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Are Virtual Labs as Effective as Hands-on Labs for Undergraduate Physics? A Comparative Study at Two Major Universities

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Abstract Most physics professors would agree that the lab experiences students have in introductory physics are central to the learning of the concepts in the course. It is also true that these physics labs require time and money for upkeep, not to mention the hours spent setting up and taking down labs. Virtual physics lab experiences can provide an alternative or supplement to these traditional hands-on labs. However, physics professors may be very hesitant to give up the hands-on labs, which have been such a central part of their courses, for a more cost and time-saving virtual alternative. Thus, it is important to investigate how the learning from these virtual experiences compares to that acquired through a hands-on experience. This study evaluated a comprehensive set of virtual labs for introductory level college physics courses and compared them to a hands-on physics lab experience. Each of the virtual labs contains everything a student needs to conduct a physics laboratory experiment, including: objectives, background theory, 3D simulation, brief video, data collection tools, pre- and postlab questions, and postlab quiz. This research was conducted with 224 students from two large universities and investigated the learning that occurred with students using the virtual labs either in a lab setting or as a supplement to hands-on labs versus a control group of students using the traditional hands-on labs only. Findings from both university settings showed the virtual labs to be as effective as the traditional hands-on physics labs.

Keywords Physics · Virtual labs · Physics labs · Comparative study

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Introduction

In any given year, an estimated 400,000 college students are enrolled in introductory physics courses. For these students, meaningful laboratory experiences are necessary to introduce, demonstrate, and reinforce physics concepts. Traditionally, physics laboratory courses have been taught as separate courses under junior faculty and/or graduate students in labs equipped with various levels of instrumentation. As budget cuts become more prevalent, it has become increasingly difficult, especially for small colleges, to afford the expense of upgrading lab equipment and maintaining adequate teaching staff. Unfortunately, these shortages have led to less than ideal experiences for students. Additionally, in cases where students miss labs for various reasons, professors find it difficult to set up the labs again for makeup purposes. With the increased number of online courses being offered, there also exists a need for the implementation of online or virtual labs as supplements or replacements for the traditional high school and college labs (Bhargava et al. 2006). Well-developed and pedagogically sound virtual laboratory experiences can serve to supplement or replace existing hands-on lab experiences, reducing the need for equipment and lab space and offering a suitable alternative to students and professors.

Students have come to expect technology in educational settings, and research has shown that technology can be used as a thinking tool to engage students and foster meaningful learning (Jonassen et al. 1999). Many professors are on a quest to determine what materials or course elements are most effective to promote learning. With physics being a course that is particularly difficult for college-level students, this quest is very important. Meltzer and Thornton (2012) compiled a list of resources for active-learning instruction in physics. Their resource letter provides a guide to the literature on research-based instruction in physics, and they include a section titled "Impact of Technology" in which they outline several research studies dealing with technology tools for physics. These authors point out that instruction in physics made a rapid advance with the introduction of the microcomputer for real-time data acquisition, graphing, and analysis and that computers enabled rapid feedback in the instructional laboratory to a degree not previously possible. Thornton (2008) also points out that an activity-based, research-based environment supporting peer learning is the best environment for student learning in physics and that this type of environment, as well as the use of computer tools such as simulations that can be manipulated by students, will support real-time data logging and result in conceptual learning.

Many examples of computer simulations for introductory physics can be found in the literature (Hansson and Bug 1995; Wieman and Perkins 2005; Bhargava et al. 2006; Pyatt and Sims 2007; Sokoloff et al. 2007; Taghavi and Colen 2009). In most of these cases, computerized labs were shown to increase understanding and provide many benefits over their hands-on counterparts. Even so, some drawbacks were noted. For example, simulations may not yet be widely accepted by accrediting agencies as alternatives for hands-on labs (Pyatt and Sims 2007), and in some cases, students may prefer to use physical equipment (Bhargava et al. 2006). However, for the most part, the evidence supports the belief that virtual simulations are a viable replacement or supplement to hands-on labs.

Several of the studies cited above show that students have learning gains with the use of virtual labs. The Swarthmore College Interactive Physics (IP) is an early example of a computer simulation used along with the hands-on laboratory component (Hansson and Bug 1995). In that study, students performed an experiment and then used the IP to simulate the setup of the same experiment. The professors using this system found that the combination of real and simulated lab tools along with real data being recorded in computer-aided form resulted in sound understanding of the physical systems. Real-time physics (RTP) (Sokoloff et al. 2007) is an example of a computer-based tool that enables students to collect, display, and analyze data in real time while acquiring traditional lab skills. This curriculum and the companion computer tools were developed using solid design principles based on the best practices for physics education (Laws 1991, 2004). These labs were adopted by over 58 colleges and universities. The research team (Sokoloff et al. 2007) also developed the force and motion conceptual evaluation (FMCE) test and used it to test the RTP modules showing that students demonstrated dramatic conceptual learning gains after using the modules. Taghavi and Colen (2009) sought to compare the effectiveness of computer simulated lab instruction versus traditional labs. They determined that both groups gained knowledge of the topic, but the group using the simulations scored significantly higher than the traditional hands-on lab group.

Other studies focused on additional benefits of virtual labs. Bhargava et al. (2006) tested the effectiveness of web-based labs and noted that virtual labs reduced equipment needs, were available at any time from any place, offered more information to students, and offered students the opportunity to work at their own pace while exploring difficult or interesting sections. Pyatt and Sims (2007) found evidence to suggest that the hands-on lab has lost instructional value, while emerging technologies such as simulations can be used as viable replacements. These researchers explored both high school and college-level lab experiences and also found that simulated labs had many benefits over the hands-on equivalents, which included: they were perceived to be more open-ended, easier to use, and easier to generate usable data; and they took less time than hands-on labs. Wieman and Perkins (2005) and their team developed and tested about 45 physics simulations in various forms for use in lecture, as part of homework problems, and as lab replacements or enhancements. These researchers pointed out that the use of a real-life demonstration or lab often includes an enormous amount of peripheral information, which can be avoided in a carefully designed computer simulation. The use of a simulation can greatly reduce the cognitive load for the student who is trying to determine what is important in the given experiment. These research studies show that simulated labs can serve as a legitimate alternative and provide many advantages over the hands-on laboratory experience.

The *Virtual Physics Lab* used in this study was developed using a four-stage process. During the first stage, physics experts provided input into the design of the labs and determined what content should be covered in each lab. During the second stage, physics experts worked with software and lesson designers to develop the labs. During the third stage, another group of physics experts, external to the project, reviewed the labs using the heuristic approach to evaluate user interfaces and the lab content and pedagogical approach. During the final stage, students enrolled in introductory college-level physics reviewed the labs using the heuristic approach to evaluate the user interfaces, and these same students were used to test student learning. The assessment of student learning discussed in this article was completed at Auburn and Penn State Universities. During the first phase of testing, four labs were tested with 68 students at Auburn University enrolled in four different Physics I lab sections. During the second phase of testing, ten labs were tested with 156 students from Penn State University enrolled in sixteen lab sections.

In previous research, it has been shown that simulated labs can impact learning in positive ways and provide many other benefits. Many of the computerized resources discussed above utilize very basic functionality and basic graphical displays. The *Virtual Physics Lab* is a next generation computerized resource that seeks to incorporate research-based active-learning characteristics as described in Meltzer and Thornton (2012) and also utilizes the most recent technologies (i.e., videos with real people, 3D interactive game-like simulations) making the experiments more "real world" and engaging for students. The labs were developed to provide a variety of problem-solving activities that can be completed during class time. Students can work alone or in small groups to complete the labs and receive rapid feedback from the computer simulation. The simulations require active engagement and provide the material in context. Conceptual thinking is emphasized, and students have the ability to complete the experiments over and over to increase understanding. This study seeks to further illustrate the point that when virtual labs are developed properly to contain all necessary components, they can be just as effective in producing learning as hands-on labs. The authors wish to address the need for virtual labs while highlighting the facts that virtual labs are shown to produce positive learning outcomes for many students in this study.

The research questions that guided the study are

- Do students using the *Virtual Physics Lab* software as a replacement for traditional hands-on perform as well on content-based evaluations as students who complete the traditional, hands-on laboratory?
- Do students using the *Virtual Physics Lab* software as a supplement to traditional hands-on perform as well or better on content-based evaluations as students who complete the traditional, hands-on laboratory?

Methods

The Intervention: *Virtual Physics Lab*™

Through a Small Business Innovation Research (SBIR) contract funded by the US Department of Education, Polyhedron Learning Media, Inc. created the *Virtual Physics Lab*™, a set of online labs suitable for college-level physics. This software incorporates the strategies of the "Five E Cycle" of engagement, exploration, explanation, elaboration, and evaluation (Bybee 2003). In this sequence, students are motivated by a question of interest, such as might be presented in a physics laboratory experiment, and then apply process skills to describe findings and apply them in developing deeper understanding. The labs were developed following a planned sequence that focused on content, technology integration, and formative assessment. Throughout the development process, formative assessment for usability, feasibility, and content was completed using a heuristic approach. Review criteria were based on project team questions and procedures and criteria from usability testing of computer interfaces (Nielsen and Mack 1994; Albion 1999; Nielsen 2010; Hvannberg et al. 2007). The feedback led to improvements in final versions of the labs.

Each lab includes general background information, theory, objectives, prelab questions, a list of equipment needed to conduct the experiment hands-on, brief video clips demonstrating an overview of the lab, postlab questions, and a postlab quiz. The primary components of the labs are the virtual laboratory experiments, featuring interactive, real-time 3D simulations of laboratory equipment along with data collection, analysis, graphing, and reporting tools that will allow users to perform all phases of the experiment online using simulated equipment. Screen captures below illustrate some one specific lab within the *Virtual Physics Lab*.

The screen shot in Fig. 1 shows how *Lab 5—Uniformly Accelerated Motion on the Air Table* simulates the motion of a puck traveling on an air table that approximates a frictionless surface. This figure illustrates the data collection screen where the table can be tilted to form an inclined plane to study the one-dimensional motion of a uniformly accelerated object. On this screen to the left of the

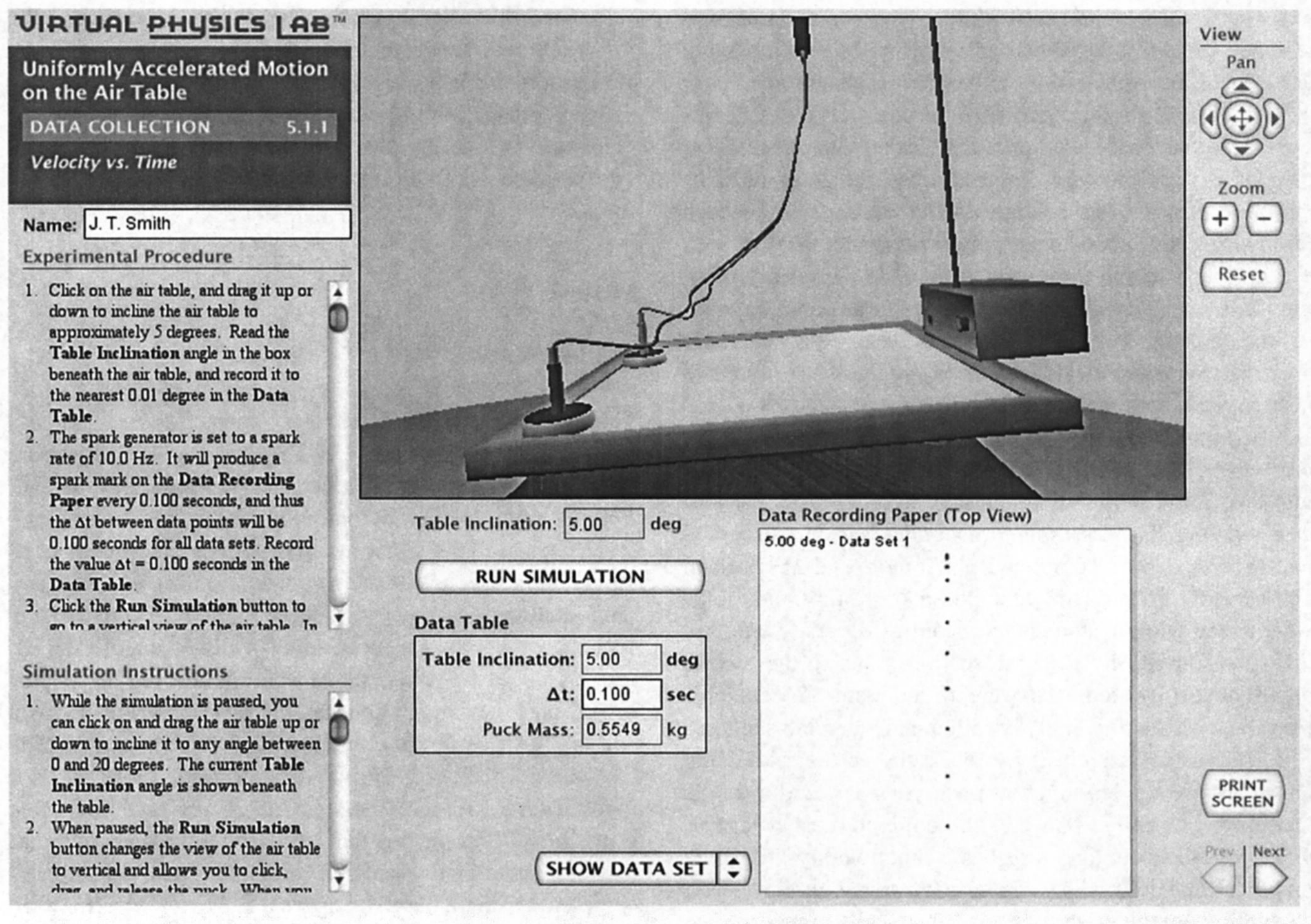


Fig. 1 Lab 5 Data Collection Screen—An example of the data collection screen where the table can be tilted to form an inclined plane to study the one-dimensional motion of a uniformly accelerated object

simulation, the student has access to the procedures for the lab and instructions for doing the experiment using the simulation. Figure 2 illustrates how the data analysis screen allows students to position a ruler on the data recording paper, created using the simulation, to measure the positions of spark marks, and to record them in the Data Table on the left (Table 1).

Figure 3 shows a screen from the *Ideal Gas Law* lab video demonstration. These demonstrations accompany each of the labs and feature students using the actual apparatus to perform the experiment. During the development of the labs, physics professor consultants pointed out the advantage of using the videos as a prelab activity for students—even for those students who perform the lab with actual equipment. They reported that a great deal of time is typically spent at the beginning of each lab period explaining the procedures to the students. Using the videos to provide this preliminary explanation can save time in class, which can be better used to debrief after the lab is completed.

As each lab is completed, a printable lab report is generated (Fig. 4), providing students with hard copy of their data and graphs, and instructors with a convenient way to assess student work.

The following labs from *Virtual Physics Lab* were tested at the two locations:

Auburn University

- Uniformly Accelerated Motion on the Air Table
- Simple Harmonic Motion
- Ideal Gas Law
- Torques and Rotational Equilibrium of a Rigid Body

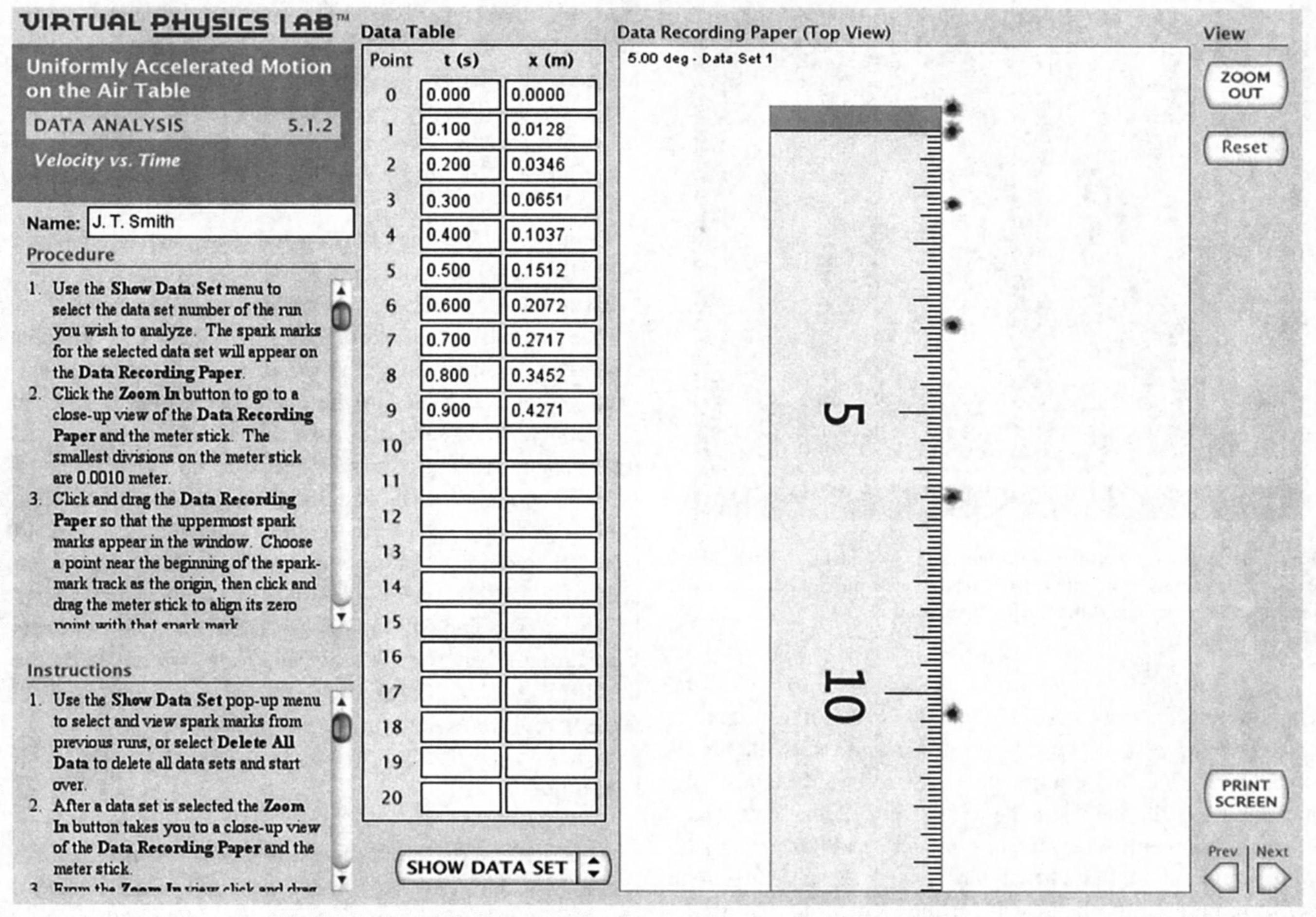


Fig. 2 Lab 5 Data Analysis Screen—This illustrates how the data analysis screen allows students to position a ruler on the data recording paper to measure the positions of spark marks and record them in the data table to the left

Table 1 Alignment of exam questions with labs for test score

Exam	Uniform	Newton	Torque	Cons. of energy	Cons. of momentum	Moment of inertia
1		10, 12, 16, 18				6, 15
2	11		10, 16, 20		3,9	
3		17, 18	3, 19	11,26	22, 24	
Total	1	6	5	2	4	2

Penn State University

- Uniformly Accelerated Motion on the Air Table
- Newton's Second Law of Motion
- Moment of Inertia and Rotational Motion
- Torques and Rotational Equilibrium of a Rigid Body
- Conservation of Momentum
- Conservation of Energy

A great deal effort was put into making the hands-on labs and the virtual labs identical. The virtual labs listed above were selected to be part of the testing based on the ability of each university to provide a true one-to-one comparison in terms of real lab equipment versus virtual lab equipment. The *Simple Harmonic Motion* virtual lab was designed after the real lab equipment at Auburn

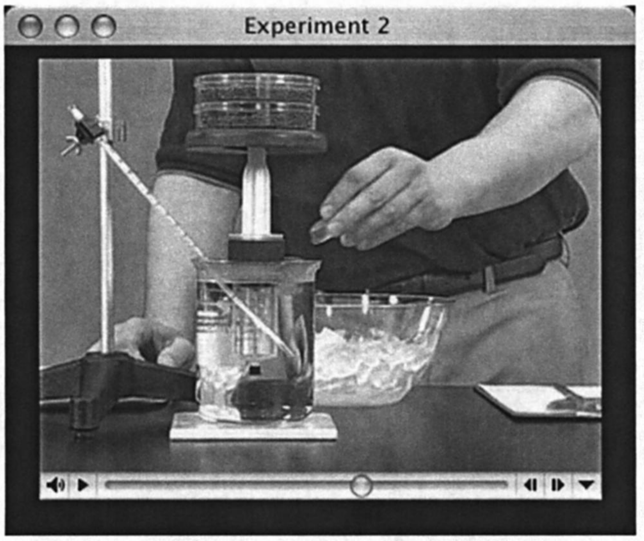


Fig. 3 Example of Video Demonstration—Students watch the experiment being conducted with hands-on equipment and then perform the same experiment using a simulation

University. Since Auburn University was not originally doing the *Ideal Gas Law* lab, or one similar to it, they obtained the needed equipment, so they could conduct a hands-on lab the same as the virtual lab. Penn State had all the equipment necessary to conduct hands-on labs that were identical to the virtual labs tested there. The only substitution at both places was for the virtual lab that used an air table. For this lab, the hands-on lab used an air track. It is important to note that this lab was a study of one-dimensional motion and so the data from an air table and an air track are the same if the angle of the air table and air track with respect to the horizontal are the same (and they were). Since it was an investigation in one dimension, this was deemed to be an appropriate substitution by all physics professors involved. In every case, the analysis portion of the hands-on lab was modified to be identical to the virtual lab analysis. All questions, the procedure followed, the data taking process and the data table, calculation, and questions asked were the same for the hands-on and the virtual labs.

Participants

Two different sets of participants were used during the first and second phases of testing. The first set of participants included 68 students from Auburn University. The students enrolled in Physics I tested four virtual labs to provide a formative assessment of the product. One group of these students ($n = 21$) used the labs as a replacement to traditional labs, one group ($n = 18$) used the labs as a supplement to their traditional lab experience, and two groups of students ($n = 17$ and $n = 19$) were used as control groups and completed traditional hands-on labs. The groups were assigned at random to one of the two treatments or control.

Group 1—Treatment 1 Virtual Lab as Replacement: ($n = 21$) Teaching Assistant 1.

Group 2—Control: ($n = 17$) Lab 02 Teaching Assistant 1.

Group 3—Treatment 2 Virtual Lab as Supplement: ($n = 18$) Teaching Assistant 2.

Group 4—Control: ($n = 19$) Teaching Assistant 2.

The second set of participants included 156 students from Penn State University enrolled in 16 different sections of Physics I. As in the previous testing at Auburn University, lab sections were randomly assigned to treatments. Students in sections 1, 2, 3, 6, 7, and 8 ($n = 60$) completed the hands-on labs and were used as a control group; students in sections 4, 5, 12, 13, and 14 ($n = 49$) completed the virtual labs; and students in sections 9, 10, 11, 15, and 16 ($n = 47$) used the virtual labs as a supplement to the hands-on lab. The students who completed the virtual labs also completed the usability student survey on several labs. A total of 76 student reviews were conducted on six labs.

Procedures

The studies at the two universities were somewhat different, so each study will be described separately instead of combining the information and data. For both universities, students were told the purpose of the study being conducted and were asked to fill out a consent form and return it to their lab instructor. Students who agreed to participate in the study were assigned a number by their instructors or the lab coordinator, and their data were entered into a spreadsheet for later analysis. If students opted not to participate in the study, they still participated in the activities in class, but their data were not used for analysis.

At Auburn University, the professor collected background information about each of the students including, math ACT[1] score, science ACT score, and Auburn math placement score from the registrar's office. These scores were investigated as covariates that could be used as baseline knowledge and possibly predictive of student success in physics lab. The lab sections were randomly assigned to one of the two treatments or the control. Students performed the labs in their regular physics lab classes. The lab posttest instrument and the lab report were used to assess the students' knowledge of the physics

[1] The ACT college readiness assessment is a curriculum- and standards-based educational and career planning tool that assesses student academic readiness for college. www.act.org.

Fig. 4 Example of Printable Lab Report—This report is generated, so the student can print it and/or email it to the professor for grading

VIRTUAL PHYSICS LAB™

Simple Harmonic Motion—Mass on a Spring
Mass Variation

Name: Student 14
Date: 9:21 AM 12/12/06

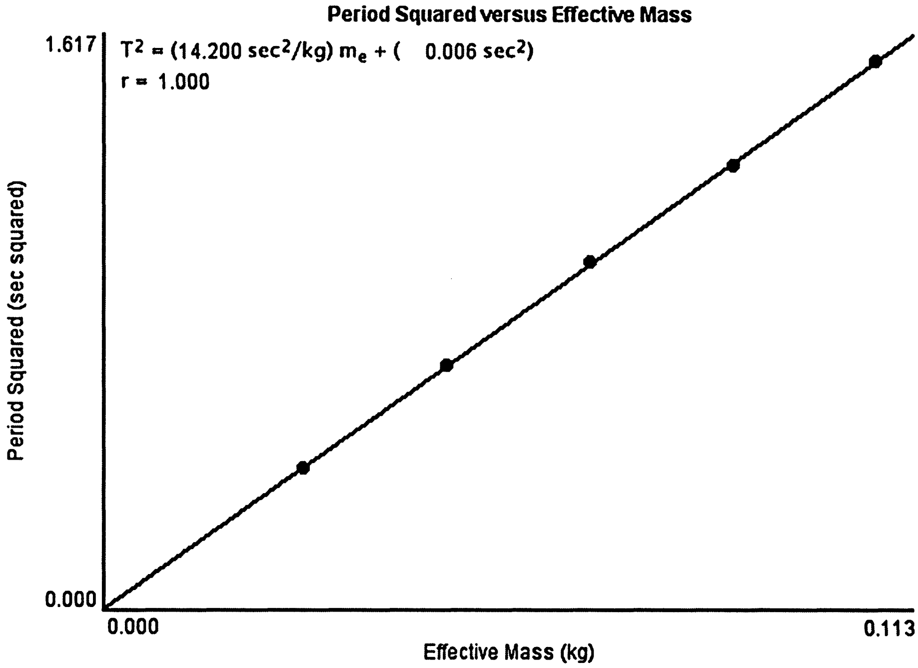
Data and Calculations Table

m_h = 0.005 kg
m_s = 0.009 kg

Data Set No.	m_d (kg)	m_e (kg)	T (s)	T^2 (s^2)
1	0.020	0.028	0.63	0.40
2	0.040	0.048	0.83	0.69
3	0.060	0.068	0.99	0.98
4	0.080	0.088	1.12	1.25
5	0.100	0.108	1.54	1.54

Slope = $4\pi^2/k$ = 14.200 sec^2 / kg
Intercept = 0.006 sec^2
r = 1.000

k (determined in Experiment 1) = 2.74 N/m
k (derived from slope) = 2.78 N/m
% diff in k = 1.46



content related to the lab. The same assessments were used with all students. During this phase of testing, the posttest instruments were also assessed to determine if they were adequate for comparing groups later in the study, and a consistent grading scheme was developed for grading the students' lab reports.

At Penn State University, the lead professor collected the math SAT[2] score for each student from the registrar and at the beginning of the semester administered the FMCE to determine baseline information for each student. These scores were investigated as covariates that could be used as baseline knowledge and possibly predictive of student success in physics lab. The sixteen lab sections were randomly assigned to one of two treatments or the control group. Following the lab experience, the students each completed a lab postquiz. During the semester, a set of questions from exams that were keyed to each lab were also used. The students also were given the FCME again at the end of the semester.

Data Collection and Analysis

The following were the instruments used to collect the data:

- Student PostLab Quizzes: These were created by content experts (physics professors) based on the objectives of the lab (Auburn University). See Appendix A for sample PostLab Quiz questions.
- Student Lab Report: These were reports of the data and information that students collected during the lab. The

[2] The SAT and SAT Subject Tests are designed to assess readiness for college. www.sat.collegeboard.org.

outline and questions on the lab reports were developed by content experts (physics professors). A grading rubric was developed to insure consistent criteria for grading the lab reports. (Auburn University)
- Student Tests: This was an instructor-developed test given to all students in all sections. The total score on 20 questions from the three semester exams were associated with six labs completed during the semester (Penn State University).

The following data were collected at Auburn University to be used for quantitative analysis.

- Lab Quiz Average—Average of all scores for lab quizzes taken after completion of labs
- Lab Report Average—Average of all scores for lab reports completed during labs
- Math ACT Score—The students' ACT scores on the math portion
- Science ACT Score—The students' ACT scores on the science portion
- Auburn University Math Placement Test—A test given to all incoming freshman to determine placement into math courses at the University.

The following data were collected at Penn State University to be used for quantitative analysis.

- Math SAT Score—The students' SAT scores on the math portion
- Test Score—The total score on 20 questions from the three semester exams that were associated with the six virtual labs completed at Penn State (see Table 3 for alignment).
- FMCE—a widely used and accepted multiple-choice test to evaluate physics instruction. (Sokoloff et al. 2007) This test was given at the beginning of the semester and also at the end.

For each of the Lab Quizzes used at Auburn, a qualitative review of the quiz questions was conducted by three Physics content experts to assure content validity and to determine if the items met minimum quality-control criteria. Classical Test Theory item analysis was run on each of the quizzes to determine if the items were appropriate (difficulty) and if they differentiate between the students who did well on the overall quiz and those who did not (discrimination). A statistical analysis was conducted after the items had been administered to determine item difficulty and discrimination levels. This analysis was run to help identify any problematic, bad, or misfit items. Some of the reasons items may be problematic include: items are poorly written, items not having a clear correct response, or items measuring something beyond the content being tested. The Lab Quizzes were eight to ten questions, and on average, one to three items on each quiz were flagged because either they had an undesirable difficulty level or were poor discriminators. This information was provided to the physics expert who used this information to improve questions for future quiz administration.

For the data from Auburn University, a t test was used to compare the Average Lab Quiz Scores (the average of four postlab quiz grades) of the various sections. First, lab section 1 (virtual) was compared to section 2 (hands-on). Both sections were taught by Instructor 1. Next, lab section 3 was compared to lab section 4. Both lab sections 3 and 4 were taught by Instructor 2, with lab section 3 completing the hands-on labs with the supplement of the virtual labs and lab section 4 completing the hands-on labs only. Finally, a t test comparison was completed for lab sections 1 and 3 versus lab sections 2 and 4. Lab sections 1 and 3 had access to the virtual labs in some way, and sections 2 and 4 did only the hands-on labs.

A one-way Analysis of Variance was run on the four sections of labs to see if there was any difference among the groups' Average Lab Quiz Scores. A one-way Analysis of Variance was also run on the Average Lab Quiz Scores of the three groups (Virtual only, Control, and Supplemental) to see if there was any difference among the three means. The bivariate correlations between the outcome variable (Average Lab Quiz Score) and all other variables were computed to determine the correlation of each of Lab Report Average, Math ACT, and Auburn University Math Placement. A multiple regression analysis was completed with dependent variables Lab Report Average, Math ACT, Science ACT, Auburn University Math Placement, and independent variable of Average Lab Quiz Score.

The Test Score used for students at Penn State was created using 20 questions from the three semester exams that aligned with the labs. Table 3 below shows exactly which questions from each test were chosen and which labs they aligned with.

To analyze the data collected from Penn State University, the first step was to compute the statistical bivariate correlations between outcome variables Test Score and Quiz Average and Math SAT Score. A multiple regression analysis was completed using Quiz Average and Math SAT Score as the dependent variables and Test Score as the independent variable. A one-way ANOVA was completed for Test Score with all students completing all three tests. First, the Hands-on Group was compared to the Virtual Group. Second, the Hands-on Group, the Virtual Group, and the Supplemental Group were all compared. The Intraclass Correlation Coefficient was then computed between the different groups (control and experimental). A one-way ANCOVA was computed between the experimental Virtual and Hands-on Groups' Test Scores controlling for Math SAT. A one-way ANCOVA was computed between the Virtual, Hands-on, and Supplemental Groups' Test Scores, controlling for SAT. A paired t test was completed to determine if there were significant gains for each group on the Pre-FMCE to the Post-FMCE test. Finally, a one-way ANOVA was used to compare the students in the three groups that completed the FMCE.

Results

For Auburn University, several statistical tests were used to provide evidence to answer the research questions stated in the Introduction. A t test was used to compare the Lab Quiz Average (the average of four post-lab quiz grades) of the various sections. First, lab section 1 ($M = 59.37$, $SD = 16.97$, $n = 23$) was compared to section 2 ($M = 58.16$, $SD = 20.86$, $n = 26$). Both sections were taught by Instructor 1. Lab section 1 did only the virtual labs, and lab section 2 did the hands-on labs. The t test shows that there is no evidence to suggest that there is any significant difference between the quiz averages for the two groups (two tailed $p = 0.826$).

Lab sections 3 and 4 were both taught by Instructor 2, with lab section 3 ($M = 52.06$, $SD = 17.18$, $n = 24$) completing the hands-on labs with the supplement of the virtual labs and lab section 4 ($M = 49.40$, $SD = 22.46$, $n = 21$) completing the hands-on labs. The t test shows that there is no evidence to suggest that there is any significant difference between the Average Lab Quiz Scores for the two groups (two tailed $p = 0.66$). Lab sections 1 and 3 had access to the virtual labs in some way, and lab sections 2 and 4 did only the hands-on labs. The t test shows that there is no evidence to suggest that there is any significant difference between the Average Lab Quiz Scores for the two groups.

A one-way Analysis of Variance was run on the four sections of labs to see if there was any difference between the four groups' Average Lab Quiz Scores. There was no significant difference among the four groups. A one-way Analysis of Variance was run on the three groups' (Virtual ($M = 59.37$, $SD = 16.97$, $n = 23$), Control ($M = 54.24$, $SD = 21.80$, $n = 47$), and Supplemental ($M = 52.06$, $SD = 17.18$, $n = 24$)) Average Lab Quiz Scores to see if there was any difference between the three means. There was no significant difference between the groups' Average Lab Quiz Scores.

The bivariate correlations between the outcome variable Lab Quiz Average and the other variables Lab Report Average, Math ACT, and Science ACT were computed. The results indicated that these variables Lab Report Average ($r = 0.45$), ACT Math ($r = 0.41$), and ACT Science ($r = 0.40$) were significantly related to the outcome (all $p < 0.05$). A multiple regression analysis revealed that, of the three covariates, Lab Report Average ($\beta = 0.41, p < 0.05$) and Math ACT ($\beta = 0.33, p < 0.05$) were uniquely predictive of Lab Quiz Average. These findings indicate that only two of the covariates (Lab Report Average and ACT Math) are uniquely and statistically significant related to the outcome.

Running an Analysis of Covariance with the Auburn University sample dataset of 42 data elements[3] yielded a difference between experimental ($M = 60.37$, $SD = 14.02$, $n = 21$) and control ($M = 63.57$, $SD = 16.76$, $n = 21$) groups. The difference in Average Lab Quiz Scores was not statistically significant, $F(1,39) = 0.59$, $p = 0.45$, after controlling for Lab Report Average and ACT Math scores.

For Auburn University, the results of the different statistical tests above indicate that there is no evidence to suggest that there is any significant difference in Average Lab Quiz Scores when students used the virtual labs only, the virtual labs as a supplement, or did the labs in the traditional hands-on manner.

For Penn State University, results of the students' Test Scores and SAT Score were used. Test Score was a combination of the scores for questions from three tests that had been keyed to the labs that were completed during the semester. The SAT Score for each student was collected and recorded by the lead instructor.

A one-way Analysis of Variance was completed for Test Scores with all students completing all three tests. First, the Hands-on Group was compared to the Virtual Group. There was no significant difference found between the groups. Second, the Hands-on Group, the Virtual Group, and the Supplemental Group Test Scores were all compared using a one-way Analysis of Variance. There was no significant difference found among the three groups.

A one-way Analysis of Covariance revealed that the difference between Virtual ($M = 42.68$, $SD = 15.30$, $n = 28$) and Hands-on ($M = 43.91$, $SD = 16.58$, $n = 23$) Groups' Test Scores was not statistically significant, $F = 0.43$, $p = 0.51$, after controlling for Math SAT Scores. A one-way Analysis of Covariance revealed that the difference among Virtual ($M = 42.68$, $SD = 15.30$, $n = 28$), Hands-on ($M = 43.91$, $SD = 16.58$, $n = 23$),

[3] All data needed for the ANCOVA was only available for this set of 42 students at Auburn University.

and Supplemental ($M = 47.92$, $SD = 15.94$, $n = 24$) groups' Test Scores was not statistically significant, $F = 0.43$, $p = 0.65$, after controlling for Math SAT scores.

Sixty-seven students completed both the FMCE at the beginning of the semester and at the end of the semester. A paired t test run for each individual group (Virtual, Hands-on, and Supplemental) showed that all groups had significant learning gains from the Pre-FMCE to the Post-FMCE. A one-way Analysis of Covariance was run using the Pre-FMCE as the covariant and the Post-FMCE as the outcome variable. This test revealed that the difference between Virtual ($M = 52.91$, $SD = 21.56$, $n = 22$), Hands-on ($M = 53.45$, $SD = 20.55$, $n = 29$), and Supplemental ($M = 59.88$, $SD = 20.63$, $n = 16$) groups' Post-FMCE Scores was not statistically significant, $F = 2.61$, $p = 0.08$ after controlling for the Pre-FMCE Scores.

There were 51 students who were in just the Virtual ($n = 22$) and Hands-on ($n = 29$) groups at Penn State. A one-way Analysis of Covariance was run using the Pre-FMCE as the covariant and the Post-FMCE as the outcome variable for just these two groups. The Supplemental group was excluded, since one could argue that they were somewhat different, receiving the lab material twice. This test revealed that the difference between Virtual ($M = 52.91$, $SD = 21.56$, $n = 22$) and Hands-on ($M = 53.45$, $SD = 20.55$, $n = 29$) groups' Post-FMCE Scores was not statistically significant, $F = 2.50$, $p = 0.09$ after controlling for the Pre-FMCE Scores.

Conclusions

Since the lab experiences students have in introductory physics are central to the learning of the concepts in the course, and the upkeep and staffing of physics labs are major investments of time and money, it is good to know that virtual physics lab experiences can provide an alternative or supplement to these traditional hands-on labs. As mentioned by Bhargava et al. (2006), there are several distinct advantages of virtual labs: They reduce equipment needs, are available at any time from any place, offer more information to students, and offer students the opportunity to work at their own pace while exploring difficult or interesting concepts. Also, one of the professors engaged in this study pointed out the excellent benefit of having the virtual labs available to students who were unable to physically attend class. The virtual labs allowed the students to maintain progress in the course, when before the only option was to return to class with a large backlog of makeup work or most commonly to drop the course altogether.

For this study, we investigated a set of next generation virtual labs that contain the important components that correspond well to hands-on labs: a demonstration presented by video using real people and real equipment, 3D interactive simulations to conduct the experiment, data collection tools, and the ability to produce a lab reports and email them directly to the teacher. The main goal of this research was to show that this type of virtual lab could produce the same learning outcomes as a traditional hands-on lab experience. This research was conducted with 224 students from two large universities. The analyses of the data at both universities show no evidence that one of the treatments (virtual or hands-on) was more effective than the other in conveying the concepts of the labs to the students. There was no significant difference noted in any of the tests, except to say there were significant learning gains for all groups from the Pre-FCME to the Post-FMCE tests. From this, we conclude that the *Virtual Physics Lab* software used in these two introductory physics courses produced similar learning outcomes as the hands-on traditional labs. These results are similar to the results found by others mentioned in the Introduction.

The *Virtual Physics Lab* is an innovative software product with embedded 3D lab equipment that can be an effective tool for professors and students to use inside and outside the classroom. The implications of these findings are important as universities struggle to equip physics labs with enough equipment to serve the rising number of students and to provide an alternative to students who need to review or make up a lab, and as the number of online physics courses grows. If at least some of the hands-on labs can be effectively replaced by virtual labs, students can expect to learn physics concepts as well as if the funding or access allowed them to conduct the experiments using traditional hands-on methods.

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Appendix

Lab 5 Quiz

Uniformly Accelerated Motion on the Air Table

A student on planet X performs an experiment similar to the one you have just performed. During the experiment, a puck slides down an incline of θ = 11.5 degrees. Shortly after the puck is released the student engages a device that puts a mark on a piece of paper (taped to the incline) every 1/10 second. The student then picks a point as $x_o = 0$ and $t_o = 0$ and makes a record of the position of the puck at each subsequent time. The table below shows the point $x_o = 0$, $t_o = 0$ and the student's record of the position and time for the puck at each subsequent time.

Time (s)	Label	t_0	t_1	t_2	t_3	t_4	t_5
	Value	0	0.100	0.200	0.300	0.400	0.500
Position (m)	Label	x_0	x_1	x_2	x_3	x_4	t_5
	Value	0	0.014	0.032	0.054	0.080	0.110

Determine the following:

1. Displacement (in m) of the puck during the time interval t_1 to t_3.

   (a) 0.068 (b) 0.080 (c) 0.086 (d) 0.040 (e) 0.034

2. Average velocity (in m/s) during the time interval t_1 to t_3.

   (a) 0.20 (b) 0.40 (c) 0.32 (d) 0.28 (e) 0.80

3. Instantaneous velocity (in m/s) at t_2.

   (a) 0.20 (b) 0.40 (c) 0.32 (d) 0.28 (e) 0.80

4. Acceleration (in m/s^2) of the puck down the incline.

   (a) 0.20 (b) 0.020 (c) 0.40 (d) 0.040 (e) 0.80

5. Value of the acceleration due to gravity (in m/s^2) on planet X.

   (a) 0.80 (b) 1.20 (c) 2.0 (d) 3.6 (e) 9.8

A given point was chosen as the origin for the analysis in the above problem. Suppose instead the next later point had been chosen for the origin. Choose below the best response for the changes the new origin would cause in the values of the acceleration a and the initial velocity v_o.

6. The value of the acceleration a would be

   (a) somewhat larger since the time is later

   (b) somewhat smaller since the time is later

   (c) essentially unchanged

   (d) significantly larger since both the time and distance are larger

   (e) significantly smaller since both the time and distance are larger

7. The value of the initial velocity v_o would be

   (a) larger since the time is later

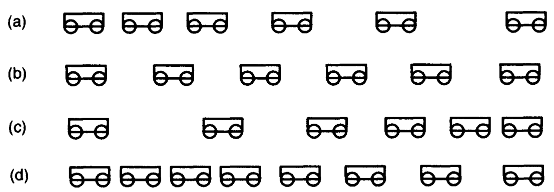
   (b) smaller since the time is later

   (c) essentially unchanged

   (d) impossible to determine

   (e) always equal to zero

Use the diagrams below to answer questions 8 - 10.



The carts pictured above are all moving in a straight line to the right. The pictures were taken 1.00 s apart. Choose which of the descriptions below matches which pictures.

8. These pictures show a cart that is moving at constant velocity.

   (a) (b) (c) (d)

9. These pictures show a cart that has constant positive acceleration throughout its motion.

   (a) (b) (c) (d)

10. These pictures show a cart that travels at a constant velocity and then has a positive acceleration.

   (a) (b) (c) (d)

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