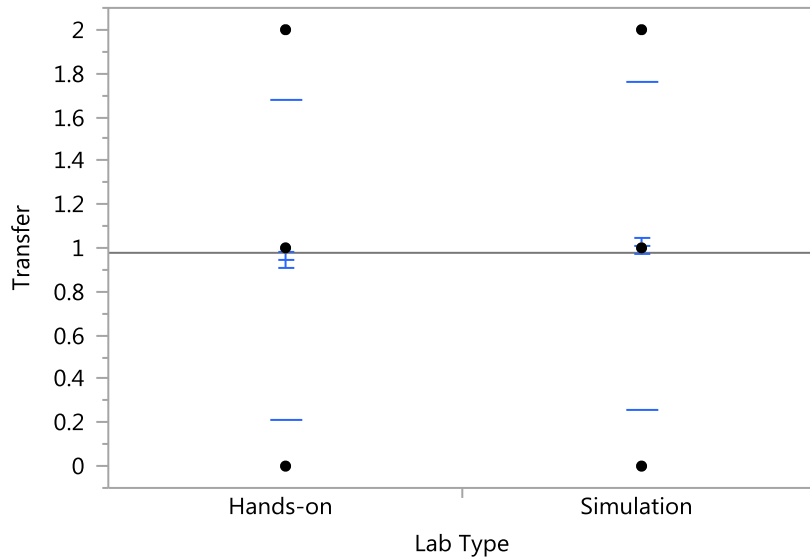
Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
Hands-on	354	0.94633	0.733613	0.03899	0.86964	1.0230
Simulation	357	1.00840	0.751356	0.03977	0.93020	1.0866

t Test
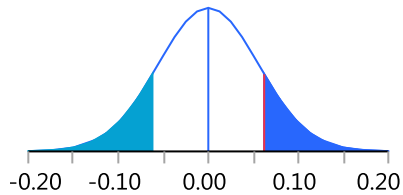Simulation-Hands-on
Assuming unequal variances

Difference	0.06208	t Ratio	1.114618
Std Err Dif	0.05569	DF	708.8309
Upper CL Dif	0.17142	Prob > |t|	0.2654
Lower CL Dif	-0.04727	Prob > t	0.1327
Confidence	0.95	Prob < t	0.8673
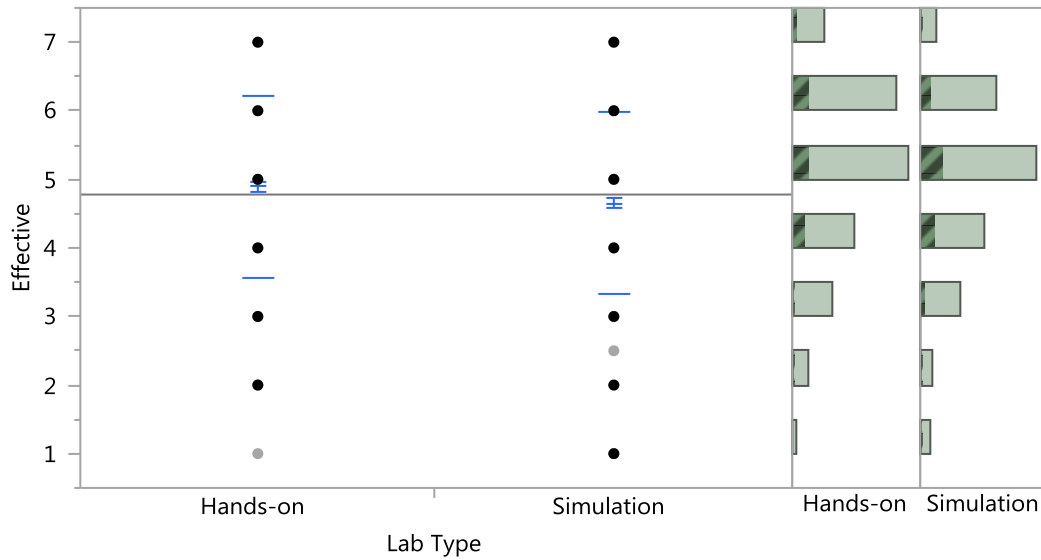
-0.20   -0.10   0.00   0.10   0.20

Oneway Analysis of Effective By Lab Type

Missing Rows   1

Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
Hands-on	354	4.90113	1.32693	0.07053	4.7624	5.0398
Simulation	356	4.65590	1.33226	0.07061	4.5170	4.7948

t Test
Simulation-Hands-on
Assuming unequal variances

Difference	-0.24523	t Ratio	-2.45728
Std Err Dif	0.09980	DF	707.9981
Upper CL Dif	-0.04930	Prob > |t|	0.0142*
Lower CL Dif	-0.44117	Prob > t	0.9929
Confidence	0.95	Prob < t	0.0071*
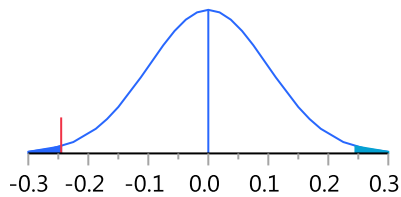
Oneway Analysis of Engagement By Lab Type
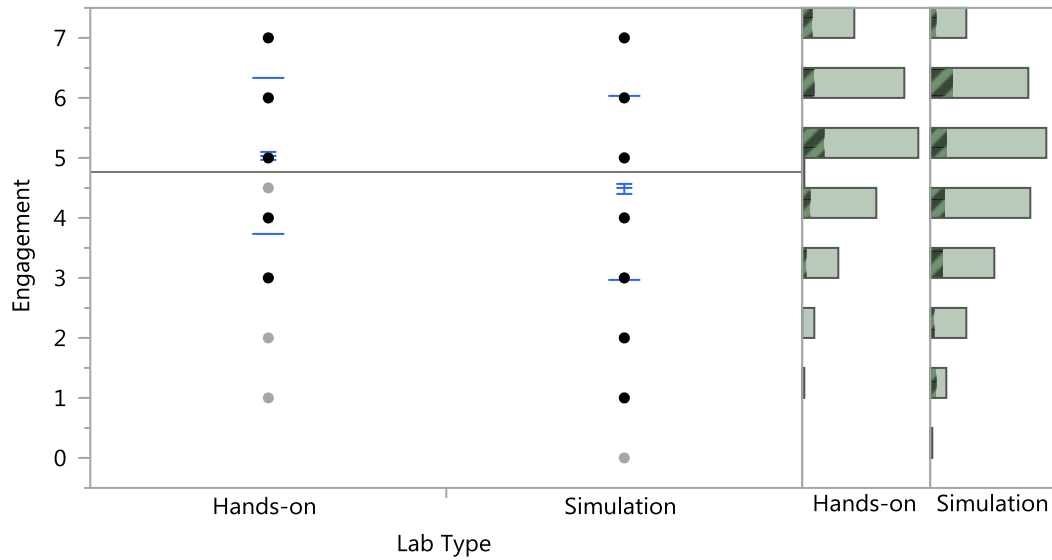
Missing Rows   5

Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
Hands-on	353	5.03824	1.29656	0.06901	4.9025	5.1740
Simulation	353	4.49292	1.52836	0.08135	4.3329	4.6529

t Test
Simulation-Hands-on
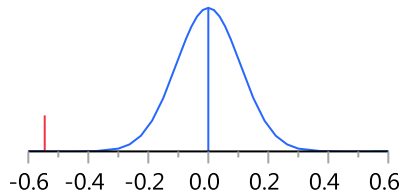Assuming unequal variances

Difference	-0.54533	t Ratio	-5.11205
Std Err Dif	0.10667	DF	685.7761
Upper CL Dif	-0.33588	Prob > |t|	<.0001*
Lower CL Dif	-0.75477	Prob > t	1.0000
Confidence	0.95	Prob < t	<.0001*

Comparison of Means by Question Type
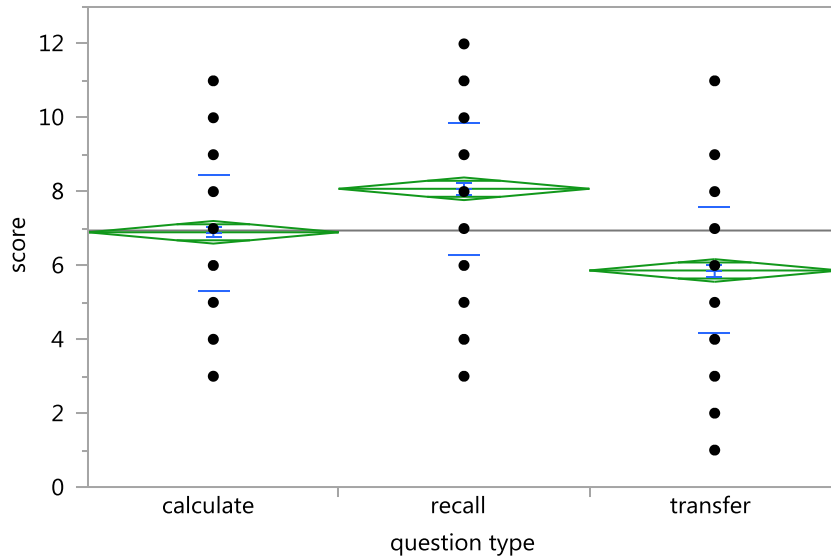
Missing Rows   1

Oneway Anova
Summary of Fit

Rsquare	0.223386
Adj Rsquare	0.21896
Root Mean Square Error	1.692049
Mean of Response	6.946328
Observations (or Sum Wgts)	354

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
type 2	2	289.0565	144.528	50.4809	<.0001*
Error	351	1004.9237	2.863		
C. Total	353	1293.9802			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
calculate	118	6.89831	0.15577	6.5920	7.2047
recall	118	8.07627	0.15577	7.7699	8.3826
transfer	118	5.86441	0.15577	5.5581	6.1708

Std Error uses a pooled estimate of error variance

Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
calculate	118	6.89831	1.56560	0.14413	6.6129	7.1837
recall	118	8.07627	1.80293	0.16597	7.7476	8.4050
transfer	118	5.86441	1.69925	0.15643	5.5546	6.1742

Correlation of Survey Responses to Quiz Score
Correlations

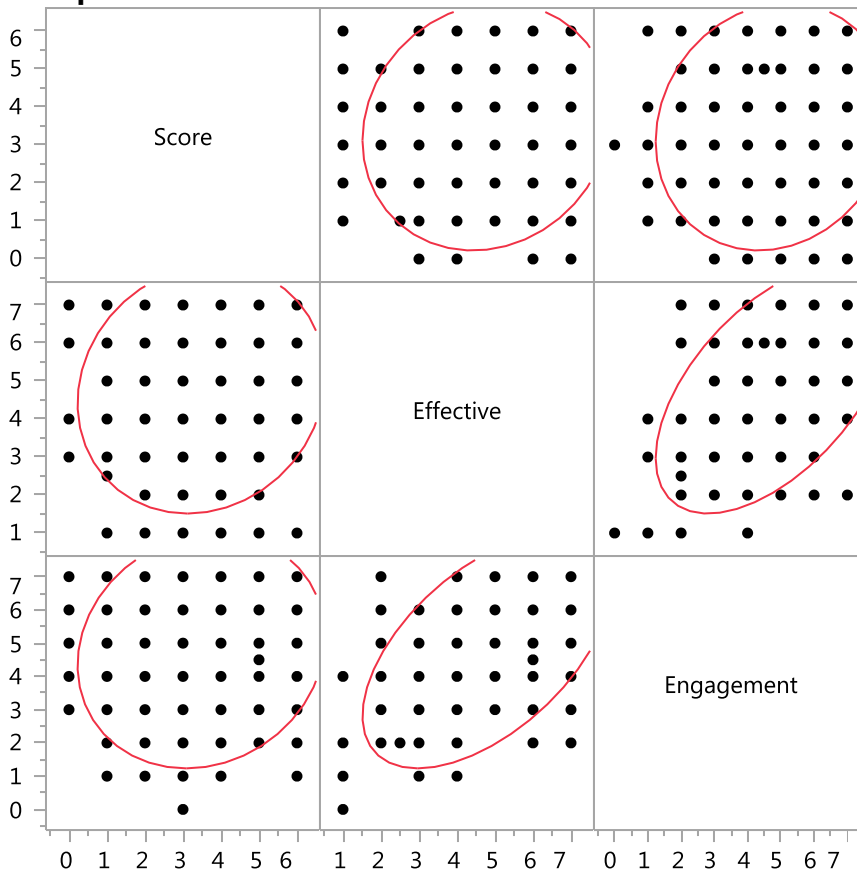|	Score	Effective	Engagement
Score	1.0000	0.1111	0.1214
Effective	0.1111	1.0000	0.5545
Engagement	0.1214	0.5545	1.0000

There are 5 missing values.   The correlations are estimated by REML method.

Correlation Probability

	Score	Effective	Engagement
Score	<.0001	0.0030	0.0012
Effective	0.0030	<.0001	<.0001
Engagement	0.0012	<.0001	<.0001

Scatterplot Matrix

APPENDIX E.   IRB APPROVAL FORMS

Institutional Review Board
for Human Subjects

Brigham Young University
A-285 ASB Provo, Utah 84602
(801) 422-3841 / Fax: (801) 422-0620

November 3, 2016

Matthew Rytting
364 W 120 S
Lindon, UT 84042

Re: X 16202
    Comparison of Simulation and Hands-on Labs in Helping Students Learn Physics Concepts

Dear Matthew Rytting

This is to inform you that Brigham Young University's IRB approval of the above research study is contingent upon the receipt of the following:

- submission of Alpine School District approval letter

The approval period is from 11-3-2016 to 11-2-2017. Your study number is X16202. Please be sure to reference this number in any correspondence with the IRB.

Continued approval is conditional upon your compliance with the following requirements.

A copy of the Informed Consent Statement, approved as of 11-3-2016 is enclosed. No other consent form should be used. In addition, each subject must be offered a copy of the signed consent form.

All protocol amendments and changes to approved research must be submitted to the IRB and not be implemented until approved by the IRB.

A few months before this date we will send out a continuing review form. There will only be two reminders. Please fill this form out in a timely manner to ensure that there is not a lapse in your approval.
If you have any questions, please do not hesitate to call me.

Sincerely,

Robert Ridge, PhD, Chair
Sandee Aina, MPA, Administrator
Institutional Review Board for Human Subjects

575 NORTH 100 EAST • AMERICAN FORK, UTAH 84003-1758 • (801) 610-8464 • dhsmith@alpinedistrict.org

David H. Smith, Director of Research and Evaluation

November 10, 2016

Matthew Rytting
364 W. 120 S.
Lindon, Utah 84042

Dear Matthew,

Thank you for completing our application to conduct your research with Alpine School District. I am granting you permission to contact the principal at the school you requested. You must contact him for permission to conduct your research at their school.

Steve Stewart, Principal
Pleasant Grove High
700 E. 200 S.
Pleasant Grove, Utah 84062
801-610-8170

Good luck in your research, and if you have any questions, please don't hesitate to call at the number stated above.

Sincerely,

David H. Smith,
Director of Research and Evaluation

DHS/cse

cc: Steve Stewart