Science Simulations: Do They Make a Difference in Student Achievement and Attitude in the Physics Laboratory?

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Introduction

Among students the rich world of science, both real and manufactured, has little effect on its audience. Student interest and appreciation for the universality and practicality of the subject is virtually non-existent. Because science represents the most basic of daily-life experiences, the argument can be made that learning science should be a natural or automatic result of a relevant curriculum. However, in many instances, neither the curriculum nor textbooks reflect the commonality and relevance of science. Too often, learning is often reduced to student passivity while the teacher becomes the “content messenger”—pouring knowledge into the empty vessel. So how can this situation be remedied? One possible solution lies within the basic tenets of constructivism which advocates the use of prior knowledge to make sense of new explorations, and thus learners “construct” meaning by synthesizing experiences, both past and present (Piaget, 1980; Byrnes, 1996). For the ever-increasing fraction of students who are experientially ill-prepared for understanding the abstract concepts, connections, and themes of science instruction (Kelly, 2000), laboratory investigations offer a context for much-needed concrete experiences. Concrete, inquiry-based experiences are important not only to promote interest (yielding a better attitude) in science, but also to demonstrate the relevance of the subject. If the content is significant, with real-life applications, then it follows that students will find that part of science more interesting because they can relate to the material being presented. As students progress in their intellectual pursuits and their knowledge base expands, they undergo a shift in understanding; that is, they no longer see knowledge as a collection of facts specific to a content domain, but rather, they view knowledge (whatever the subject) in an evolving framework that expands and contracts, modified through experience (King & Kitchener, 1994; Baxter, 1999; Palmer & Marra, 2004). Of all the science subjects, physics poses the greatest impediment to concrete learning because of the "…extremely high level of abstraction and idealization" (Duit et al., 2007, p. 605). In addition, students automatically assume that the topic is not only difficult to understand, but that it is also, somehow, not relevant or applicable to them in real life. This kind of alienation from the subject presents significant and numerous obstacles to the teacher, but they may be overcome by effectively engaging the student in active learning opportunities.

Laboratory Investigations. The laboratory experience, both real and simulated, provides opportunity for the learner to experience science through investigation. Physics is one of the subjects in which computers and software applications have been developed and used frequently to support and promote conceptual understanding. Historically, physics simulations were presented as procedural or sequential in nature. This required students to complete a specific task to reach a specific outcome. Generally simulations of this type were intended as iterative processes rather than a problem-solving experience. In recent years computer-based simulations have morphed into an interactive interface for student exploration. Learners are able to manipulate the parameters of the virtual environment within the simulation and construct new understanding of the underlying concepts through inferring and predicting possible outcomes. These simulations extend the range of student exploration by making the "abstract" experience more concrete and by providing immediate feedback about the experience, which is often an improvement over lecture and reinforcement strategies (Ronen & Eliahu, 2000; Trumper, 2003). Research on student performance as a result of engagement in simulation activity is mixed.

Some studies have reported enhanced student achievement with the use of simulations (Steinberg, 2000; Stieff & Wilensky, 2003; Zacharia, 2003; Sethi, 2005) while other findings have noted little or no significant difference in student performance after using simulations (Cummings, Marx, & Kuhl, 1999; Kulik, 2002; Robertson, 2003).

Attitude. Research has demonstrated that student attitude influences perception of and interest in the subject of science (Hall, 1992; Anderson & Mitchener, 1994; Duit, Niedderer, & Schencker, 2007). Simpson (1978) estimated that student interest and attitude toward science account for as much as 25% of the variability in academic achievement in the subject at the university level whereas Willson (1983) and Willson, Ackerman, & Malone (2000) found that the relationship between attitude and achievement is not very strong. Other studies have shown that the kind of science teaching students experience affects attitude toward the subject (Ebenezer & Zoller 1993; Sundberg, Dini, & Li, 1994; Adams, Perkins, Dubson, Finkelstein, & Wieman, 2005; Perkins, Adams, Pollock, Finkelstein, & Wieman, 2005), yet sometimes, even with the utilization of innovative instructional strategies, student attitudes and subsequent achievement, especially in physics, do not improve (Willson, Ackerman, & Malove, 2000; Redish, 2003).

Attitudinal research formally began in the 1920s when an author by the name of Thurstone declared in an article that attitudes were measurable (Simpson, Koballa, Oliver, & Crawley, 1994). By the 1960s and 1970s, attitudinal research had become voluminous and usually focused in three areas: 1) measurement of student attitudes; 2) measurement of change in student attitudes following various treatment methods; and 3) identification of relationships in support of student attitude and science-related behaviors (Simpson et al., 1994). Researchers in the late 1970s and early 1980s regarded attitudes as “both the facilitators and products of science learning and research efforts focused on documenting student attitudes and their relationship to science achievement" (Koballa & Glynn, 2007, p. 77). By the 1990s, attitudinal research lagged somewhat because there appeared to be no real direction or results that provided for improving classroom practice. However, within the last decade, attitudes and implications for change in instructional dynamics to improve the classroom experience appears to be the emphasized direction. Corresponding with the evolving research on attitude, much has been written regarding definitions, descriptions, attributes, and characteristics of the term. Numerous studies have described attitude as a favorable or unfavorable feeling toward something (Zacharias, 2003). Still others have moved beyond the affective domain in their definitions to perceptions and beliefs. For purposes of discussion in this paper, science attitude or scientific attitude will refer to an individual's perceptions, thoughts, or motivations to understand science, particularly physics. The "scientific" attitude discussed here represents a cognitive orientation; thus, any relationship to specific affective factors will be addressed only as they appear from data analysis.

Purpose and Context of Research

This study focused on both the cognitive and affective domains of learning physics in the laboratory environment. We investigated the role of simulation and traditional (equipment) laboratory explorations on student achievement and changes in attitude toward science. We posed such questions as: 1) Was there a difference in student performance when comparing simulation and equipment laboratory activities?; and 2) Did student attitude change from beginning to end of the semester after experiencing both simulation and equipment laboratory investigations?

Methodology

The research conducted herein took place in first-semester, laboratory sections of introductory physics classes (trigonometry and calculus-based) at a private university in the Southwest. The laboratory sessions occurred weekly, and a total of 96 students were assigned to different sections, but only those students who completed both pre- and post- lab reports and pre- and post- attitudinal surveys were considered as participants in this study. Students in different lab sections were randomly assigned to do simulations and equipment activities, so numbers were not of equal size, and only those students who completed both pre- and post- laboratory reports and pre- and post- CLASS surveys.

Simulations and Equipment Labs

The laboratory activities stressed inquiry (through simulation and equipment experiences) rather than traditional, iterative practice. For analysis of data, students were distinguished by lab group (simulation or equipment), gender, and math background. The data were examined for significance (at the .05 level) using t-tests and descriptive statistics.

All students participated in a total of twelve laboratory experiences of which six consisted of either simulation or equipment investigations. Each laboratory exploration targeted the following major concepts: Lab 1 involved graphing, measurement accuracy, and uncertainty; Lab 2 was concerned with motion (constant acceleration) with uncertainty analysis; Lab 3 related to 2D motion of projectiles (constant nonzero acceleration in one component only); Lab 5 focused on frictional forces (net force is zero, acceleration is zero, with velocity constant and sometimes non-zero), Lab 10 looked at buoyancy and density from analysis of vectors; and Lab 11 required oscillatory comparative measurements (mass and spring combinations and simple pendulum).

The simulations for the six laboratory exercises were created by the physics professor (author) using physlets which are flexible Java applets that can be programmed to demonstrate different physics concepts through interaction or animation. They were imbedded in html documents so that they could be viewed and controlled via an internet browser. Physlets respect real time and so can be programmed to simulate actual physical processes. All created simulations aligned with the equipment investigations. As much as possible, they looked like the objects used in real laboratory activities. Sometimes, images of real things were used (e.g., brass weights, a chunk of aluminum, a blown-glass figurine, etc.). Otherwise, simple graphics were created to look very similar to the actual experiments set up in the lab course. All simulations were interactive, in the same sense that equipment labs were interactive. Students answered the exact same questions given to students who did the labs with equipment, and they reported their observations and findings in a post-lab report. Both simulation and equipment students were asked to collect and analyze data, to estimate measurement uncertainties, to compare the results of various measures and calculations, and to compare their results with theoretical expectations.

The data were used to make comparisons on student achievement between simulation and equipment labs on graded pre- and post-lab reports. The pre-lab reports were implemented to insure that students attended lab sessions prepared. The pre-lab served as “warm-up” activity for the actual lab; theoretical and application questions, all related to the upcoming lab session, were posed to the students, and they were required to write their responses and submit for a pre-lab grade. Post-lab report grades consisted of student response to the laboratory investigation. Lab reports were graded upon completion of the lab, response to questions, synthesis of experimental findings.

Attitudinal Survey

Survey Instrument. The Colorado Learning Attitudes About Science Survey (CLASS) instrument was selected to collect pre- and post-data on our students. CLASS survey validity and reliability had already been documented in the Adams et al. (2005) study. Our purpose in using the CLASS was not to reflect upon the instrument per se, but rather to use the survey instrument to characterize and compare student attitudes in introductory physics classes before and after a semester of laboratory investigations.

The CLASS Survey (version 2) was created at the University of Colorado to assess student attitudes about and interest in physics as well as to probe their strategies for learning and views regarding conceptual understanding of the subject (Perkins et al. 2005). The CLASS is relatively new in development and was patterned after earlier attitude surveys such as the MPEX (Maryland Physics Expectations Survey) , VASS (Views About Science Survey), and EBAPS (Epistemological Beliefs Assessment for Physical Science) (Perkins et al. 2005). The instrument uses a Likert 5-point (strongly agree to strongly disagree) scale on 37 statements to gauge student attitudes and beliefs about physics. Factor analysis was used by the survey developers to validate the instrument; eight factors were derived. Since our purpose was to examine student response to individual statements, we examined each statement as a basis for comparison rather than by categorical classification.

Data Analysis and CLASS Scoring. The CLASS surveys were conducted twice, once at the beginning of the semester and again at the end of the semester. Attitude scores were calculated by comparison of student responses with those of experts. Expert scores were determined from the averaged responses of the four faculty and six graduate student laboratory assistants providing physics lecture and laboratory instruction for these students during the course.

In the scoring of the CLASS survey, we followed the (scoring) procedures reported in the version 3 CLASS (Adams et al., 2006). Using this approach, each student's percentage score was calculated for agreement with the experts, then the scores were averaged together to determine the average percent agreement (in this case, it was 64.9% overall). The data were used to make overall pre- and post- score and individual survey statement comparisons in the areas of math background, gender, and achievement (final laboratory grade) in the class with the assumption being that laboratory practice (ie., simulation would promote achievement and attitude). Analysis of the data for significance was performed using various parametric statistics including independent and dependent t-tests and Pearson correlation. An alpha level of .05 was used for all statistical tests and analyses.

Results

Findings in this study were mixed; that is, when comparing simulation with equipment laboratory investigation no significant differences in student achievement were noted on the laboratory reports. However, in five out of six laboratory investigations, on average, students did score higher on simulated lab experiences than on equipment labs. On questionnaires and during interviews, more students indicated a preference for simulations explorations over equipment labs. However, in interviews, students noted that there was a need for both types of laboratory procedures rather than one over the other. Changes in attitude toward physics (when comparing pre- and post- CLASS survey results) did not correspond to simulation or equipment lab report scores or final laboratory grade. CLASS pre- surveys demonstrated higher agreement with physics experts than did post- CLASS surveys, yet over three-quarters (77.3%) of the students made an A or B for their semester laboratory grade.

Simulation vs. Equipment Laboratory Investigations. When comparing simulation lab report grades to equipment lab report grades, independent, two-tailed, t-tests demonstrated no significant difference for any of the six laboratory investigations which included both simulation and equipment experiences: Lab 1, $t(67) = .035$, $p > .05$; Lab 2, $t(67) = .326$, $p > .05$; Lab 3, $t(68) = .480$, $p > .05$; Equipment Lab 5, $t(90) = 1.329$, $p > .05$; Lab 10, $t(90) = .173$, $p > .05$; and Lab 11, $t(87) = .661$, $p > .05$. Simulation lab report grades were, on average, one to four percentage points higher than equipment averages, except on lab 11. On lab 11, equipment report grades were higher by about four percentage points. Refer to Table 1 for average scores on each lab.

Insert Table 1 About Here

Mathematics Background. Overall, mathematical background did not play a significant role with regard to grade performance on simulation or equipment lab investigations. Only on lab #2 was there a significant difference between trigonometry and calculus students who performed simulation $t(28) = 3.397$, $p < .05$ and equipment labs $t(37) = 2.355$, $p < .05$. In both instances, trigonometry students scored significantly higher on this (lab #2) investigation. Analysis of other simulation labs revealed the following when comparing math backgrounds (trigonometry vs. calculus): Lab 1, $t(40) = .822$, $p > .05$; Lab 3, $t(27) = .153$, $p > .05$; Lab 5, $t(49) = 1.195$, $p > .05$; Lab 10, $t(37) = .476$, $p > .05$; and Lab 11, $t(12) = .981$, $p > .05$. Equipment lab calculations indicated no significant difference on the final reports: Lab 1, $t(25) = 1.332$, $p > .05$; Lab 3, $t(39) = .347$, $p > .05$; Lab 5, $t(39) = 1.263$, $p > .05$; Lab 10, $t(51) = .561$, $p > .05$; and Lab 11, $t(73) = 1.583$, $p > .05$.

Gender. Further data analyses using independent t-tests demonstrated no significant differences when contrasting gender with simulation and equipment experiences. Analysis revealed that males and females did not differ on simulation or equipment grades. Simulation comparisons include: Lab 1, t(40) = .966, p>.05; Lab 2 (28) = 1.119, p>.05; Lab 3, t(27) = .417, p>.05; Lab 5, t(39) = .401, p>.05; Lab 10, t(37) = 1.278, p>.05; and Lab 11, t(73) = .115, p>.05. A review of equipment lab final report scores determined the following: Lab 1, t(25) = 1.623, p>.05; Lab 2 (37) = 1.160, p>.05; Lab 3, t(39) = .159, p>.05; Lab 5, t(39) = 1.284, p>.05; Lab 10, t(51) = .181, p>.05; and Lab 11, t(73) = .115, p>.05. Females did tend to score higher on their laboratory reports than did males. On average, females scored between 3 to 5 percentage points above males on simulations, except on lab 5, and, in that instance, average lab report grades varied by less than one percentage point. On equipment lab report grades, females outscored males, although, there was little or no difference in scores on labs 3, 10, and 11(less than one percentage point). In review, females scored modestly better on simulation labs than on equipment labs (about one percentage point difference). However, for final overall laboratory grades, males (51.4%) made slightly more As and Bs than did females (48.6%).

Post-lab attitudinal questionnaire and end-of-course interview. A questionnaire, which was a required assignment in every post-laboratory report submitted to the instructor, found that students enjoyed both the hands-on equipment labs and the interactive simulations. Questionnaire comments on equipment labs ranged from, “I enjoyed working with the lab apparatus,” to “It’s nice not having to work on a computer,” and finally, “I didn’t like the good chance for human error.” Regarding simulations, student responses included such items as, “I didn’t understand variables until I started working with simulations,” to “The thing I liked best about this lab was the ease in doing it,” and last, “I am a retard when it comes to using Excel, so doing these labs helps me learn technology, too.” Overall, students indicated a preference for doing simulation labs over equipment labs on five out of six investigations. These findings paralleled student performance on the laboratory reports. Simulation averages and a preference for simulation labs aligned with higher lab report grades on Labs 1, 2, 3, 5, and 10. Only on lab #11 (76.9% of equipment lab students to 50.7% of simulation students) did students exhibit a greater preference for equipment labs, and it is only on lab #11 that lab report averages were higher than simulation averages (81.58% to 76.74%). Overall, 69.3% of the students expressed a preference for simulation labs compared to only 57.6% of the equipment labs.

Interviews conducted at the end of course revealed that students enjoyed a combination of doing equipment and simulation labs; interviewees did not indicate that they liked doing one lab procedure over another. However, many did state that they wanted better quality in the simulation labs, either re-design or refinements to the current lab. For others, the simulations were either too limited or too simplistic in presentation format.

CLASS Attitude Survey. Significant differences in attitude were calculated on student pre- and post- survey on 15 (40.5%) of the 37 possible statements ($p<.05$, two-tailed, paired t-test). The significant statements included the following: #3, 5, 9, 12, 13, 22, 25, 26, 27, 29, 31, 32, 33, and 36 (for a complete list of CLASS survey statements, refer to Table 2**).** Six statements (#3, 9, 12, 25, 27) made a personal interest and real world connection; however, only # 3 ("I think about physics I experience in everyday life") [($t(86) = 2.887$, $p < .05$)] demonstrated a positive response increase from pre- to post- surveys. The remaining five statements (#9, 12, 25, 27) in this category showed that students experienced a decrease in personal interest and real world connection with physics.

Mathematical background. Of the 87 students who participated in the CLASS pre- and post- surveys, 44 had a math background in calculus and 43 had prior math knowledge through trigonometry. In both pre- and post- survey comparisons, student responses to these survey statements indicated a strong reliance on mathematical calculations and less on an understanding of physics.

No significant difference was determined between calculus and trigonometry students on their overall CLASS scores on pre- [(t(86) = 1.0756, $p > .05$)] or post-CLASS surveys [(t(86) = 0.604, $p > .05$)]. End-of-semester, post- survey analysis of each CLASS item determined that math background significantly affected responses on questions #1, 12, 17, 20, 22, 26, 29, 33,and 34 (refer to Table 2)**.** Survey statements such as #20 ("In doing a physics problem, if my calculation gives a result very different from what I'd expect, I'd trust the calculation rather than going back through the problem.") [t(86) = 2.189, $p < .05$] and #26 ("To learn physics, I only need to memorize important equations and definitions.") [t(86) = 3.197, $p < .05$] revealed a change in student perceptions about the way to utilize math in physics. Only on statement # 29 ("Spending a lot of time figuring out and understanding the derivations or proofs of formulas is a waste of time. As long as I know a formula works, it doesn't matter where it came from.") [t(85) = 2.735, $p < .05$] did trigonometry students (93.0%) agree more with the experts than did calculus students (75%). Overall, calculus students agreed more with the (physics) experts than did trigonometry students on the pre-CLASS surveys.

Gender. Some differences in gender were evident in the CLASS. Favorable survey responses tended to be more prevalent among males. At the beginning of the semester and before the start of the lab exercises, 55.4% of male students completed surveys with agreement scores above the overall agreement average of 64.9% while only 40.0% of females had agreement scores at that percentage (64.9%) or above. Further analysis determined that overall, both males and females agreed less with the experts after course lab instruction than at the beginning of the semester. After instruction, 38.3% of the males responded positively with an agreement score of 64.9% or higher while only 22.5% of the females did the same. T-tests revealed no significant difference between pre- [t(85) = 0.243, p > 05)] or post- [t(85) = 0.383, p >05)] CLASS surveys.

In analyzing specific survey statements for gender differences on the pre-instruction survey, survey items #13, 25, 30, and 32 were significant (p<.05, two-tailed, independent t-test). Post-instruction survey comparisons were significant (p<.05, two-tailed, independent t-test) for statements # 3, 5, 12, 14, 18, 21, 24, 29, & 30. Of those statements with a significant difference, only item #5 ("After I study a topic in physics and feel that I understand it, I have difficulty solving problems on the same topic.") [t(85) = 3.025, p < .05] and item #14 ("If a theory or explanation is given on a website, it is probably correct.") [t(85) = 2.799, p < .05] displayed stronger expert agreement by females rather than males.

CLASS Survey Agreement and Final Laboratory Grade. Of those students who scored 64.9% or higher on the post-instruction survey, 34.5% made a final laboratory grade of A; 38.8% received Bs; and 10.5% earned a C, D, or F. For those students who made an A or B in the class, correlation and linear regression analyses did not demonstrate a significant relationship between final laboratory grade and an attitude agreement score of 64.9% or higher.

Results Summary. In summary, this study determined the following about simulation and equipment laboratory investigations and student attitude (CLASS survey) toward physics:

- Comparisons between simulation and equipment labs demonstrated no significant difference in achievement although final laboratory report scores were higher on simulations than equipment lab grades (refer to Table 1);
- Only simulation lab #2 revealed significance in mathematical background comparisons, and trigonometry students scored higher;

- There were no significant gender differences in simulation and equipment laboratory performance, although females tended to score higher on laboratory reports, on average, than males. However, for final overall laboratory grades, males (51.4%) made slightly more As and Bs than did females (48.6%);
- Student questionnaires reflected a preference for simulations, although student interviews revealed that students liked doing both simulation and equipment lab investigations; they liked the hands-on of the equipment lab, but they also liked the ease of doing simulations;
- From pre-CLASS to post-CLASS, overall attitude agreement scores with experts declined by statement overall (refer to figure 1);
- Calculus students and male students exhibited higher levels of agreement with experts than did trigonometry students and female students on the CLASS survey; and
- Attitudes (student agreement-with- scores on the CLASS) can be poor indicators of academic success (at least for a final laboratory grade in physics). In this particular study, students were motivated by academic achievement, not their attitude toward physics.

Discussion

The findings from this research demonstrate that there is very little difference in learning that takes place in a real (equipment) laboratory environment and learning that occurs in the laboratory simulation setting. The question must be asked: Should science simulations replace the real laboratory experience? The answer is probably not. Simulations should be viewed as a viable alternative or supplement to the equipment lab, but not necessarily a replacement (Hasson & Bug, 1995; Doerr, 1997). Windschitl and Andre (1998) have suggested using simulations as a pre-laboratory format to introduce or remediate physics concepts. There are advantages in using simulations in a laboratory environment which cannot be overlooked. First, simulations place students in a realm of science exploration otherwise impossible in the classroom setting. The usefulness of the computer-based simulation lies within the dynamics of the real world theory/model it endeavors to reproduce. Second, well-designed simulations can provide non-threatening and more effective science instruction, if they are used in conjunction with quality teaching which encourages students to construct new knowledge through prior connections and understanding.

We focused on the laboratory experience, choosing to provide students with inquiry-based investigations which challenged the students to problem solve and move beyond rote memorization. Students explored the conceptual nature of physics through actual experience (equipment labs) and laboratory simulations. Laboratory exercises were intended to promote interest in the physical sciences and move students to understand the nature of physics beyond the classroom application and into real world problem solving. We conjecture that through this semester-long laboratory course, student perspectives reverted from initially somewhat idealistic notions (i.e., expecting that things will be as they 'should' be) to more novice-like (non-expert) expectations. Near the end of the semester, students' survey responses reflected a stronger concern about course outcome (grade) rather than a deeper conceptual understanding of physics principles and how they might extend their knowledge beyond course boundaries. A review of the lab questionnaires, which accompanied each final laboratory report, determined that males, more than females found the laboratory investigations beneficial to their understanding of physics and technology. Both genders were motivated by academic achievement more than an understanding of the subject content.

CLASS Survey. Did laboratory investigations make a noticeable difference in student attitude toward physics? Very little. Neither simulation nor equipment laboratory exercises seemed to influence student attitudes about physics. Initially, the students entered introductory physics classes with a wide range of attitudes and perspectives as measured by the CLASS survey. Results indicated that students were personally-oriented (introspective) on both of pre- and post-surveys that were administered. Inconsistency in survey answers indicated that students recognized the need for learning physics, but at the same time, pragmatically, they knew that they might never be able to fully understand or explain physics phenomena (eg., #9, " I am not satisfied until I understand why it is something works the way it does."). On this question, CLASS averages changed significantly from 4.13 on the Likert scale to 3.85 [$t(86) = 2.865$, $p < .05$)]. Consistent with this change in belief were students' realization that they might never have proficiency in mathematical problem solving (using formulas and algorithms). Student modifications in pre- and post-survey responses to statement # 22 ("In physics, mathematical formulas express meaningful relationships among variables") [$t(86) = 3.080$, $p < .05$)] and statement #26 ("To learn physics, I only need to memorize important equations and definitions)" [$t(86) = 3.197$, $p < .05$)] supported the notion that sometimes learning may be reduced to memorization and formulization because striving to understand at a higher conceptual level may take more effort than students are willing to do, or academically, students were not at a point in their learning to comprehend and master the material given them.

We inferred from the analysis of the CLASS pre- and post-statements that students came to realize that physics does not exist in a classroom vacuum, but, at the same time, these novices on-a-learning-curve doubted their own ability to make sense of what they had experienced. Making connections to other areas outside the realm of physics seemed to be of less importance to students because they may have felt they simply did not have the expertise to make connections; the alternative might be that they were not motivated to have an interest or appreciation for the universality and practicality of the subject.

In comparing mathematical backgrounds, more trigonometry students posted As and Bs (85.0% of trigonometry students) in the course than did calculus students (68.8% of calculus students), yet calculus students agreed more with experts on the CLASS survey (both pre- and post) than did trigonometry students. Specific responses to certain survey statements with significance seemed to show that trigonometry students were focused more on grades and performance in the course itself rather than on learning concepts and making connections that extended beyond the classroom learning experience. As an example, statement #12 ("I study physics to learn knowledge that will be useful in life") was significant on pre- and post-evaluations, but trigonometry students did not place as high a value on this statement as did calculus students. This basic premise was echoed again in survey statement #32, "The subject of physics has little relation to what I experience in the real world." Again, trigonometry students disagreed with calculus students. This finding might be attributable to calculus students being more knowledgeable and skilled in the physical sciences from either high school or college courses. At the same time, calculus students also focused more of their energies on the mathematics of physics in understanding and memorizing as the semester progressed (refer to survey statements 1, 15, 17, 26, & 29 in Table 2).

Regarding gender differences, males displayed a stronger and more resilient tendency to agree with the experts than females. This finding was in agreement with other studies which demonstrated that females' interest in physics is lower than that of males (Keeves & Kotte, 1996; Baker, 1998). However, dramatic shifts in attitude were found in female pre- to post- survey responses than males. Females seemed most interested in performing well in class to receive a “good” grade. Males, on the other hand, were more engaged in learning physics to understand it and use it rather than making the grade, although they were motivated by academic achievement as well.

Conclusion

Clearly, science simulations have a place in the physics laboratory. In this study, students recognized the benefits of using simulations, such as the ease in performing the investigation and doing problem-solving without equipment constraints. They also indicated that simulations piqued their curiosity. The only caveat---they expressed the need for improved simulation quality. Regarding equipment laboratory activities, students liked the hands-on investigations, yet they looked for ways to “streamline” the experience. Too, they expected the hands-on labs to be as efficient (and error free) as the simulation labs, which was not the case. However, the equipment lab should remind students that science is not “error free” and involves a certain amount of serendipity. Further studies are warranted to compare and contrast student ability to transfer and apply information gleaned from laboratory activity during simulation or traditional labs.

With regard to student attitudes measured by the CLASS survey, students exhibited a higher degree of naiveté, unrealistic perceptions, and contradictory opinions about the nature of physics in general at the beginning of the semester class. Pre-course CLASS survey responses revealed that students felt anyone could learn physics; mathematical knowledge and reasoning ability were not necessarily prerequisites to success in physics, yet knowing the derivation of formulas and understanding how physics “works” helped with problem solving; physics content can be learned by reading and studying the textbook, although a teacher who can explain the content is beneficial; memorization is not the key to learning physics, rather understanding is the key; and finally, reasoning skills learned in physics transfer to real life problem solving. By the end of the course, students' perceptions and beliefs about the nature of physics had changed rather considerably. Post-CLASS surveys revealed more novice-like attitudes about physics: Memorization of information was more important in learning physics than reasoning and problem-solving ability; knowledge of mathematical formulas was necessary to perform physics calculations; a physics teacher who teaches and explains information so that it is understood was probably more important than reading the textbook; there was a greater concern for getting the "right" answer, although students believed that there was more than one way to solve a physics problem; and, finally, reasoning skills learned in physics may not be helpful in everyday life (as students had initially indicated on the pre- CLASS).

While changes in attitude may impact classroom achievement, our research suggests that students are motivated more by academic achievement. Additional study is necessary to determine in what way simulations and real laboratory activities can best be utilized in the classroom to further promote and improve attitude and achievement among students.

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Table 1. Average Final Laboratory Report Comparisons (%)

Labs	Equipment Average	Simulation Average
#1	80.49%	84.31%
#2	80.49	84.31
#3	83.16	85.66
#5	81.74	85.71
#10	81.94	82.24
#11	81.58	76.74

Table 2. CLASS Survey Statements. Highlighted numbers (and t-scores) indicate statements with statistically significant pre- to post-instruction response change in this study.

No. v2	CLASS Statements and t-scores for statements with significant response change.
1	A significant challenge when learning physics is being able to memorize all the information I need to know.
2	After I have answered a question in a physics problem, I examine the answer to see if it makes sense.
3	I think about the physics I experience in everyday life. **** t(86) = 2.887, p < .05**
4	If the results of a carefully performed physics experiment vary widely, it is ok as long as it worked once.
5	After I study a topic in physics and feel that I understand it, I have difficulty solving problems on the same topic. **** t(86) = 4.920, p < .05**
6	Knowledge in physics consists of many disconnected topics.
7	For me, reading the text in detail and working through many of the text examples is necessary to learn physics.
8	For me, solving a physics problem more than one way helps develop my reasoning skills and is not a waste of time.
9	I am not satisfied until I understand why it is something works the way it does.**** t(86) = 2.865, p < .05**
10	I cannot learn physics if the teacher does not explain things well in class.
11	I do not expect to understand physics equations in an intuitive sense; they must just be taken as givens.
12	I study physics to learn knowledge that will be useful in life. **** t(86) = 2.923, p < .05**
13	I think anyone can learn physics. **** t(86) = 2.328, p < .05**
14	If a theory or explanation is given on a website, it is probably correct.
15	If I came up with two different approaches to a problem and they gave different answers, I would not worry about it; the answer depends on how you look at it.
16	To understand physics I discuss it with friends and other students.
17	If I don't remember a particular equation needed for a problem on an exam, there's nothing much I can do (legally!) to come up with it.
18	If I want to apply a method used for solving one physics problem to another problem, the objects involved in the two problems must be exactly the same.
19	If something is widely publicized by the media, it is almost certainly true.
20	In doing a physics problem, if my calculation gives a result very different from what I'd expect, I'd trust the calculation rather than going back through the problem. **** t(86) = 2.189, p < .05**
21	In physics, it is important for me to make sense out of formulas before I can use them correctly.
22	In physics, mathematical formulas express meaningful relationships among variables. **** t(86) = 3.080, p < .05**
23	It is important for the government to approve new scientific theories before they can be widely accepted.
24	Knowledge in chemistry is independent of knowledge in physics.
25	Learning physics changes my ideas about how the world works.**** t(86) = 2.204, p < .05**
26	To learn physics, I only need to memorize important equations and definitions. **** t(86) = 3.197, p < .05**
27	Reasoning skills used to learn physics can be helpful to me in my everyday life. **** t(86) = 4.978, p < .05**
28	Since Einstein's theory of relativity is just a theory, scientists may believe it's completely wrong tomorrow.
29	Spending a lot of time figuring out and understanding the derivations or proofs of formulas is a waste of time. As long as I know a formula works it doesn't matter where it came from. **** t(86) = 3.165, p < .05**
30	For me to learn physics, it is much more useful to solve many problems rather than by carefully analyzing just a few in detail.
31	The physics used today, which is firmly based on experiment, is certain to be useful in the future. **** t(86) = 2.649, p < .05**
32	The subject of physics has little relation to what I experience in the real world. **** t(86) = 2.365, p < .05**
33	There is only one correct approach to solving any given physics problem. **** t(86) = 2.642, p < .05**
34	To understand physics, I sometimes think about my personal experiences and relate them to the topic being analyzed.
35	It is possible to learn physics without mathematical formulas.
36	When I solve a physics problem, I explicitly think about the concepts within the problem. **** t(86) = 2.997, p < .05**
37	When studying physics, I reorganize the important information rather than just memorizing it the way it is presented.

Figure 1. Pre- and Post- CLASS attitude survey student agreement with experts