Journal of Interactive Online Learning **Volume 5, Number 1, Spring 2006**
www.ncolr.org/jiol **ISSN: 1541-4914**

The Efficacy of Online MBL Activities

David Slykhuis
James Madison University

John C. Park
North Carolina State University

Abstract

The focus of this study was twofold: one, to determine if students could increase their physics content knowledge through the completion of an online hands-on Microcomputer-Based Laboratory (MBL) unit on motion; and two to determine if the demonstrated learning gains were equivalent to those of students who completed the same MBL activities in a more traditional classroom setting with their teacher. One hundred and fifty high school physics students from five diverse high schools participated in the study. Ninety-five were in the classroom group and 55 were in the online group. The online group showed significant comprehension gains from pre-test to post-test. When compared to the classroom group, there was not a significant difference in the gain scores between the two groups. This suggests that further study could lead to the development of online, hands-on physics classes that could be offered to students whose schools do not offer physics due to the lack of resources or physics teachers.

High school students should take advantage of the opportunity to learn physics. Those students who do seize this opportunity deserve to be exposed to the preeminent teaching methods available because the conceptual understanding of physics by students is extremely low. Methodologies utilizing constructivist principles whereby students actively participate in the learning process have been especially effective at inducing conceptual change in students. The Internet can provide a medium through which constructivist teaching principles can be preserved and even enhanced.

Literature Review

Solving complex problems and understanding modeling and estimation are skills that should be learned by students. These skills can be taught in a physics classroom (Redish, 2002). The best way for students to learn physics is to progress away from the traditional lecture and mathematical problem-solving approach that has been used for so many years. In a study of over 6,000 students, Hake (1998) found that students who received physics instruction that promoted "heads-on" and "hands-on" activities performed more than two standard deviations higher than students who received lecture-based instruction on conceptual and problem-solving tests in mechanics .

Physics instruction can deviate from traditional lecture in varying degrees. A small step from traditional lecture is the use of interactive lecture demonstrations. These demonstrations, which use student predictions coupled with real-time data projected to the class, have been shown to increase student understanding (Johnston & Millar, 2000). A larger step away from lecture was illustrated in a study by Chang (2001) involving 159 tenth grade students. Chang compared groups receiving problem-based computer-assisted instruction versus a more traditional lecture-centered approach. Students receiving the problem-based computer-assisted instruction scored significantly higher on knowledge and comprehension post-tests. Another instructional model differing from lecture (to be described in greater detail later) is what Redish (2000) classifies as research-based active engagement instructional methods.

Many of the methods listed above can be incorporated into a constructivist classroom. While research has shown that constructivist philosophies can be effective (Lord, 1999; McKittrick, Mulhall, & Gunstone, 1999; Yager & Weld, 1999), these philosophies can be carried to an extreme, known as radical constructivism. One interpretation of radical constructivism defines it as removing any form of teacher assistance, and instead relying on the student to assemble all knowledge, with no objective truth (Rezaei & Katz, 2002). In their study, Rezaei and Katz showed that inventive teaching, a mild form of constructivism where the teacher assisted students with their knowledge construction, significantly outperformed radical constructivist methods.

Another instructional method that has been championed in education is that of computer-assisted instruction (CAI). Computer-assisted instruction is a broad term that relates to any intervention by a computer with a student. In an analysis of 24 studies involving CAI versus traditional classroom settings, Christmann and Badgett (1999) found an average effect size of .266 for CAI. This meant students who received the CAI scored higher than 60.4% of the students in the traditional group. The effect size for CAI in physics classes was .280. In a more recent and broad meta-analysis, Bayraktar (2001) found 42 studies, with 108 different effect sizes, providing adequate statistics comparing CAI and traditional teaching strategies. The average effect size of these studies was .273. Another way of understanding this effect size is that it would indicate in a student an increase from the 50th to the 62nd percentile. Physics in particular had an effect size of .555. A more recent example of such a study would be the work completed by Kiboss (2002). One hundred eighteen students in Kenya underwent a six-month physics course on measurement. These students were divided into collaborative computer-based or traditional, primarily lecture, groups. The post-test analysis demonstrated better understanding by the collaborative computer-based group than by the traditional group.

Besides the learning gains of CAI, students tend to enjoy and prefer this method of instruction over traditional lecture settings (Chang, 2002; Kiboss, 2002). For 27 consecutive semesters, students have rated CAI as the most helpful part of instruction in a physics course at the University of Illinois despite different instructors, different teaching styles, and different textbooks (Jones & Kane, 1994). Students who were left unguided with CAI were outperformed by both traditional students and students using the same CAI who were given guidance by their teacher (Ardac & Sezen, 2002).

Although CAI encompasses many different applications and treatments, the technology in any CAI system should be designed to fit the teacher, so that the teacher does not have to change to fit the technology. A well-designed system should make the technology transparent, allow for reinterpretation by different users, and utilize common technologies (Zhao, 1998). For example, in a study where the teacher had little technology training, no difference was found between the CAI and traditional classroom groups. On examination of videotape of the classroom, it was found that considerable amount of time was spent on learning and operating the technology (Duffy & Barowy, 1995).

The use of the Internet (or WWW depending on language used in a given study) is a newer form of CAI. Research has been conducted on the feasibility of teaching science classes via the Internet. One important factor to determine was if the Internet was inherently biased against certain groups. Hargis (2001) determined factors such as age, gender, racial identity, attitude and aptitude do not have an effect on learning completed via the Internet. A second major concern, particular to science teachers, is teachers' interest in maintaining laboratory activities in online classes. To date, the most common ways of managing this issue have been through the use of computer simulations, videos, the sending of lab materials in kits to distant sites, and through the manipulation of laboratory equipment remotely through the computer (Forinash & Wisman, 2001).

The Internet can be used in the classroom for a wide variety of reasons. Reasons can include, but certainly aren't limited to, finding information, accessing tutorial or constructivist content, communicating, and collaborating (Bazley, Herklots, & Branson, 2002). More specifically for the physics classroom, the Internet is appropriate for applications such as showing graphics that promote understanding, and interactive applets where the students can change and control parameters (Clinch & Richards, 2002). Another example that utilizes the power of the Internet in the physics classroom and ties the classroom to the real world, is to collect current data on social related physics concepts such as power consumption and power production (Hammond, 2002). The Internet can allow students to complete studies that are not normally possible or practical in a traditional classroom. Post-Zwicker et al. (1999) reported on a unit completed by high school students that involved the modeling and manipulation of topics relating to plasma physics. These students not only simulated experiments that would not be possible, they also were in contact with physicists throughout the duration of the project.

Use of the Internet can have benefits in the classroom beyond aiding in knowledge acquisition. Some of these additional benefits include a variety of different information presentation styles, the transparency of gender and race in online communication, and the fostering of creativity (Bazley et al., 2002). One study compared students who completed a traditional lecture class to those who researched a topic and constructed their own web page on the material. Those who created their own web page not only were allowed to express their own creativity, but at the end of the unit had changed their preferred learning style to one that favored questioning over the traditional lecture with which they were most familiar (Lin, Cheng, Chang, & Hu, 2002).

Shortly after the invention of the microcomputer, science teachers were taking advantage of this new technology. One of the methods was the use of microcomputer-based laboratories (MBL's). Teachers who were given the opportunity to experiment with motion detectors for the first time reported envisioning uses in the classroom that ranged from replacing equipment in traditional reinforcement labs to developing concepts (Solomon et al., 1991). These activities use a sensor and the computer to collect and display, in real-time, data collected from an experiment. Teachers and researchers were quick to realize that besides aiding in the understanding of science concepts, this could also have a positive impact on students' ability to interpret graphs. Mokros and Tinker (1987) studied the effect of using MBL's on 125 seventh graders. These students were split into two groups and one group used MBL's in their science classes at least 20 times over the course of study. This group of students demonstrated significant gains versus the other group on a graph interpretation post-test, despite having received no explicit instruction on graphs. Mokros and Tinker (1987) suggest four reasons for the effectiveness of MBL's:

> It is very likely the combination of these four factors (multimodal reinforcement, real-time linking of concrete and abstract, meaningful context, and elimination of drudgery) that contributes to the power of learning via MBL. When students are in control of a learning experience that they design, are given real-time feedback about that experience, and are freed from the painstaking task of producing a graph, they are in an ideal position to learn what a graph says and means. (p. 382)

Shortly thereafter, it was determined that the real-time graphing feature of MBL's was indeed a critical component for student learning. If the graph presentation was delayed until the conclusion of the event, then the improvement effect on student outcomes by MBL's disappeared (Brasell, 1987).

MBL's have quickly spread throughout the science education community and have been studied for many different effects. They showed no significant gains to graph interpretation in a biology classroom (Adams & Shrum, 1990) and no significant gains on the science reasoning skills of 8th graders (Friedler, Nachmias, & Linn, 1990). Women in a college physics class who were less inclined to like the computers than their male counterparts at the beginning of the semester had equally positive attitudes toward computers after a semester of MBL instruction (Laws, Rosborough, & Poodry, 1995).

MBL's continued to prove effective in producing conceptual change in physics students. When MBL's replaced small group problem solving sessions for mechanics students at the University of Maryland, performance significantly improved compared to traditional methods (Redish, Saul, & Steinberg, 1997). It was also found that the best way to use MBL's was in combination with having students predict the outcome of the experiments. Bernhard (2000) examined the use of MBL's with and without this element of prediction and established that using MBL's in conjunction with prediction produced higher levels of conceptual change in a university physics course for non-physics majors.

Methodology

This research project combines constructivist approaches with MBL's within an Internet course. The MBL curriculum that was chosen for this study was the Tools for Scientific Thinking: Motion and Force units developed by Sokoloff and Thornton (1998). Thornton began experimenting with MBL's in the classroom soon after their development. He was especially interested in the use of the motion detector and its applications. He placed the motion detector and some sample lab activities into the hands of both sixth grade and undergraduate students and noticed how these two very different groups both enjoyed the activities, were engaged in the learning process and were able to quickly understand how to use the technology (Thornton, 1986, 1987a).

The development of the Tools for Scientific Thinking (TST) curriculum was the result of this work. Thornton (1987b) believed the motion detector and the MBL were ideal tools to encourage the inquiry needed in the physics classroom. The tools themselves, however, were not enough; they needed to be coupled in a pedagogically sound curriculum. Students would be active participants in the science process and encouraged to learn from peers. Students can easily extend the classroom activities to investigate topics in greater depth. The goals of the TST curriculum are to make abstract concepts more concrete through the immediate feedback provided, thus assisting the under-prepared student or the student with science anxiety. The TST curriculum was first tested with university physics classes, both calculus-based and non-calculus based, and was found to significantly decrease the number of misconceptions on kinematics graph interpretation and to significantly increase the retention of this material (Thornton & Sokoloff, 1990).

This study uses six investigations of the TST curriculum regarding motion presented in two treatments. First, it was presented in normal classroom setting with a physics teacher and the computer resources to necessary complete the activities. The second treatment included the computer resources to necessary complete the activities presented via a web site with minimal to no teacher interaction. This design was implemented to determine first; can high school students learn physics through the use of WWW-based MBL activities? Second, was there a difference between the WWW-based MBL units and classroom-based MBL units on kinematics?

Population

Participants included 150 North Carolina high school physics students. Fifty-five students from two high schools completed the curriculum online. These students are referred to as the online group. This group ranged in age from 15 (6% of this subset of the population) to 18 (6%) and the students were in the 11th (38%) or 12th (62%) grade. There was a nearly equal split of males and females and they were 75% African-American. Forty-eight members of this group were currently enrolled in a math class with 25 (52%) of them in pre-calculus and 12 (25%) in calculus. The school year prior to this study, 14 (27%) students had completed pre-calculus and 20 (38%) had completed algebra II. They accessed a website designed by the researcher that placed the TST curriculum on the WWW. Students were presented with the same lab activities and directions. When these students answered questions their responses were sent to the researcher from the website. The teachers in these classes were requested to provide no help with the physics concepts, but were asked to assist with any technical difficulties. There is evidence that the teachers in this group did not assist the students with concept formation. One of the free-response answers given several times by students for reasons this unit was different from their normal science classes was because their teacher was not available for help.

Ninety-five students from three high schools completed the curriculum in a traditional CAI manner. These students are referred to as the classroom group. They received paper copies of the labs and worked in groups of two to four people at a computer with a motion detector. Their physics teachers presented the curriculum to them and assisted them as needed throughout the duration of the study. This group ranged in age from 15 (8%) to 18 (3%) and the students were in the 10th (1%) through 12th (59%) grade. There were 57 (60%) males and 38 (40%) females and they were 78% Caucasian and 13% African-American. Seventy-three members of this group were currently enrolled in a math class with 31 (42%) of them in pre-calculus and 19 (26%) in calculus. The school year prior to this study 43 (46%) students had completed algebra III and 27 (29%) had completed algebra II. Schools, and therefore students, were placed in either the online or classroom group based upon the available technology in the science classrooms. Schools that could support the online instruction were the ones to receive it.

Treatments

For both groups this unit took place within the first two months of the school year. Therefore, the students involved in the study had received minimal physics instruction on any topic, and no instruction on kinematics in the physics class where this unit was completed, prior to this unit.

The online group contained two schools from different areas in North Carolina. One school was a large urban school, and the other a smaller rural school. A teacher in each of the two schools volunteered their classes for participation in the project. Each teacher was provided with the motion detectors and LabPro interface devices; however, each of these schools provided their own online computers for use in the physics classrooms throughout the project. The teachers reported being familiar with MBL's but had not used the TST curriculum prior to this study. Two to four weeks were required to complete the unit. The teachers in the online group were asked not to help with the physics concept development of the students. This was requested to encourage the students to use the website, Internet, and peer resources to complete the activities. The Fysics Is Fun website had a set of links where the students could go for help. There were also multiple links for the students to reach the researcher electronically with questions or comments. The website included a section where the students were able to post thoughts, frustrations, and successes with each other. The TST activities themselves were identical to the classroom group except they were on web pages instead of paper. The students only used paper when directed by the website to print graphs so that they could make predictive sketches of the motion they were about to observe. The online group required more computer savvy from the students. They had to be able to move fluently between two windows, the browser window with the website, and the Logger Pro window that displays the real-time graphs created by the motion detector. They also were required to download and print the occasional graph as mentioned earlier. At the request of the teachers before the project began, the Fysics Is Fun website included a portion that supplemented the TST curriculum with an introduction to kinematics problem solving. The questions from the activities and homework of the TST curriculum were completed on the web and the answers were automatically forwarded to the researcher when submitted. The researcher scored these responses and sent them back to the classroom teacher to use as grades for the students.

The classroom group consisted of three schools from different regions of North Carolina. One teacher in each of the three schools volunteered their classes for participation in the project. Each teacher was provided with motion detectors, LabPro interface devices, and laptop computers. All of the teachers reported being familiar with using MBL's but had not used the TST curriculum prior to this study. Two to four weeks were required to complete the unit, and the teachers were asked to present the curriculum in their normal teaching style. Although the TST lab activities included directions, concept development, and homework, teachers were free, and encouraged, to t*each* the students as they completed the labs. The teachers were requested to score the lab activities and use them as grades as they were completed.

Pre- and Post-Test

The test administered in this study was the Test of Understanding Graphs-Kinematics (TUG-K see Appendix A) by Beichner (1998). This test was born out of a study to determine if the learning gains from MBL activities were primarily due to the display of the real-time graphs or the kinesthetic creation of the graph coupled with the real-time display of the graph (Beichner, 1990). Beichner reported that the kinesthetic element of the unit in combination with the real-time graph display was significantly better than watching the event and the graph together.

Beichner (1994) further studied the validity and reliability of the TUG-K so that it could be used explicitly with MBL studies that relied heavily on graph interpretation to convey physics concepts. The test was revised several times and given repeatedly to high school, junior college, and university students. The KR-20 reliability statistic for the TUG-K was .83, well above the .70 required for a reliable test. The Point-Biserial Coefficient of .74, was well above the .20 required for reliable items. Fifteen science educators established the validity. The final version was administered to an additional 524 post-instruction high school and college students to establish the baseline data expectations. The mean score established for all students was 8.5 (40%).

Results

The pre-test mean on the TUG-K, with 21 as the top possible score, for the online group was 3.3 with a range from 0-11. The post-test mean on the TUG-K was 7.6, with a range from 2-18. The average gain score was 4.3 (see Table 4.1).

Table 4.1
Comparison of Pre- and Post-Test Test Scores of the Online Group (n=55)

	Mean	SD
Pre-Test	3.3	2.2
Post-Test	7.6	3.8

$p < 0.0001$

A one-tailed paired t-test showed there were significant gains from pre- to post-instruction. The resulting t-statistic had a p-value that was <.0001. This strongly suggests that learning occurred during the treatment period for the online group. While the mean post-test score, 7.6, is still relatively low for a test of 21 questions, it is near the mean level, 8.5, established for the TUG-K by *post instruction* high school and college physics students.

A similar analysis of the classroom results showed that there was also a statistically significant improvement in their scores (see table 4.2).

Table 4.2
Comparison of Pre- and Post-Test Scores of the Classroom Group (n=95)

	Mean	SD
Pre-Test	5.9	3.8
Post-Test	9.4	4.3

$p < .0001$

A one-tailed paired t-test of the classroom group resulted in a t-statistic with a p-value that was < .0001. This also strongly suggests that learning occurred for the classroom group during the treatment period. Figure 4.1 shows the distribution of pre- and post-test scores for both groups combined.

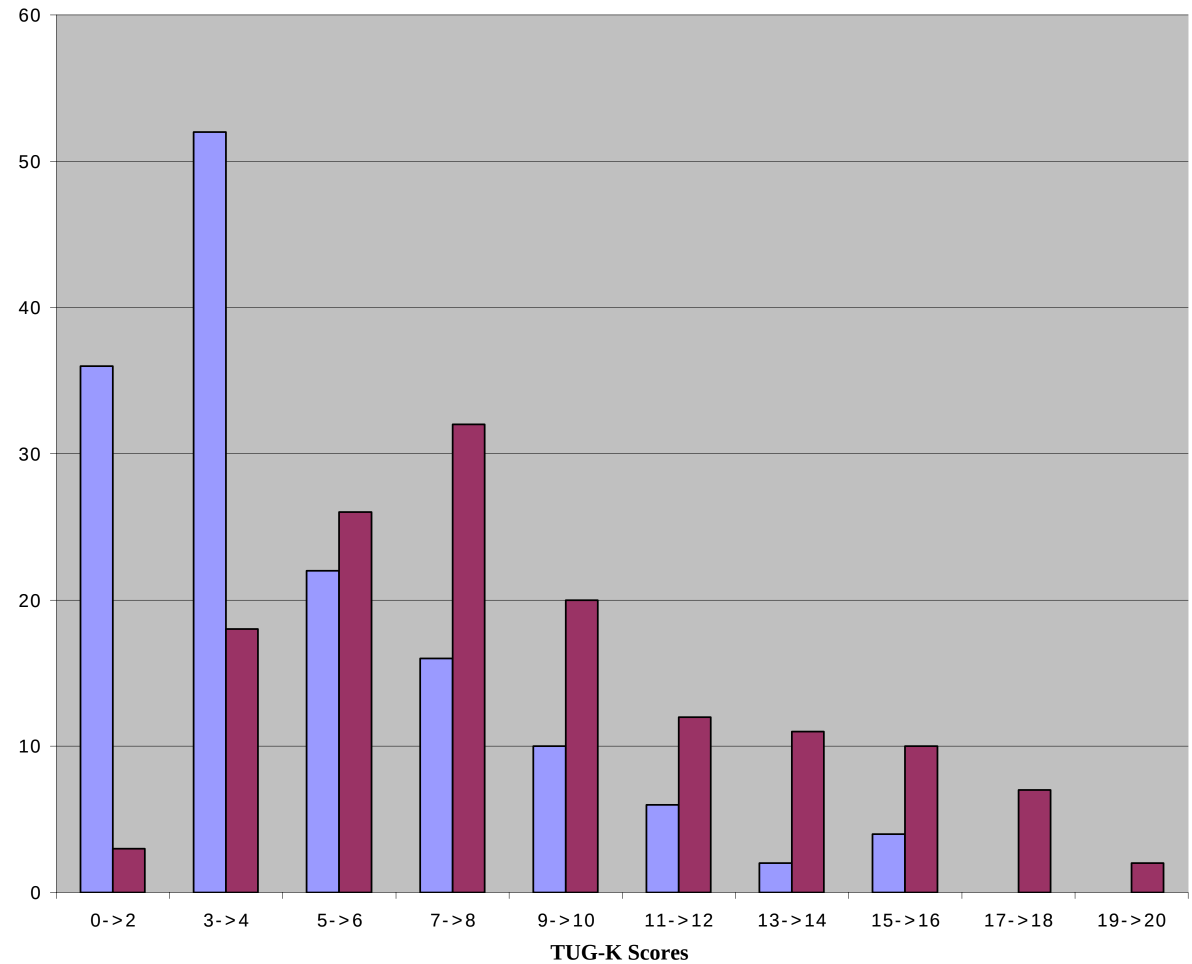

Figure 4.1- Combined Groups Distribution of Pre- and Post-Test Scores

T-tests were preformed to determine if there was a difference between the groups on the pre-test, the post-test and in gain score (Table 4.3).

Table 4.3
Comparison of Online and Classroom Groups (unequal variances)

	T	DF	Prob>|t|
Pre-Test Score	5.157	145.975	<.0001
Post-Test Score	2.602	112.116	.0105
Gain Score	-1.482	99.6129	.1415

There is a significant difference, $p < .05$, between the online and classroom groups in both the pre-test and the post-test. There is not a significant difference, $p>.05$, between groups on the gain scores (See Figure 4.2).

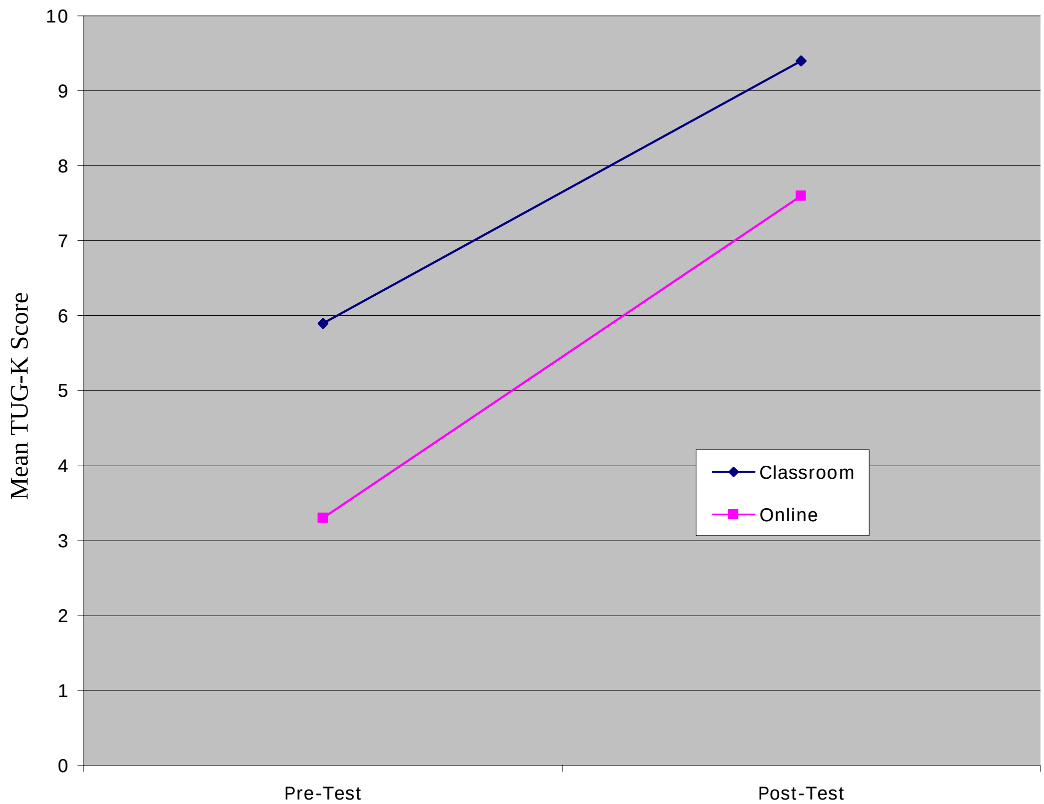

Figure 4.2- Mean TUG-K Scores by Group

These statistical tests indicate that the classroom group started and ended with higher scores, but that the gain, or amount learned by each group was not significantly different. This suggests that unit was equally effective for both groups.

A second statistical analysis was completed to confirm these results. An ANCOVA was performed to compare the groups on the post-test, using the pre-test as a covariate. The first model fit included an interaction term for whether or not the groups differed in the relationship between post-test and pre-test. The result of this test, $p = 0.4666$, indicated that the interaction was not significant, and the cross-product term between the variables was removed from further analysis.

The ANCOVA results (Table 4.4) indicate similar results as the t-test. Examination of the post-test score with control for an individual's pre-test score does not reveal a significant difference between the groups. This suggests that the amount of learning exhibited by both groups was similar, and that the difference in post-test scores is a consequence of the classroom group having started at a higher pre-test score.

Table 4.4
ANCOVA of Post-test on Pre-test and Group

Source	DF	Sum Squares	F Ratio	Prob> F
Pre-test	1	1129.6	120.84	<.0001
Group	1	5.1036	.5460	.4612

One of the concerns of this study was that the treatments were taking place in five different schools, with five correspondingly different teachers, and that some of the effect could be attributable to school instead of group. Indeed, in an ANOVA on pre-test by school, there was a significant difference between the schools. The difference broke the schools into three groups. School A, was the highest and different from the second school, School B. School B was different from the next three schools, Schools C, D, and E, which were all similar. The classroom group contained school A, school B, and one school from the third group. Both of the online schools were in the third group. In a similar analysis with the post-test score, only school A was significantly higher than the other four schools, which were all similar.

To determine if school had an effect on achievement, an ANCOVA analysis was completed in a similar manner as was carried out with the variable group. First, the post-test was analyzed in a model including a cross-product term between school and pre-test to determine if there was an interaction between these variables. This was not significant and omitted from subsequent analyses. When post-test was modeled by pre-test and school (Table 4.5) it was determined that school was not a significant factor. The p-value, .23, indicates that once you control for the pre-test score, the school attended by the individual is not a significant factor when determining the post-test score.

Table 4.5
ANCOVA of Post-Test on Pre-Test and School

Source	DF	Sum Squares	F Ratio	Prob > F
Pre-Test	1	1075.8	116.89	<.0001
School	4	52.432	1.4242	.2293

Beichner (1994) established that there was a difference in achievement on the TUG-K according to gender. A t-Test was performed on the pre-test, post-test and gain scores by gender (Table 4.6). There were significant differences between the genders on both the pre- and post-test. The gain scores, however, were not significantly different.

Table 4.6
t-Test of Gender (with unequal variance)

	Mean (F)	Mean (M)	t-Test	DF	Prob > |t|
Pre-Test	3.918	6.067	-3.735	127.75	.0003
Post-Test	7.431	10.11	-3.744	124.85	.0003
Gain	3.517	3.900	-.706	123.81	.4818

An ANCOVA of the post-test scores controlling for pre-test and gender (see Table 4.7), completed in a similar manner as those on group and gender, confirmed these results.

Table 4.7
ANCOVA of Post-Test on Pre-Test and Gender

Source	DF	Sum Squares	F Ratio	Prob > F
TUG-K Pre	1	1047.6	114.7	< .0001
Gender	1	22.4	2.4	.12

Discussion

The results indicate that neither gender nor school significantly affected the post-test performance of a student once the pre-test score was controlled. More importantly for this study, the results also indicate the presentation mode of the MBL activities did not significantly affect students' performance. It is important to note that in most studies that compare CAI with traditional classes, no computers are involved in the traditional group. This study was unique; it compared different degrees of reliance on the computer when using CAI. When using a well-designed constructivist-based curriculum with MBL's involving the students kinesthetically and displaying real-time data, students' computer abilities are sufficiently sophisticated to take the complete instruction from the Internet with no decrease in the quantity of learning that occurs.

This study also indicates that both groups gained understandings of kinematics through the graphs they created as tested by the TUG-K. While it appears as if the amount of learning for both groups may not have been as high as desired, the mean for both groups on the post-test was 8.79. This compares favorably to the mean found by Beichner (1994) of 8.5. Beichner's TUG-K baseline mean was obtained from a combination of high school and college students after the completion of a physics course. The 8.79 mean obtained in this study was for high school students who were in their second month of physics instruction.

Neither the design nor the results of this study were intended to imply that teachers are not a critical component of the classroom. A quality teacher provides students with many aspects of support that a computer cannot. A teacher can be a mentor, a role model and even a friend in time of need. A teacher can sense the mood and emotional needs of a student that a computer cannot. A teacher can monitor students working in a group to find the individual that is not participating or not understanding the material.

The results of the study do, however, suggest some exciting opportunities for web-based instruction. The marriage of MBL curriculum and the online environment is relatively unique. MBL physics curriculum, when designed with constructivist principals, has prior been shown by itself to be equivalent or better than traditional (here meaning lecture-based) physics classroom settings. This study has shown that online MBL curriculum is not significantly different from the traditional, teacher-led, MBL curriculum. The promise of these results is tempered by the fact that the study was short term with a moderate sized population. Further research would be needed to determine if similar results would be achieved over the course of a semester or full year of physics instruction.

Schools in many regions across the country have difficulties finding physics teachers, especially "highly qualified" physics teachers. A method of physics instruction that is online and involves the use of MBL equipment could be an avenue that schools can pursue if they cannot fill physics teacher vacancies. This could be especially attractive to small high schools that may only have a handful of students interested in pursuing a physics class.

This study also offers direction for additional research. One of the limitations of this study was that the online group had a teacher present who was asked to be a technician only. It would be useful to test this approach in an environment that is truly devoid of a physics teacher. Another area that needs further study is the content of the unit itself. The TST curriculum has two parts, Motion and Force, and Heat and Temperature. Of those, only the motion component was part of this study. If this research were to indeed be expanded to a full physics course, these units would be good starting points, but more curriculum using similar pedagogy would have to be developed to encompass all that is learned in a year of high school physics.

References

Adams, D. D., & Shrum, J. W. (1990). The Effects of Microcomputer-based Laboratory Exercises on the Acquisition of Line Graph Construction and Interpretation Skills by High School Biology Students. *Journal of Research in Science Teaching, 27*(8), 777-787.

Ardac, D., & Sezen, A. H. (2002). Effectiveness of Computer-Based Chemistry Instruction in Enhancing the Learning of Content and Variable Control Under Guided versus Unguided Conditions. *Journal of Science Education and Technology, 11*(1), 39-48.

Bayraktar, S. (2001). A Meta-Analysis of the Effectiveness of Computer-Assisted Instruction in Science Education. *Journal of Research on Technology in Education, 34*(2), 173-188.

Bazley, M., Herklots, L., & Branson, L. (2002). Using the Internet to Make Physics Connect. *Physics Education, 37*(2), 118-121.

Beichner, R. J. (1990). The Effect of Simultaneous Motion Presentation and Graph Generation in a Kinematics Lab. *Journal of Research in Science Teaching, 27*(8), 803-815.

Beichner, R. J. (1994). Testing Student Interpretation of Kinematics Graphs. *American Journal of Physics, 62*(8), 750-762.

Beichner, R. J. (1998, Feb. 17, 1998). *Kinematics Graph Interpretation Project*. Retrieved Feb. 26, 2004, from www.physics.ncsu.edu:8380/physics_ed/TUGK.html

Bernhard, J. (2000). Can a Combination of Hands-on Experiments and Computers Facilitate Better Learning in Mechanics? *CAL-Laborate*, 1-5.

Brasell, H. (1987). The Effect of Real-time Laboratory Graphing on Learning Graphic Representations of Distance and Velocity. *Journal of Research in Science Teaching, 24*(4), 385-395.

Chang, C.-Y. (2001). Comparing the Impacts of a Problem-based Computer-Assisted Instruction and the Direct-Interactive Teaching Method on Student Science Achievement. *Journal of Science Education and Technology, 10*(2), 147-153.

Chang, C.-Y. (2002). Does Computer-Assisted Instruction + Problem Solving = Improved Science Outcomes? A Pioneer Study. *Journal of Educational Research, 95*(3), 143-150.

Christmann, E., & Badgett, J. (1999). A Comparative Analysis of the Effects of Computer-Assisted Instruction on Student Achievement in Differing Science and

Demographical Areas. *The Journal of Computers in Mathematics and Science Teaching, 18*(2), 135-143.

Clinch, J., & Richards, K. (2002). How Can the Internet Be Used To Enhance the Teaching of Physics? *Physics Education, 37*(2), 109-114.

Duffy, M., & Barowy, W. (1995). Effects of Constructivist and Computer-Facilitated Strategies on Achievement in Heterogeneous Secondary Biology.

Forinash, K., & Wisman, R. (2001). The Viability of Distance Education Science Laboratories. *T.H.E. Journal, 29*(2), 38.

Friedler, Y., Nachmias, R., & Linn, M. C. (1990). Learning Scientific Reasoning Skills in Microcomputer-based Laboratories. *Journal of Research in Science Teaching, 27*(2), 173-191.

Hake, R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics, 66,* 64-74.

Hammond, R. (2002). Using the Internet To Teach Physics. *Physics Education, 37*(2), 115-117.

Hargis, J. (2001). Can Students Learn Science Using the Internet? *Journal of Research on Technology in Education, 33*(4).

Johnston, I., & Millar, R. (2000). Is There a Right Way to Teach Physics? *CAL-Laborate,* 10-13.

Jones, L. M., & Kane, D. J. (1994). Student evaluation of computer-based instruction in a large university mechanics course. *American Journal of Physics, 62*(9), 832-836.

Kiboss, J. K. (2002). Impact of a Computer-Based Physics Instruction Program on Pupils' Understanding of Measurement Concepts and Methods Associated with School Science. *Journal of Science Education and Technology, 11*(2), 193-198.

Laws, P. W., Rosborough, P. J., & Poodry, F. J. (1995). Women's Responses to an Activity-Based Introductory Physics Program. *New Directions for Teaching and Learning* (61), 77-87.

Lin, C.-y., Cheng, Y.-j., Chang, Y.-t., & Hu, R. (2002). The Use of Internet-Based Learning in Biology. *Innovations in Education and Teaching International, 39*(3), 237-242.

Lord, T. R. (1999). A Comparison between Traditional and Constructivist Teaching in Environmental Science. *Journal of Environmental Education, 30*(3), 2-27.

McKittrick, B., Mulhall, P., & Gunstone, R. (1999). Improving Understanding in Physics: An Effective Teaching Procedure. *Australian Science Teachers' Journal, 45*(3), 27-33.

Mokros, J. R., & Tinker, R. F. (1987). The Impact of Microcomputer-based Labs on Children's Ability to Interpret Graphs. *Journal of Research in Science Teaching, 24*(4), 369-383.

Post-Zwicker, A. P., Davis, W., Grip, R., McKay, M., Stotler, D. P., & Pfaff, R. (1999). Teaching Contemporary Physics Topics Using Real-Time Data Obtained via the World Wide Web. *Journal of Science Education and Technology*, *8*(4), 273-281.

Redish, E. F. (2000). New Models of Physics Instruction Based on Physics Education Research.

Redish, E. F. (2002). Who Needs To Learn Physics in the 21st Century--And Why? U.S. Maryland.

Redish, E. F., Saul, J. M., & Steinberg, R. N. (1997). On the Effectiveness of Active-Engagement Microcomputer-Based Laboratories. *American Journal of Physics, 65*, 45-54.

Rezaei, A. R., & Katz, L. (2002). Using Computer Assisted Instruction To Compare the Inventive Model and the Radical Constructivist Approach to Teaching Physics. *Journal of Science Education and Technology, 11*(4), 367-380.

Sokoloff, D. R., & Thornton, R. K. (1998). *Tools for Scientific Thinking: Motion and Force*. Beaverton, OR: Vernier Software & Technology.

Solomon, J., Bevans, R., Frost, A., Reynolds, H., Summers, M., & Zimmerman, C. (1991). Can Pupils Learn through Their Own Movement? A Study of the Use of a Motion Sensor Interface. *Physics Education, 26*(6), 345-349.

Thornton, R. K. (1986, June 4-6). *Tools for Scientific Thinking: Microcomputer-Based Laboratories for the Naive Science Learner*. Paper presented at the National Educational Computing Conference, San Diego, CA.

Thornton, R. K. (1987a). Access to College Science: Microcomputer-Based Laboratories for the Naive Science Learner. *Collegiate Microcomputer, 5*(1), 100-106.

Thornton, R. K. (1987b). Tools for Scientific Thinking--Microcomputer-Based Laboratories for Physics Teaching. *Physics Education, 22*(4), 230-238.

Thornton, R. K., & Sokoloff, D. R. (1990). Learning motion concepts using real-time microcomputer-based laboratory tools. *American Journal of Physics*, *58*, 858-867.

Yager, R. E., & Weld, J. D. (1999). Scope, Sequence and Coordination: The Iowa Project, A National Reform Effort in the USA. *International Journal of Science Education, 21*(2), 169-194.

Zhao, Y. (1998). Design for Adoption: The Development of an Integrated Web-Based Education Environment. *Journal of Research on Computing in Education, 30*(3), 307-328.