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The Impact of Virtual Simulations on Student Comprehension of Mechanics

Ann Sanchez Couch
Louisiana State University and Agricultural and Mechanical College

THE IMPACT OF VIRTUAL SIMULATIONS ON STUDENT COMPREHENSION OF MECHANICS

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TABLE OF CONTENTS

ABSTRACT

The use of technology in classrooms has become an increasing trend throughout all levels of education. Often times, teachers are left to figure out how to incorporate the many different types of available technologies into their lessons. This study examines the use of one specific type of technology in the classroom: computer simulations, specifically the impact of virtual lab simulations on student understanding of mechanics concepts. In this study, the experimental group and the control group received identical instruction in the form of lectures, practice problems, homework, and tests. The difference between the two groups was the use of virtual lab activities in the experimental group, while the control group completed paper-and-pencil based worksheets. The analysis of normalized gains on the Force Concept Inventory and chapter tests shows no statistically significant difference arose from using virtual labs instead of worksheets. However, based on teacher observations, the simulations appeared to increase student effort and engagement.

INTRODUCTION

A driving force in education in recent years has been the advancement and integration of technology in the classroom. Being a teacher in a program emphasizing mathematics, science and the arts, utilizing multiple technologies is a required aspect of my daily instruction. When the school opened, it housed only seventh, eighth, and ninth grades. As these students progressed, the following grades were added to the school. I began teaching physical science at the school the year following its opening when the first group of ninth grade students became tenth graders. When this group was headed to twelfth grade, I was approached by the administration to teach physics. In moving to this new subject, I was not provided with many resources. Specifically, a common, useful technology for teaching physics, traditional laboratory equipment, was not provided to me for use in my class. This lack of physical tools seemed to make teaching physics impossible. Being thrust into the physics classroom with no resources was somewhat overwhelming, and because physics is about how "stuff" works, I now had to figure out two things: 1) How do I teach my students physics, and 2) How can I show my students the phenomena that physics describes?

In lieu of equipment, every student and teacher at my school is assigned a laptop computer for use throughout the school year. Since the emergence of computer technology in the classroom, both educators and educational researchers have been exploring and developing uses of computers to benefit education. Today, computers offer many opportunities to facilitate teaching in the physics classroom. One of the important uses of the computer is learning guided by computer simulations. These computer simulations and their utilizations have been developed to focus on student engagement and to help create environments that often times are not capable of being produced in the lab or classroom (Bozkurt and Ilik, 2010).

In searching for a way to incorporate the use of the computers into my lessons, I stumbled upon the Physics Education Technology (PhET) simulations (www.phet.colorado.edu). For the next several years, I used the simulations sparingly in my classes mostly as a “fun” activity when time allowed. Many students are very “tech savvy”; and whether it is through computers, cell phones, or video games, today’s technology seems to capture their attention in a powerful way. Even though the students were obviously drawn to the computers, when using the simulations I wanted to investigate whether utilizing this technology would truly impact their learning.

Employing techniques such as laboratory exercises that utilize visual recognition of concepts is an effective approach to engage students in their learning and reinforce lecture material for a deeper understanding. “As is now thoroughly documented in the physics education research community and elsewhere, environments that interactively engage students are supportive of student learning” (Finkelstein, et.al., 2006).

The interesting thing about the PhET simulations is that they offer an interactive exploration of physics labs without any equipment. The PhET project has developed a suite of simulations that are designed to be highly interactive, engaging, and open learning environments that provide animated feedback to the user. "The simulations are physically accurate and provide highly visual, dynamic representations of physics principles. Simultaneously, the simulations seek to build explicit bridges between students' everyday understanding of the world and the underlying physical principles, often by making the physical models explicit" (Finkelstein, et.al. 2006).

Simulations have been shown to be as productive, and often more so, than traditional educational tools, such as textbooks, live demonstrations, and real equipment (Finkelstein, et.al. 2006). As my research on PhET simulations suggested that this technique is beneficial to student understanding of physics concepts, I began to wonder if this was a tool that I should fully employ in my teaching approach.

The accessibility of these simulations is another factor that stimulates the desire to implement these applications in my classroom. They can be run directly from the website, or they can be downloaded and installed to be used offline. This is an important aspect because the students can download the simulation while at school and still be able to run it at home whether or not they have Internet access.

Another benefit of the PhET simulations is that they can be effectively used in several different environments. These simulations have been shown to be effective in lecture while serving as visual aids, among other uses. They have been used in lab or recitations sessions by allowing students to explore the concepts and create their own understanding of physics concepts (Perkins et. al., 2006). It was also shown that pairing the simulations with guided inquiry for homework has effective uses as well. Research has also shown that students indicate positive experiences with the simulations (Perkins et. al., 2006).

Through the minimal prior use of simulations in my class coupled with research claiming the benefits of computer simulations, I wanted to discover if these activities were actually worth using in my class. I believe these simulations could have an impact on student learning and could fill an important resource gap in my classroom.

LITERATURE REVIEW

Computer simulations are designed to be highly active, highly engaging tools to facilitate student learning. These open learning environments allow students to develop understanding about phenomena and physical laws by testing ideas. Research has shown that simulations can be, in fact, useful tools in teaching and learning physics and it is important to examine effective uses of these simulations. There are many uses of simulations in the classroom. They can be used by the teacher as a demonstration, by the student as pre-lab activity, for homework, as an aid to a lecture, and in some cases, in place of a physical lab.

A 2005 study by Finkelstein and coworkers (Finkelstein, et al., 2005) was conducted at the University of Colorado to examine the effectiveness of replacing traditional laboratory equipment with computer simulations in an introductory physics course studying direct currents. The goal of the study was to determine if simulations could effectively replace real equipment, if the students learn the same concepts as well as using real equipment, and whether students would develop lab skills to work with real equipment.

The researchers included ten sections of the physics course in their study. These sections were divided into two groups, one that worked with a computer simulation called CCK (Circuit Construction Kit) and a second that worked with real laboratory equipment called TRAD (traditional conditions). The CCK group consisted of 4 sections with a total of 99 students. The TRAD group consisted of 6 sections with a total of 132 students. A four question pre-lab activity was given to all students. Three of the questions were the same for all students, and the fourth varied based upon group. Both groups completed the same laboratory activity, but the CCK groups used the simulations, and the TRAD group used the real equipment. At the end of each lab section, the students were to complete a challenge worksheet and construct a circuit using real lab equipment. Additionally, the challenge was given to students taking a calculus based physics course (no lab, N=107). These students only received lecture on the topic. The data analyzed in this study included timing data – how long to students to build the circuit and complete the challenge sheet, lab challenge write-ups, and three final exam questions. The timing data revealed the CCK group as having the lowest average circuit construction challenge time with a mean ≈ 14 minutes. The TRAD and No Lab groups showed ≈ 17 minutes and ≈27 minutes respectively. The circuit challenge write-ups were evaluated on a 0 to 3 scale, 0 represented no knowledge of the topic, and 3 represented correct and complete knowledge. The experimental group (CCK) scored an average of 1.86, while the TRAD group scored an average of 1.64 indicating a statistically significant difference ($p < 0.03$). The No Lab group scored an average of 1.91, which showed a significant difference to the TRAD group in a two-tailed t-test ($p < 0.02$). The average of the three final exam questions yielded results of 0.593 for CCK group and 0.476 for the TRAD group shows a significant difference between the two groups ($p < 0.001$). Based upon the data, the researchers were able to claim that the simulations can effectively replace traditional laboratory equipment when used in the right conditions. However, it was noted that although this is effective, not all hands-on circuit labs should be replaced (Finkelstein, et al., 2005).

Through this study, the researchers were able to identify two important characteristics of computer-based simulations: increase student access to productive concepts and representations, and constrain the students in productive ways. The simulations allow the students to visualize the invisible (Finkelstein, et al., 2005). Other work has found that, through the use of simulation, students are able to produce conceptual models with "real world" applications (Otero, 2003).

Finkelstein et al. did raise some concerns with the use of simulations. These concerns are similar to those that arise when using any type of equipment. For example, systems shutting down or inadvertent operating behavior, can cause frustration for the user. While these concerns are legitimate, this study still exhibits the effectiveness in replacing a physical lab with a simulation.

It is claimed that "Simulations provide a bridge between students' prior knowledge and the learning of new physical concepts" (Jimoyiannis, 2001). Through simulations, students are able to isolate and manipulate factors as well as view different representations of information to help understand the physical concepts. Additionally, simulations allow students to investigate phenomena that are too complex or dangerous to create in the lab or classroom (Jimoyiannis, 2001).

These ideas were investigated in a study conducted by Jimoyiannis et al in 2000. This experiment focused on the use of computer simulations to change “alternative concepts” pertaining to basic kinematical concepts of instantaneous velocity and acceleration. In this study, 57 first year upper secondary students participated. Four tasks were given to the students as a pretest six months after the students received instruction on kinematics. For example, Task 1 asked students to interpret the figure and determine an answer about the objects’ velocities, accelerations, and types of motion. The students were required to answer each part of the question and justify their responses. Two weeks later, after students worked through the *Interactive Physics* simulation, they were given the same four tasks as a posttest. The data of this study shows the shift of student responses from inefficient answers to more effectual answers in higher frequencies for tasks 1 and 2. The shift in frequencies of inefficient to other answers or more effectual answers for tasks 3 and 4 was at a lower degree than for tasks 1 and 2 (Jimoyiannis, et al., 2000).

Observations of researchers during a study can often times bring light to aspects that may be difficult to measure. The researchers here noted the “enthusiasm and convenience with which students were engaged in simulations”. The ability of simulations to capture student interest allows for greater exploration with physical phenomena that may not otherwise be possible. Through simulations, students are able to check their current ideas and interact with those ideas virtually. This process could eventually cause the student to alter their original ideas and encourage conceptual change (Jimoyiannis, et al., 2000).

Jimoyiannis went on to conduct another study using computer simulations to examine a different area of mechanics. In a second study conducted in Ioannina, Greece, researchers focused on using computer simulations to help students' "alternative conceptions transformation", but this time, on velocity and acceleration in the earth's gravitational field (Jimoyiannis, 2001). This study looked into measuring the shift of conceptual development for upper secondary (high school) students. In this work, students from three public high schools with varied achievement levels were studied. The students used the simulation program *Interactive Physics* (www.interactivephysics.com) to complete tasks related to projectile motion. The experimental group (n=30) was given the opportunity to complete two 1-hour lessons dealing with velocity and acceleration, while the control group (n=60) received no extra instruction on the topic. Students in all groups were given a questionnaire that presented three tasks and were asked to give qualitative responses with justifications for their answers. Their answers were scored based upon the responses and justifications. For example, students could receive an "I" for an inefficient answer or an "E" for an effectual answer. To obtain the score of "E" students must both have the correct response and justification. Each task on the questionnaire required two responses: one response comparing the velocities of two falling objects and one comparing their accelerations (Jimoyiannis, 2001).

While much of the data provided was qualitative in nature, the researchers were able to provide evidence supporting the use of computer simulations based upon the decreased frequency of "alternative conceptions" responses within the experimental group. According to the researchers, it seems working with simulations helps students overcome cognitive restraints while improving their conceptions about trajectory motion (Jimoyiannis, 2001).

Both studies by Jimoyiannis et al. provide evidence that computer simulations can result in positive impacts on students' conceptions of kinematic motion. However, there are some concerns that have surfaced. In the first study by Jimoyiannis, all students participated in the computer simulations. There was no control group to compare the results to. In the second study, while it did have experimental and control groups, the experimental group received extra time on the topic when completing the simulation. Even though these concerns exist, the use of computer simulations in physics is still revealed to be a good resource for the science teacher.

In another study conducted at the University of Maryland (Steinberg, 2000), computer simulations were used to help students work through a tutorial on air resistance. The study compared interactive learning using computer simulations to interactive learning using non-computer-based activities. In the study, three classes participated and all three classes used tutorials. Two of the classes used the computer-based simulation with the tutorials, while the third used paper and pencil activities.

To compare the two types of instruction, all students took the Force Concept Inventory before and after instruction. Additionally, the students were given typical exam questions and the researcher and his teaching assistants made informal observations during the tutorial sessions. All classes in the study used the same book, had lectures three times every week, and one tutorial session a week. Classes A (n=79) and B (n=67) both received the computer-based air resistance simulation tutorial. Class C (n=83) was non-computer-based with the paper and pencil air resistance tutorial.

All classes received lecture and homework prior to taking the pretest. The tutorial session on air resistance took place during the same week for all three classes and came after traditional instruction and a pretest on air resistance. A midterm exam was given two weeks after the tutorial. On the exam, students were given a multi-part question to assess their understanding of air resistance in several different ways. Results of the exam question showed no significant difference amongst student performance whether administered with or without the computer simulation. While the study shows that the success of the students does not correspond to the use of the simulation, advantages of using simulations are suggested. For example, simulations allow users to explore and actively engage in discovering the concept being taught as opposed to mere observation (Steinberg, 2000).

The fact that Steinberg does not note a statistically significant difference could be due to the how the simulations were used. Each group in this study used interactive tutorials developed by the Physics Education Research Group at the university. Two versions of the tutorial were developed, one for each group, and both tutorials were designed to cover the same content and to be equally engaging. Since tutorials are already highly interactive and engaging, and virtual simulations are touted to be interactive and engaging, the effectiveness of the virtual lab could have been down played by the use of the tutorials. The researchers could have developed other activities for the students to complete using the computer simulations to determine if the simulations were as effective as other interactive engagement methods.

This research clearly seems to indicate that virtual simulations have a place in a traditional classroom. Seeing the benefits of using the simulations in different environments and across different topics brought about the idea of using the simulations to test student understanding of mechanics concepts. Can using virtual simulations increase my students' conceptual understanding of Newton's laws?

METHODS

This study was conducted during the 2013-2014 academic school year. The data collected was from all high school physics classes in my school, which consisted of a mix of eleventh and twelfth grade students. The school is rural public high school in Iberville Parish, Louisiana. Demographically, the classes are 68% Caucasian and 32% African American. Additionally, 47% of these students qualified for free or reduced lunch. As a whole, the school is considered to be a college preparatory school and boasts a graduation rate of 100%. Approximately 95% of these students are college bound. A total of 31 students were enrolled in the physics classes and 29 of those students are included in this study. A breakdown of these students is provided in Table 1.

Table 1: Entire sample broken down by gender and grade level.

Group	Total	Junior	Senior	Male	Female
Worksheet	11	2	9	6	5
Virtual Simulation	18	10	8	8	10

The juniors in this sample are enrolled in physics so they would be able to take dual enrollment or upper level science courses as seniors. These students were put on this science track as ninth graders because they have excelled in science on standardized tests.

The students enrolled in physics were divided into two classes. One class served as the control (worksheet) group (n=11) and the other class served as the experimental (virtual simulations) group (n=18). Both classes were taught in the same manner. The groups received the same lecture presentations, practice problems, homework assignments, and quizzes/tests. Some of the resource materials used for both classes was from the Hewitt (2009) Conceptual Physics textbook and teacher resources. The timeline that was followed for both groups was the same and was consistent for each topic. Each new topic took about two weeks to complete and typically began with a power-point lecture followed by practice problems.

The intervention occurred during the next phase of instruction. At the beginning of the second week of instruction on a topic, the students in both groups were given different in-class activities. The control group received paper-and-pencil based worksheets pertaining to the information being covered. The materials for the control group were a combination of teacher made worksheets and worksheets that go along with the textbook. An example of a control group activity can be found in Appendix A. The experimental group completed activities that required them to view and manipulate virtual simulations on their computers using PhET interactive simulations in place of the worksheets. The activities given to the experimental group are teacher made activities that are based on some of the teacher resource materials found on the PhET website (Appendix B). The different activities were given to both classes on the same day of instruction. The activities for both groups typically took one class period. All classes covered the same chapters in the same amount of time and both groups were held equally accountable by having an equal number of assignments and points throughout the study.

The purpose of this study was to determine the impact of virtual simulations on student comprehension of mechanics by testing their conceptual knowledge of kinematics and Newton's laws. Most students have limited knowledge of mechanics concepts in physics prior to completing the course. Since this population of physics students did not take a high school level physical science course, most of their prior knowledge is from a minimal amount of exposure to these ideas presented to the students in their sixth grade science class. Both classes were given a pre-test to test their knowledge of forces and motion concepts prior to the study. The same test was given at the end of the units involving force and motion as a post-test to measure learning gains.

The educational tool used to assess the student's knowledge of specific physics concepts was the Force Concept Inventory (FCI) (Halloun et. al., 1995). The FCI was designed to evaluate student comprehension of key concepts in Newtonian physics (Hestenes and Halloun, 1995). The FCI is composed of 30 forced-choice questions. It examines six conceptual dimensions of the Newtonian force concept: kinematics: Newton's First, Second, and Third Laws, the superposition principle, and types of forces. Each question offers only one correct Newtonian solution, with common-sense alternatives that are based upon students' misconceptions about that topic (Hestenes, 1991). The FCI is designed to evaluate conceptual understanding rather than mechanical problem solving, and therefore is useful not only at the college level, but at the high school level as well.

Three regular classroom tests on Newton's laws were administered to examine traditional measures of student achievement. Each test was composed of five true/false questions, eight multiple choice questions, two problem solving and one essay question where students were required to verbalize their ideas on the concepts being tested. These tests were administered during the third nine-weeks grading period. Each test was given at the end of the instruction for each chapter. Throughout the year, all students were required to learn the same material according to the state mandated grade level expectations for Physics.

DATA ANALYSIS/RESULTS

After administering the pre-test, the data were analyzed to determine if all students entered the study at the same knowledge level pertaining to mechanics concepts. The statistical analysis used to compare the data was a two-tailed t-test. The purpose of this test is to determine if there is a significant difference between the two groups of this study. For all comparisons throughout the study, a confidence level of 95% ($\alpha = 0.05$) was used. Furthermore, all errors expressed here represent the uncertainty in the means.

The mean scores for the pretest, shown in Figure 1, were 18% ± 2% for the control group, and 22% ± 2% for the experimental group. The analysis of the FCI pre-test data showed there was no statistically significant difference between the means of the two groups based on a p-value of 0.26. This value indicates that both groups initially share similar conceptual understanding of mechanics concepts.

The post-test means, also shown in Figure 1, were 36% ± 4% for the control group and 31% ± 4% for the experimental group. The analysis of the FCI post-test data showed that the experimental and control groups are considered to have similar conceptual knowledge post-instruction, whether they completed activities using virtual simulations or worksheets. This is indicated by a t-test result of $p=0.4$ (Figure 1).

An additional analysis of the data showed that the students learned regardless of whether they used a virtual simulation or not. Statistically, both groups displayed growth from pre-test to post-test based on t-tests indicating p=0.001 for the control group and p=0.02 for the experimental group (Figure 1). Because both groups showed growth, a t-test was done to compare the means of normalized gains between the two groups on the FCI.

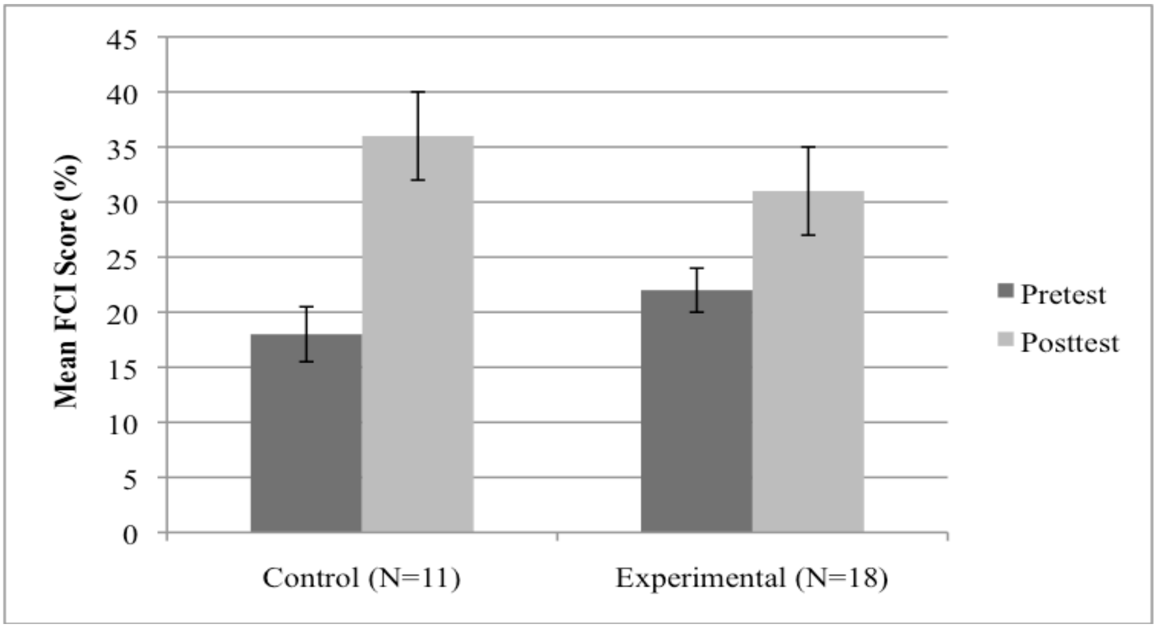

Figure 1: Mean FCI pre-test versus post-test scores, in percent, for both control and experimental groups.

Normalized gains are used to account for a wide range in student pretest scores by taking into account the achievement potential of students (Hake, 1998). Normalized gains also allow for students from different groups to be compared to national norms. The normalized gain, g, is calculated to measure the difference in pre-test to post-test scores divided by the maximum possible increase in score. The equation is as follows:

The mean scores for normalized gains in this study were 22% ± 4% for the control group and 13% ± 4 % for the experimental group. These gains are consistent with those seen nationally from teacher-centered instruction, which is consistent with the way in which my class was run. According to the research, traditional teaching yields gains ranging from 19% to 27% on the FCI (Hake, 1998). Again, this analysis of the normalized gain also showed no statistically significant difference between the groups with a p-value of p = 0.12, shown in Figure 2. From this data, it appears that the virtual simulations the students used did not have a significant impact on their understanding of mechanics concepts when compared to the group using the worksheets.

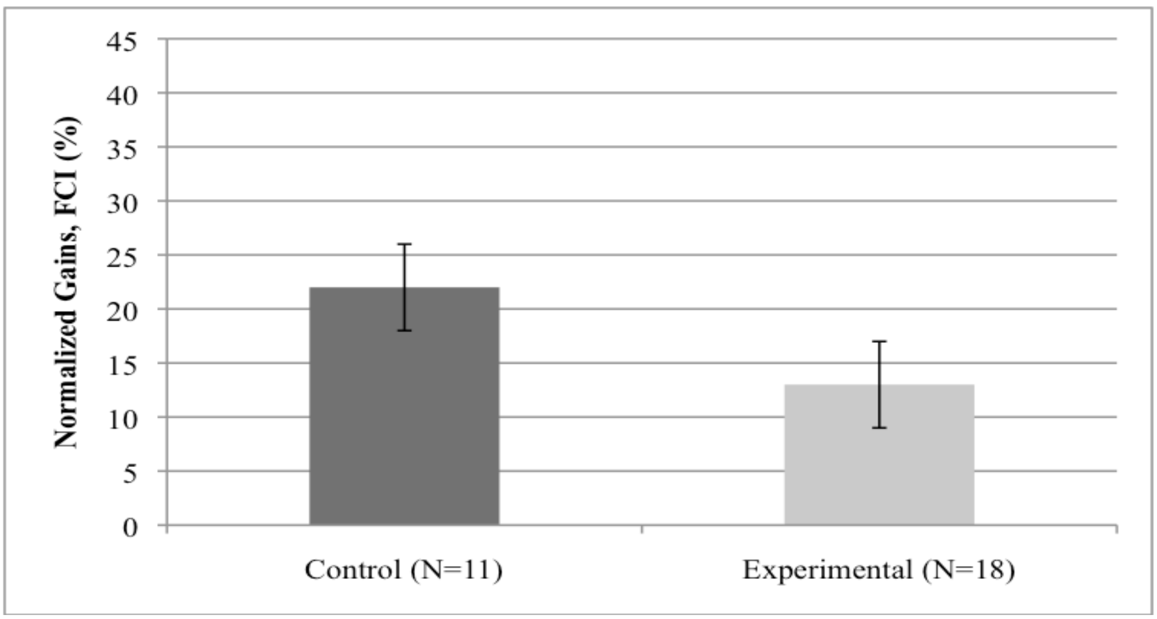

Figure 2: Mean normalized gains on FCI, in percent, for each group.

Next, a breakdown by categories represented on the FCI was analyzed to determine if any differences exist between the groups for each category. The categories examined were: kinematics, Newton's 1st Law, Newton's 2nd Law, Newton's 3rd Law, and kinds of forces. The values calculated from this analysis indicate that one group does not have greater prior understanding of physics concepts over the other group in any specific category. When analyzing the means, a t-test was done to compare the pre-test values, which can be found in Table 2. The result of this analysis is shown in Figure 3.

Table 2: Pre-test means and p-values of t-test by category represented on FCI, $p<0.05$ indicates a significant difference between groups.

Category	Pre-Test Means (Worksheet)	Pre-Test Means (Virtual Simulation)	Pre-Test p-values
Kinematics	22% ± 6%	23% ± 5%	0.86
Newton's 1st Law	30% ± 5%	27% ± 3%	0.66
Newton's 2nd Law	12% ± 7%	22% ± 5%	0.26
Newton's 3rd Law	7% ±4%	13% ± 6%	0.50
Kinds of Forces	14% ± 4%	20% ± 3%	0.24

When analyzing gains between the two groups by category, one category produced a statistical difference when comparing t-test outcomes, shown in Table 3. A p-value of less than 0.05 was calculated in the area that isolates questions based on 'Kinds of Forces'.

This difference may be attributed to the control group having more practice identifying forces than the experimental group. In the experimental group, the simulation did the force identification for them, rather than the students identifying the existing forces on their own. All other categories did not show a significant difference between the two groups based on p-values that were less

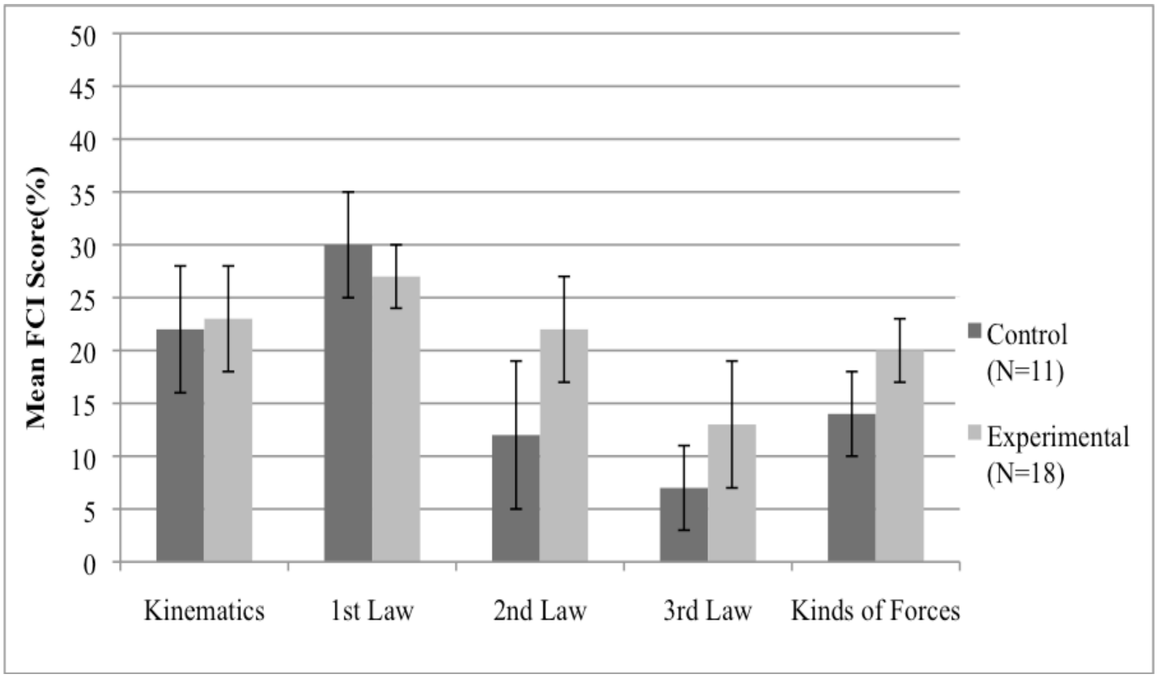

Figure 3: Mean pre-test scores per category on FCI, in percent, for both groups.

than the 95% confidence level (p>0.05) when comparing the normalized gains, shown in Table 3. This similarity could be due to the activities that were completed for each of these topics. These activities were likely similar, in terms of the types of questions and detail required by the students, for both groups. Students showed reasonable gains on questions pertaining to Newton's Third Law, but gains for kinematics and Newton's Second Law questions were low, as shown in Figure 4.

Finally, three regular classroom tests were analyzed to determine of the virtual simulations had an impact on short-term retention. Each test covered one of Newton's three laws of motion. Overall, the class averages on each test were higher for the experimental group than for the control group, shown in Figure 5.

Table 3: Normalized gain means and p-values of t-test presented by categories represented on the FCI, $p<0.05$ indicates a significant difference between groups. The one significant difference seen is in bold type.

Category	Normalized Gains (Control)	Normalized Gains (Experimental)	t-test p-values
Kinematics	6% ± 7%	7% ± 9%	0.90
Newton's1st Law	17% ± 9%	9% ± 5%	0.45
Newton's 2nd Law	5% ± 7%	-4% ± 9%	0.54
Newton's 3rd Law	29% ± 8%	28% ± 9%	0.92
Kinds of Forces	33% ± 5%	8% ± 7%	**0.02**

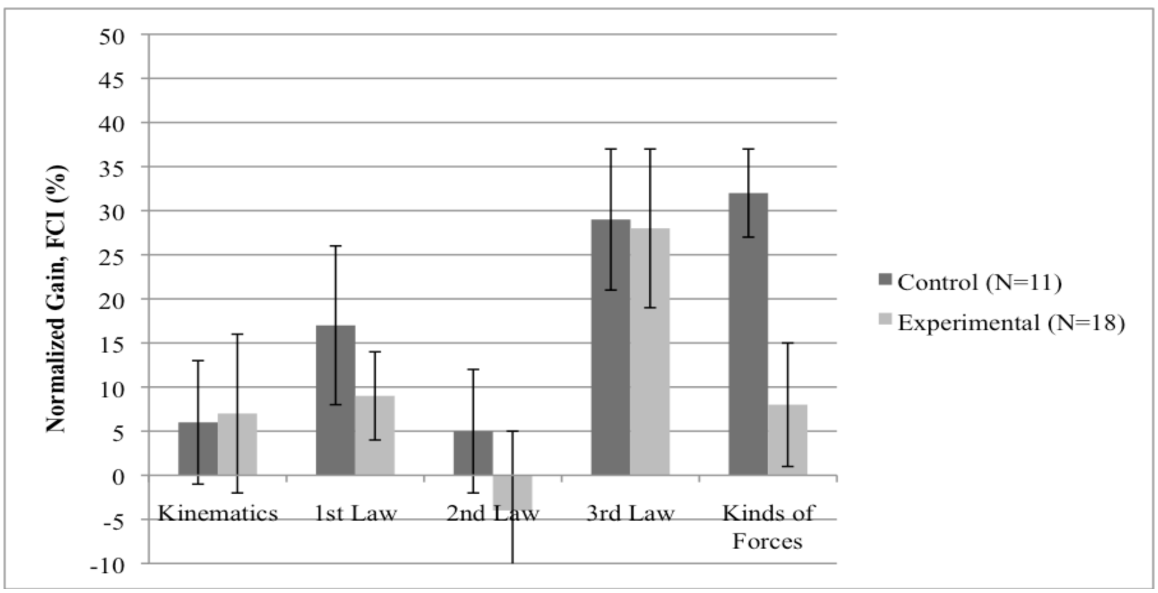

Figure 4: Mean normalized gains per category on FCI, in percent, for each group.

However, no significant differences were calculated when a t-test was conducted to compare the two groups. The p-values for these tests were as follows: Newton's First Law $p=0.19$, Newton's Second Law $p=0.43$, and Newton's Third Law $p=0.64$.

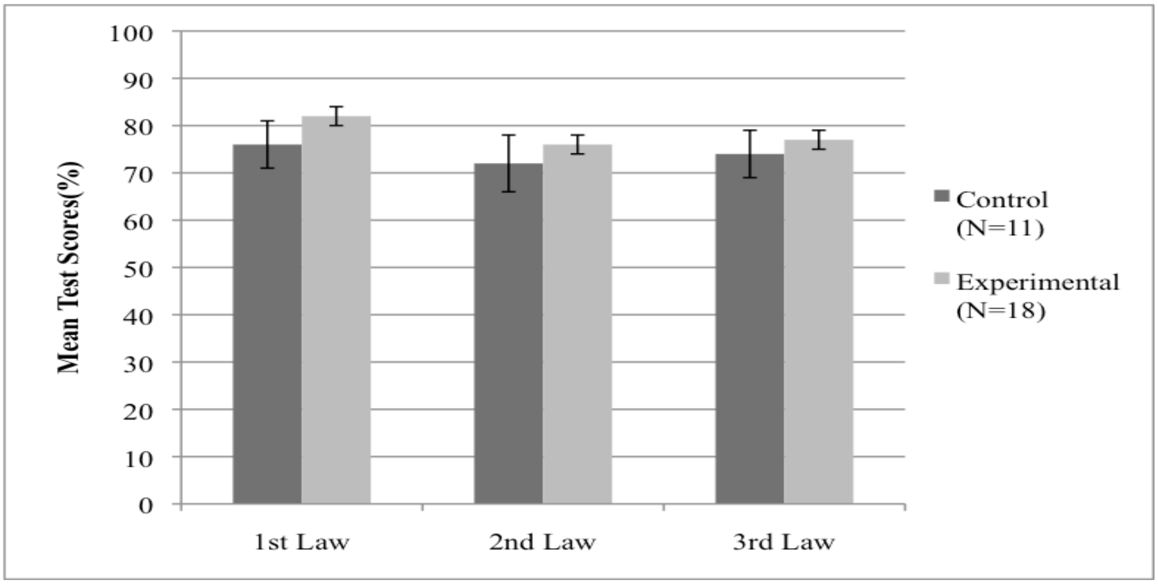

Figure 5: Mean scores, in percent, on chapter tests for each group.

The data from the chapter tests are consistent with all FCI data presented in this study. Based on the student scores on the chapter tests and their scores on the respective FCI categories, it appears the students have similar knowledge of each of Newton's laws. All the analyses indicate there is not a statistically significant difference between the experimental group and the control group.

SUMMARY AND CONCLUSION

The purpose of this research project was to determine the impact of virtual simulations on student understanding of mechanics. After analyzing the results of this study, it was determined that there was no difference in gains in knowledge of mechanics concepts between the control group and the experimental group. Although both groups learned, in my experience the virtual simulations did not create a measured impact on understanding over the traditional worksheets. However, other research has shown positive influences on student learning and similar outcomes were expected for this study.

Then again, my study is different from previous research conducted. Prior research has shown improvements when using virtual simulations for a single topic where no standardized measuring tool was used for comparison. In my study, multiple topics were covered, and a validated research instrument, the FCI, was used to measure student understanding. It was additionally noted that the amount of time spent using virtual simulations was different for each prior study and the study I conducted. The time my students spent on the simulation occupied approximately one class period. Since it has previously been shown that traditional instruction typically yields low learning gains, it is reasonable to consider that the learning may have taken place in this one class period and the students may have learned from these simulations.

To examine the data in more detail, the FCI scores were broken down by category and analyzed to determine if the experimental group out-performed the control group at the categorical level. An interesting observation from this analysis was that the control group had significantly higher normalized gains for the ‘kinds of forces’ category. This could be due to the fact that the control had more practice drawing force diagrams due to the nature of the worksheet for that lesson, while students in the experimental group were just required to view these diagrams or reiterate what was on the screen. However, there is no specific evidence to support a reason for this statistical difference. All other categorical analyses resulted in no significant difference between the two groups.

Because all students were given the same chapter tests, three tests on Newton’s laws were analyzed as well. Again, there was no significant difference between the two groups for all three tests. This could be attributed to the possibility that the activities the students performed may not have been aligned to what they were tested on. However, the gains measured on the FCI for each of Newton’s laws are similar for both groups, as well as their scores on the chapter tests. One aspect of this study that may have had an effect on these results was a limited sample size. The control group consisted of only 11 students, while the experimental group had 18 students.

Although statistically significant gains were not seen between the control and experimental groups, it should be noted that the students in the experimental group were often more interested in the material when it was presented through the virtual simulations. From my observations during the activities, the students in the control group often were more concerned with having a finished product than the quality of their answers. These students did not appear to engage in the material and only wanted to complete the worksheets and move on.

Meanwhile, the students in the experimental group appeared to take their assignments more seriously. They would often get frustrated when trying to manipulate the simulations, which was probably due to unclear instructions. Once they figured out how the simulations worked, they stayed engaged during their tasks. I also noticed that even after they finished the assigned task they would continue to explore the simulations, whereas the worksheet group would begin to talk off topic. This tinkering seemed to happen more often with the males than the females. At times, the males would make the simulations into a competition. For example, on the projectile motion simulation they would compete to see who could make an object travel the farthest horizontal distance. The class that used the virtual simulations had more female students than male students; and while gender data was examined for both classes, it was not analyzed due to the very small sample size. It would be interesting to see if this tinkering might somehow affect their understanding, and if gender plays a role as well. The overall effort put forth from the experimental group also appeared to be greater than that of the control group. Students in the control group seemingly "gave up" on questions more frequently than those in the experimental group did. The students using the simulations would occasionally check their work with the simulation.

Even though this study did not produce significant differences between the control and experimental group, I still plan to use the virtual simulations for student activities in my class. The issue of unclear instructions is something that would need to be addressed going forward. To do this, I would need to spend more time developing the activities to make sure they are guiding the students through the learning process for the concept being taught. Another issue to be addressed is how the students viewed the simulations. Did they view them as a game or reality? To gain some understanding of this, I would compare how students work through a simulation to how they work through a physical lab on the same topic. Having an understanding of their views on the simulation could help to identify ways to implement the simulations going forward. Additionally, I believe implementing activities that encourage student tinkering would help me to get a better perception of how the simulations could improve their understanding. Having activities that are less verification type and more discovery type could possibly help to increase understanding. Also, instead of using either the worksheets or the virtual simulations, it would be interesting to see if students benefit from using both.

Another future implication of this study would be for use as a pre-laboratory activity. Research conducted by Zacharias Zacharia and Roger Anderson provided evidence that using computer simulations prior to inquiry-based lab experiments can improve students' capacity to make adequate predictions and explanations of the phenomena in the experiment. The use of the simulations prior to lab activities also produced greater conceptual change in the physics content being studied (Zacharia and Anderson, 2003). This is important to me because in the event that laboratory equipment is ever available for my classroom, I have yet another use of the virtual simulations that could help to improve my students' conceptual understanding. Through my research and my experience with using virtual simulations in my classroom, I believe these tools can be beneficial to student learning in high school physics.

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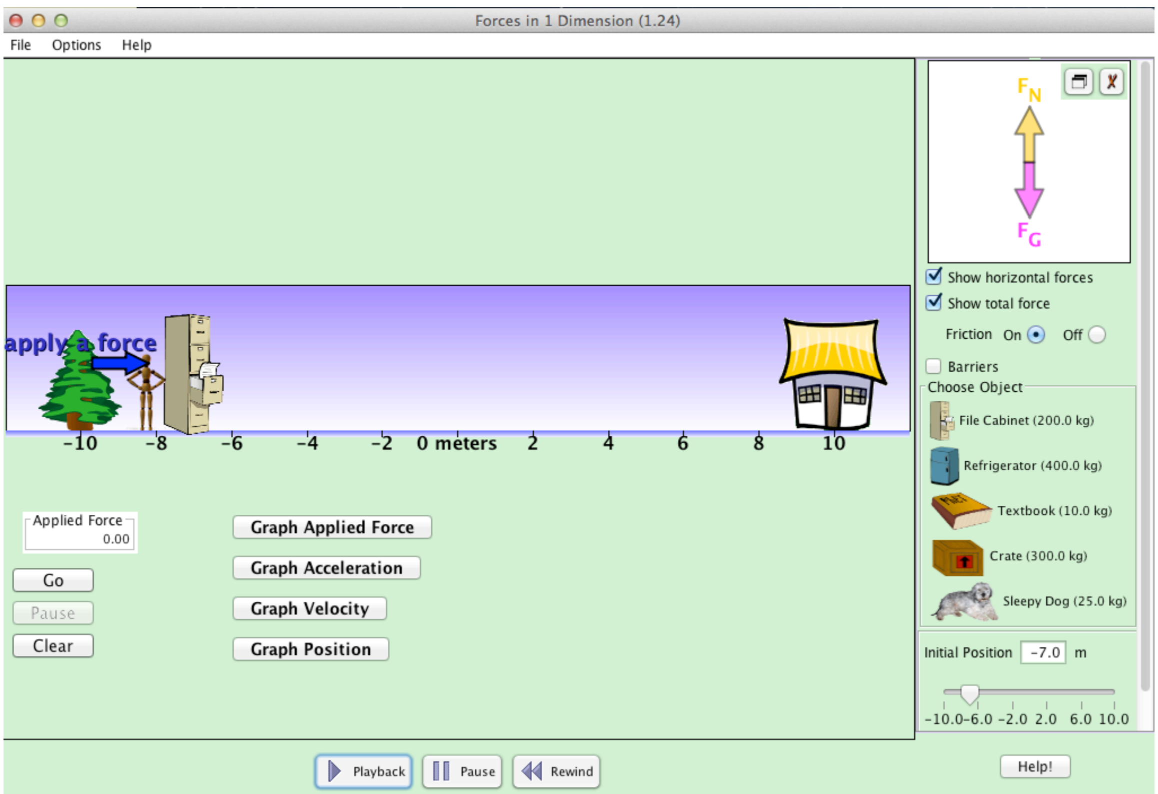
APPENDIX A: SAMPLE EXPERIMENTAL GROUP ACTIVITY

Newton's Second Law PhET Lab

Name____________________ Date___________

In your own words, explain Newton's Second Law:_________________________
____
____

In this activity, you are going to explore the relationship between force, mass, and acceleration. On your computer, go to phet.colorado.edu/en/simulations/force-1d. Click run now. Your screen should look like the screenshot below.



You are now ready to begin your virtual lab!

Explore

- Take a few minutes to get acquainted with the simulation.
- Use this time to figure out how to manipulate the variables.
    - How can you change the mass?
    - How can you change the force? Can you determine net force?

- How can you figure out the acceleration of the object?
- Record any information you have discovered in the space below. It may help you later on!

Experiment 1: Force and Acceleration - Frictionless

Make a prediction: How will increasing the force affect the acceleration of an object?
____
____
____

Exp 1 – Part 1:
- Turn off friction
- Pick an object from the list on the right.
- Keep the object the same throughout this activity
- Push the object with different magnitudes of force.
- Record mass, force, and acceleration in the chart below.

Mass of object (kg)	Net (total) Force (N)	Acceleration (m/s^2)
1.		
2.		
3.		
4.		
5.		

Now calculate the force divided by the mass for each trial above. Record your work and your answers below.

1. **2.** **3.**

4. **5.**

Compare these values to the magnitudes of acceleration from the simulation. What do you notice?

Pick two of your trials from above and list all forces acting on the object in each.

1. 2.

Draw a free body diagram for each situation.

1. 2.

Exp. 1 – Part 2:

- Now keep your force constant and pick different objects from the list.
- Fill in the chart below with your values for force, mass, and acceleration.

Mass (kg)	Net Force (N)	Acceleration (m/s^2)

How does changing the mass affect the acceleration?

Experiment 2: Forces and Acceleration With Friction

Prediction: How will adding friction change your results from experiment 1? ____
____

- Turn friction off.
- Repeat the steps from part 1.
- Start with the same object from part 1 of experiment 1.

Mass of object (kg)	Net Force (N)	Acceleration (m/s^2)
1.		
2.		
3.		
4.		
5.		

Calculate force divided by mass for each trial. Show your work and answers below.

1. 2. 3.

4. 5.

List all forces acting on the object for two of your trials above. Then draw a free body diagram of each.

1. 2.

How did your results from experiment 1 compare to your results from experiment 2?

___

___

___

Were you able to discover a relationship between force, mass, and acceleration? If so, explain that relationship.

___

___

___

Apply:

Certain cells in the table below were left blank. Predict what you think the answers should be and then using the simulation to determine if your predictions were correct.

Mass (kg)	Net Force (N)	Acceleration (m/s^2)	Predicted Answer	Simulation Answer
5	100	?		
?	500	10		
10	?	5		
100	?	20		
?	1500	10		
50	2500	?		

Based on this activity, does your idea about the relationship of force, mass, and acceleration change? Why or why not?

___

___

___

___

Draw:

Use the simulation to create the following scenarios. Draw the free-body diagrams associated with each scenario in the space provided. Make sure you label all forces!

1. The 10 kg book is at rest.

2. An applied force of 600 N to the right pushes the 300 kg crate across a frictionless surface.

3. A 900 N force pushes the 200 kg filing cabinet to the right on a rigid surface.

4. A 500 N force is used to accelerate a 25 kg dog across a surface. Consider friction.

APPENDIX B: SAMPLE CONTROL GROUP ACTIVITY

Name ___________________________ Class _________________ Date ___________

Chapter 6 Newton's Second Law of Motion—Force and Acceleration

Exercises

6.1 Force Causes Acceleration (page 87)

1. When a hockey puck is struck with a hockey stick, a(n) _______________ acts on the puck and the puck _______________.
2. Circle the letter of the type of force that causes acceleration.
   a. balanced b. negligible
   c. zero d. unbalanced
3. The combination of forces acting on an object is known as the __________ force.
4. The acceleration of an object is directly proportional to the net force acting on it. This means that, as the net force acting on the object increases, the acceleration of the object _______________.
5. Circle the letter of each statement about force and acceleration that is true.
   a. Balanced forces cause constant acceleration.
   b. The forces acting on an object at rest are unbalanced.
   c. A net force acting on an object causes acceleration.
   d. Force is not required for an object to accelerate.
6. Two shopping carts of equal mass are pushed by two different people. One cart accelerates three times as fast as the other cart. Describe the forces acting on each cart.

   ____

   ____

6.2 Mass Resists Acceleration (page 87)

7. For a constant force, how does an increase in an object's mass affect its acceleration?

   ____

8. What does it mean for two quantities to be inversely proportional to one another?

   ____

9. Circle the letter showing how mass and acceleration are related.
   a. acceleration ~ mass b. acceleration ~ 1/mass
   c. acceleration ~ mass^2 d. acceleration ~ $\frac{1}{2}$ mass

6.3 Newton's Second Law (pages 88–89)

10. Circle the letter of each quantity related by Newton's second law.
    a. mass b. force
    c. time d. acceleration

11. Circle the letter of each statement related to Newton's second law that is true.

a. Acceleration is directly proportional to the net force.

b. The direction of acceleration is the same as the net force.

c. Acceleration is inversely proportional to mass.

d. Net force and mass are always equal.

12. When using the equation for Newton's second law, if force is measured in newtons, then the unit for acceleration is __________ and the unit for mass is __________.

13. Is the following sentence true or false? The acceleration of an object is equal to the net force acting on it divided by the object's mass. __________

14. A 100-N force is used to accelerate a large push cart across the floor. Circle the letter of the force required to accelerate the push cart twice as fast.

a. 50 N

b. 100 N

c. 150 N

d. 200 N

15. An object accelerates when a net force is applied to it. Circle the letter describing the conditions that would double the object's acceleration.

a. doubling the mass

b. halving the force

c. doubling the mass and halving the force

d. halving the mass

16. During a lab experiment, a net force is applied to an object and the object accelerates. The mass of the object is then doubled, and the net force applied to it also doubles. Describe the object's acceleration.

____

____

17. Circle the letter of the equation that describes Newton's second law of motion.

a. $a = \frac{F}{m}$

b. $F = ma^2$

c. $F = \frac{a}{m}$

d. $F = \frac{1}{2}(am)^2$

6.4 Friction (page 90–91)

18. Describe what causes friction between two solid surfaces.

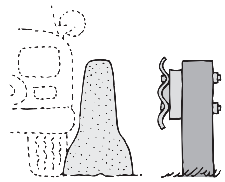
____

____

____

19. Is the following sentence true or false? Friction does not depend on the types of materials in contact with each other. __________

20. Is the following sentence true or false? Friction depends on how much the materials in contact are pushed together. __________



21. The figure above shows where an out-of-control car might strike a concrete road divider. In terms of friction, explain why the concrete barrier is superior to the steel barrier in the figure.

____

____

22. Substances that are liquids or gases are also called ____________.

23. Is the following sentence true or false? When friction is present, an object can move with constant velocity even when an outside force is applied.

____

24. A ____________ is a diagram in which all of the forces acting on an object are shown.

6.5 Applying Force—Pressure (pages 91–92)

25. Circle the letter of each quantity related to pressure.

a. time
b. force
c. weight
d. area

26. Circle the letter that best describes pressure.

a. the applied force that acts on an object
b. force per unit of area
c. the area to which a force is applied
d. force times surface area

27. Imagine standing on a bathroom scale on two feet and then one foot. Describe the force and pressure exerted in each case.

____

____

28. As the area a force acts on increases, the force exerted on each unit of area ____________.

29. What is the equation for pressure when the force is perpendicular to the surface area?

____

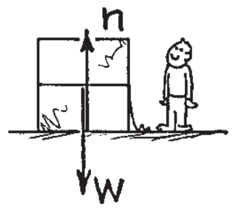
30. Circle the letter that describes the unit of pressure known as a pascal.

a. newtons × area
b. newton · meter
c. newtons per square meter
d. square meters per second

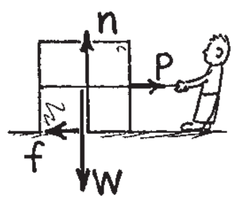
Name ______________________ Class ______________ Date ______________

Concept-Development Practice Page **6-1**

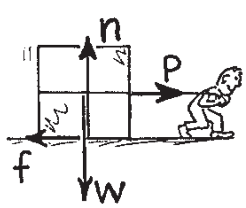
Friction



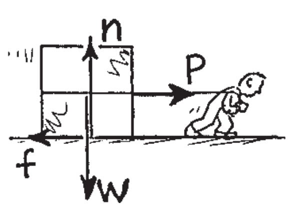
1. A crate filled with delicious junk food rests on a horizontal floor. Only gravity and the support force of the floor act on it, as shown by the vectors for weight **W** and normal force **n**.
   a. The net force on the crate is (zero) (greater than zero).
   b. Evidence for this is ______________________.



2. A slight pull **P** is exerted on the crate, not enough to move it.
   a. The force of friction **f** acting on the crate is (less than) (equal to) (greater than) **P**.
   b. The net force on the crate is (zero) (greater than zero).



3. Pull **P** is increased until the crate begins to move. It is pulled so that it moves with constant velocity across the floor.
   a. Friction **f** is (less than) (equal to) (greater than) **P**.
   b. Constant velocity means acceleration is (zero) (greater than zero).
   c. The net force on the crate is (less than) (equal to) (greater than) zero.



4. Pull **P** is further increased and is now greater than friction **f**.
   a. The net force on the crate is (less than) (equal to) (greater than) zero.
   b. The net force acts toward the right, so acceleration acts toward the (left) (right).

5. If the pulling force **P** is 150 N and the crate doesn't move, what is the magnitude of **f**? __________
6. If the pulling force **P** is 200 N and the crate doesn't move, what is the magnitude of **f**? __________
7. If the force of sliding friction is 250 N, what force is necessary to keep the crate sliding at constant velocity? __________
8. If the mass of the crate is 50 kg and sliding friction is 250 N, what is the acceleration of the crate when the pulling force is 250 N? __________ 300 N? __________ 500 N? __________

CONCEPTUAL PHYSICS

Name ______________________ Class ______________ Date ______________

Concept-Development Practice Page 6-2

Force and Acceleration

1. Skelly the skater, total mass 25 kg, is propelled by rocket power.

   a. Complete Table I (neglect resistance)

   b. Complete Table II for a constant 50-N resistance.

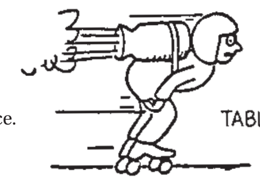


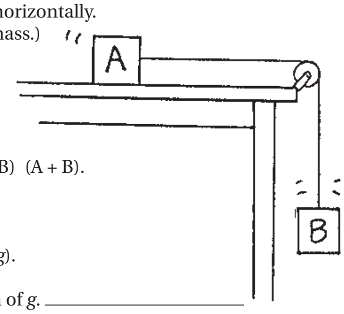
TABLE I

FORCE	ACCELERATION
100 N	
200 N	
	10 m/s²

TABLE II

FORCE	ACCELERATION
50 N	0 m/s²
100 N	
200 N	

2. Block A on a horizontal friction-free table is accelerated by a force from a string attached to Block B. B falls vertically and drags A horizontally. Both blocks have the same mass *m*. (Neglect the string's mass.)



   Circle the correct answers.

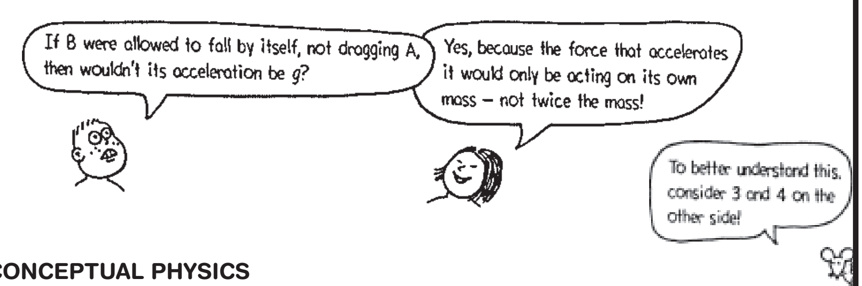
   a. The *mass* of the system (A + B) is (m) ($2m$).

   b. The *force* that accelerates (A + B) is the weight of (A) (B) (A + B).

   c. The weight of B is ($mg/2$) (mg) ($2mg$).

   d. Acceleration of (A + B) is (less than g) (g) (more than g).

   e. Use $a =$ to show the acceleration of (A + B) as a fraction of g. ______________



Draw: Free-Body Diagrams

Construct a free body diagram for the following situations. Be sure to label all forces!

1. A 5 kg book at rest on a table.

2. A box being pushed to the right across the room at a constant velocity.

3. A horizontal force is exerted to accelerate a desk across a rough surface.

4. A hockey puck glides across the ice.

5. A ball is falling and has reached terminal velocity.

APPENDIX C: INSTITUTIONAL REVIEW BOARD APPROVAL

Application for Exemption from Institutional Oversight

LSU
Institutional Review Board
Dr. Robert Mathews, Chair
131 David Boyd Hall
Baton Rouge, LA 70803
P: 225.578.8692
F: 225.578.5983
irb@lsu.edu
lsu.edu/irb

Unless qualified as meeting the specific criteria for exemption from Institutional Review Board (IRB) oversight, ALL LSU research/ projects using living humans as subjects, or samples, or data obtained from humans, directly or indirectly, with or without their consent, must be approved or exempted in advance by the LSU IRB. This Form helps the PI determine if a project may be exempted, and is used to request an exemption.

-- Applicant, Please fill out the application in its entirety and include the completed application as well as parts A-F, listed below, when submitting to the IRB. Once the application is completed, please the completed application to the IRB Office or to a member of the Human Subjects Screening Committee. Members of this committee can be found at http://research.lsu.edu/CompliancePoliciesProcedures/InstitutionalReviewBoard%28IRB%29/item24737.html

-- A Complete Application Includes All of the Following:
- **(A)** A copy of this completed form and a copy of parts B thru F.
- **(B)** A brief project description (adequate to evaluate risks to subjects and to explain your responses to Parts 1&2)
- **(C)** Copies of all instruments to be used.
  *If this proposal is part of a grant proposal, include a copy of the proposal and all recruitment material.
- **(D)** The consent form that you will use in the study (see part 3 for more information.)
- **(E)** Certificate of Completion of Human Subjects Protection Training for all personnel involved in the project, including students who are involved with testing or handling data, unless already on file with the IRB. Training link: (http://phrp.nihtraining.com/users/login.php)
- **(F)** IRB Security of Data Agreement: (http://research.lsu.edu/files/item26774.pdf)

1) Principal Investigator: Ann Couch **Rank:** Graduate Student

Dept: Natural Science **Ph:** (225) 776-4428 **E-mail:** anncouch@ipsb.net

2) Co Investigator(s): please include department, rank, phone and e-mail for each
*If student, please identify and name supervising professor in this space

Dr. Dana A. Browne, Professor, Dept. of Physics and Astronomy, 578-6843, phowne@lsu.edu

IRB# E8348 LSU Proposal #
✓ Complete Application
✓ Human Subjects Training
✓ IRB Security of Data Agreement

3) Project Title: The Effect of Virtual Simulation Laboratory Actities in High School Physics

Study Exempted By:
Dr. Robert C. Mathews, Chairman
Institutional Review Board
Louisiana State University
203 B-1 David Boyd Hall
225-578-8692 | www.lsu.edu/irb
Exemption Expires: 7/14/2016

4) Proposal? (yes or no) NO **If Yes, LSU Proposal Number**

Also, if YES, either ○ **This application completely matches the scope of work in the grant**
OR ○ **More IRB Applications will be filed later**

5) Subject pool (e.g. Psychology students) High School Students

*Circle any **"vulnerable populations" to be used:** (children <18; the mentally impaired, pregnant women, the ages, other). Projects with incarcerated persons cannot be exempted.

6) PI Signature Ann Couch **Date** 07/03/2013 (no per signatures)

**** I certify my responses are accurate and complete.** If the project scope or design is later changes, I will resubmit for review. I will obtain written approval from the Authorized Representative of all non-LSU institutions in which the study is conducted. I also understand that it is my responsibility to maintain copies of all consent forms at LSU for three years after completion of the study. If I leave LSU before that time the consent forms should be preserved in the Departmental Office.

Screening Committee Action: Exempted ✓ Not Exempted ____ Category/Paragraph 1

Signed Consent Waived?: Yes No

Reviewer Mathews **Signature** Robt C Mathews **Date** 7/15/13

VITA

Ann S. Couch was born in Baton Rouge, Louisiana, in November 1984. She attended elementary, middle, and high school in Plaquemine, Louisiana. She graduated from St. John High School in May 2002. In August 2002, she entered Louisiana State University Agricultural and Mechanical College where she earned a Bachelor's of Science in Kinesiology in August 2006. She entered Louisiana State University Graduate School in June 2012 and is a candidate for a Master of Natural Science. She is currently a high school Physics, Physical Science, and Biology teacher in Iberville Parish and teaches at the Math, Science, and Arts Academy – West Campus.