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Instructional technology research and development in a US physics education group

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The purpose of this brief paper is to provide insight into the kinds of work being done by an education research group in a US physics department. As will be evident, instructional technology raises many interesting questions and lends itself to a wide variety of studies. References and contacts are provided for readers wanting more detailed information on the research. The paper is based on a presentation given at the Workshop on Best Practices of ICT Use in a University Environment, 24 September 2004, in Zürich.

Keywords: Technology; Physics; Curriculum

1. Introduction

The Physics Education Research and Development Group† resides in the Physics Department at North Carolina State University. There are currently 3.5 faculty, two post-docs, five graduate students, and three undergraduates in the group. The main focus of all team members is studying the learning of physics and developing curricular materials based on research—ours as well as others. We have benefited from substantial funding provided by several US government agencies, most notably the National Science Foundation and the Department of Education. We have also received grants from a private foundation, several instructional equipment manufacturers, and educational publishers. This paper tries to provide a brief overview of some of the group's technology-related efforts. The key point to be made is that all our development work starts from a foundation of research on what students know about a particular topic and how they add to their knowledge.

Since the focus is on instructional technology, it is important to realize that our definition of 'technology' is broader than most. The Greek word τεχνολογία a comes from two root words: τέχνη meaning 'skill or method of accomplishing', and λόγος meaning 'understanding or carefully considered'. (The second root often appears at the end of English words like biology or cosmology and means 'study of'.) Based on these roots, we define technology as 'a carefully considered means of accomplishing something'. This is closer to the

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†More information about the group is available at <http://www.ncsu.edu/PER>.

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original meaning of the word before computers became commonplace. Nowadays, nearly everyone thinks of electronics when they hear ‘technology’, so we will start by describing projects of this type that our group has worked on. At the end of the paper we will discuss a large project that is directly related to our expanded definition.

2. Micro and video-based laboratories

Microcomputer-based labs (MBL) are probably the most commonly seen applications of computer technology in the physics classroom. Basically, small sensors detect relevant physical

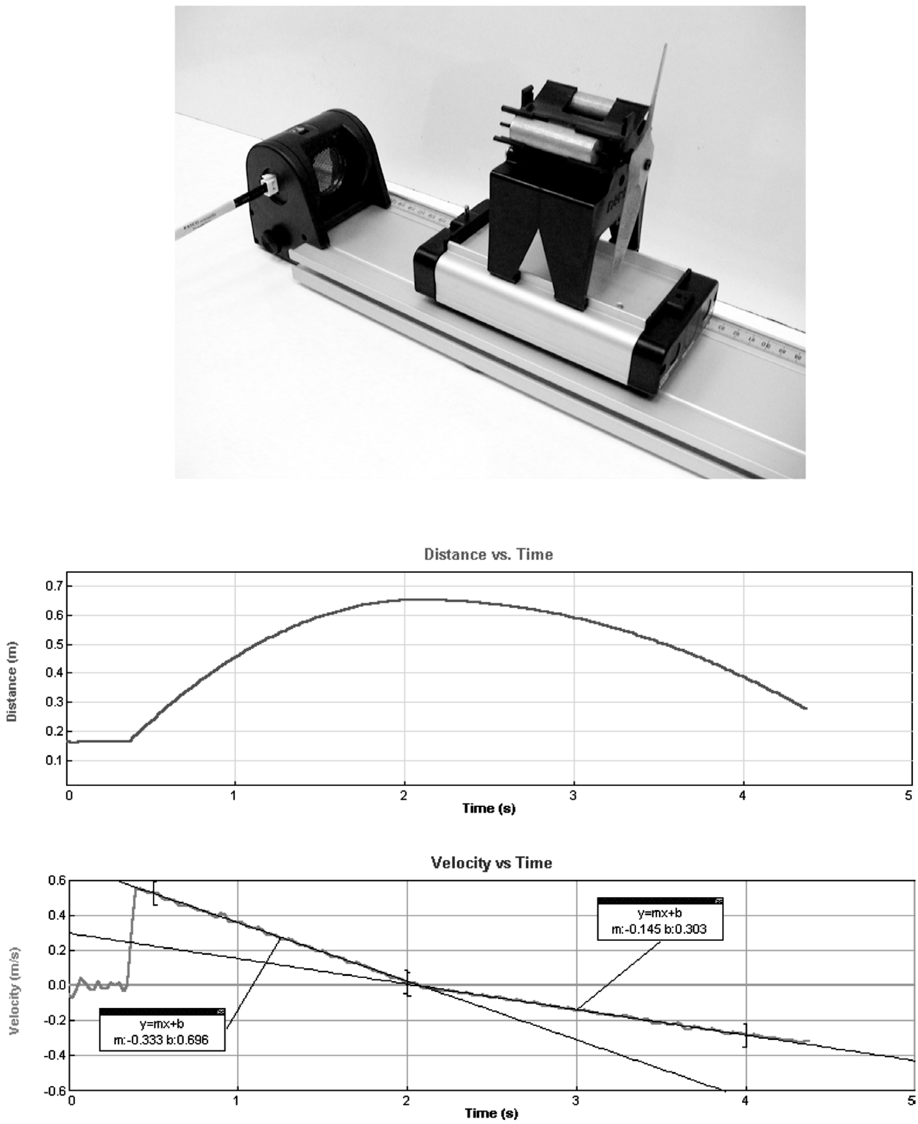

Figure 1. An ultrasonic position detector maps distance and velocity for a low-friction cart powered by a small propeller. Note that the two slopes on the velocity–time graph allow a determination of the (very small) frictional force acting on the cart.

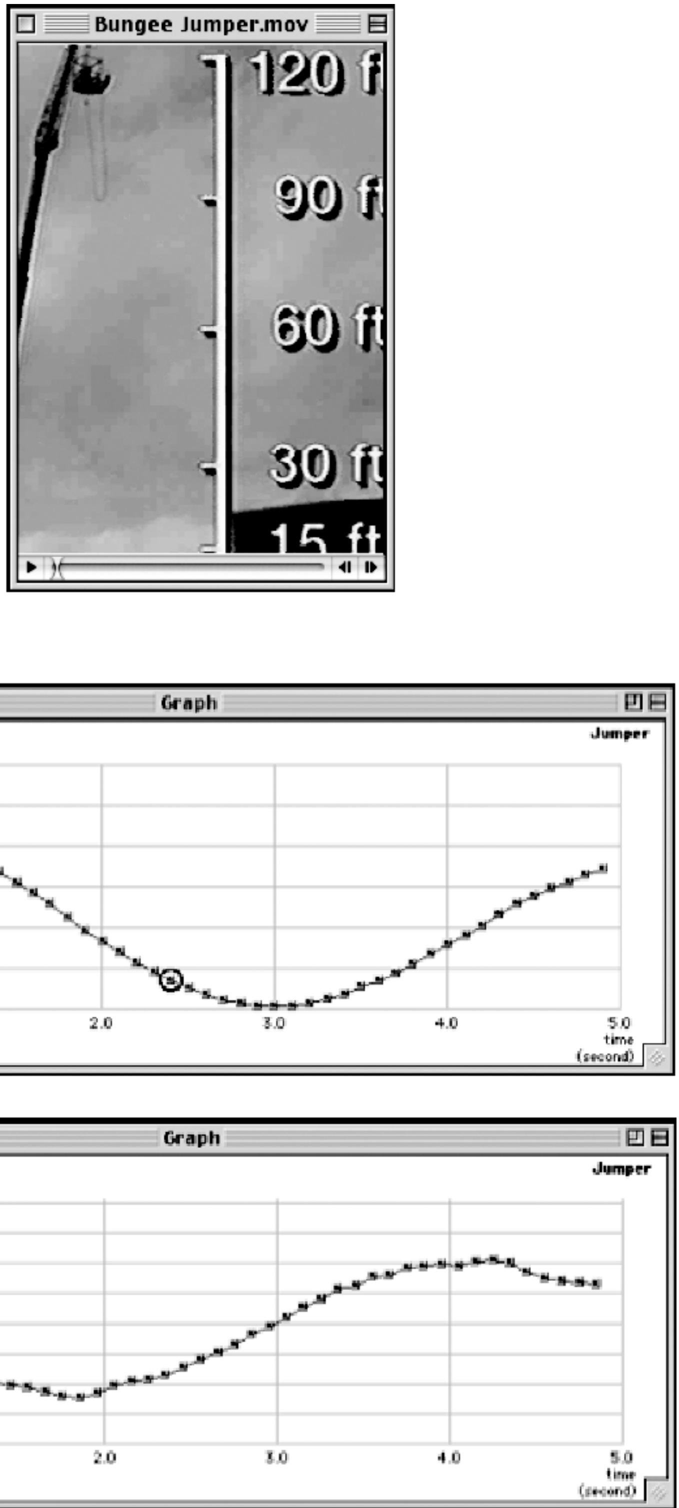

Figure 2. A videoclip of a bungee jumper is analyzed by *VideoGraph* software developed by the author. The first frame of the video shows the jumper still standing on a crane-suspended platform in the top-left corner of the picture.

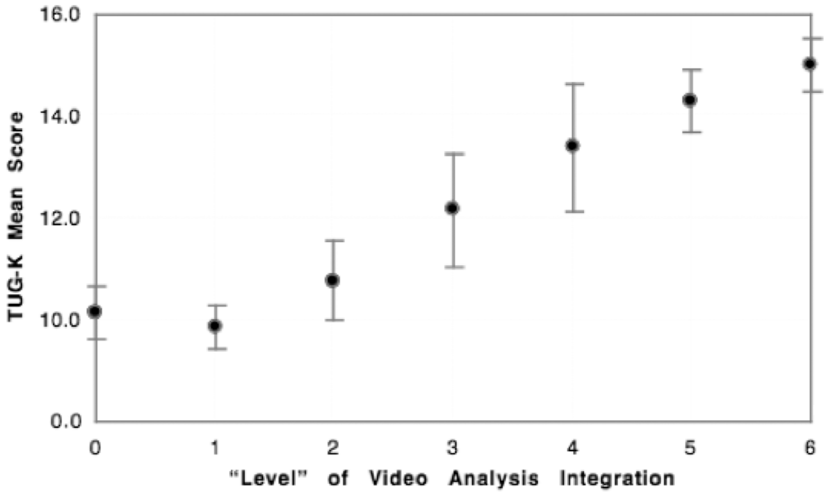

Figure 3. Student ability to interpret kinematics graphs improves as they take advantage of VBL instructional materials.

quantities like position, voltage, or force and send the information to a computer for analysis. (See figure 1.) The critical aspect of instructional materials utilizing these devices is that displays of the data (almost always graphical) are presented in real time. Brasell (1987) found that simply introducing a 20 s delay between data collection and its display on the screen cut the effectiveness of the instructional task in half. Studies we have done (Beichner 1990) indicate that it is the real-time nature of the feedback (as compared to the kinesthetic or visual feedback) that makes the difference. In related research (Beichner 1996), we found that video-based lab (VBL) software, which we invented (Beichner *et al.* 1988) as part of this project, is more effective than traditional instruction. (The software is shown in figure 2.) We were able to relate varying means of utilizing VBL materials to different levels of student success. Figure 3 shows that increased use of VBL software (ranging from seeing it demonstrated by the teacher, to students analyzing self-produced video clips) resulted in better scores on a nationally standardized test (Beichner 1994) of interpreting kinematics graphs. Others have since created more powerful versions of VBL software (Beichner and Abbott 1999). The most popular of these is *VideoPoint*,[†] by Laws, Luetzelschwaub, and Gile at Dickinson College. It is used in high schools and colleges around the world.

3. Web-based assessment

One of the problems faced by teachers with large classes is how to grade homework. We have developed a web-based homework system to deal with this situation. Aaron Titus[‡] came to our group in 1995 as a graduate student interested in taking advantage of students' visual perception to help them learn physics. Titus wanted to see if particular types of physics problems were particularly well-suited to video presentation. To help answer this question (Titus 1998), he developed web-based software to deliver multimedia problems to students. Larry Martin[§] joined us in 1997 on a two-year sabbatical from North Park College. He added his

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[†]Available at http://www.lsw.com/videopoint/

[‡]Dr. Titus in now at High Point University, http://www.highpoint.edu/~atitus/

[§]Dr. Martin is now deceased—a great loss to all his friends and colleagues.

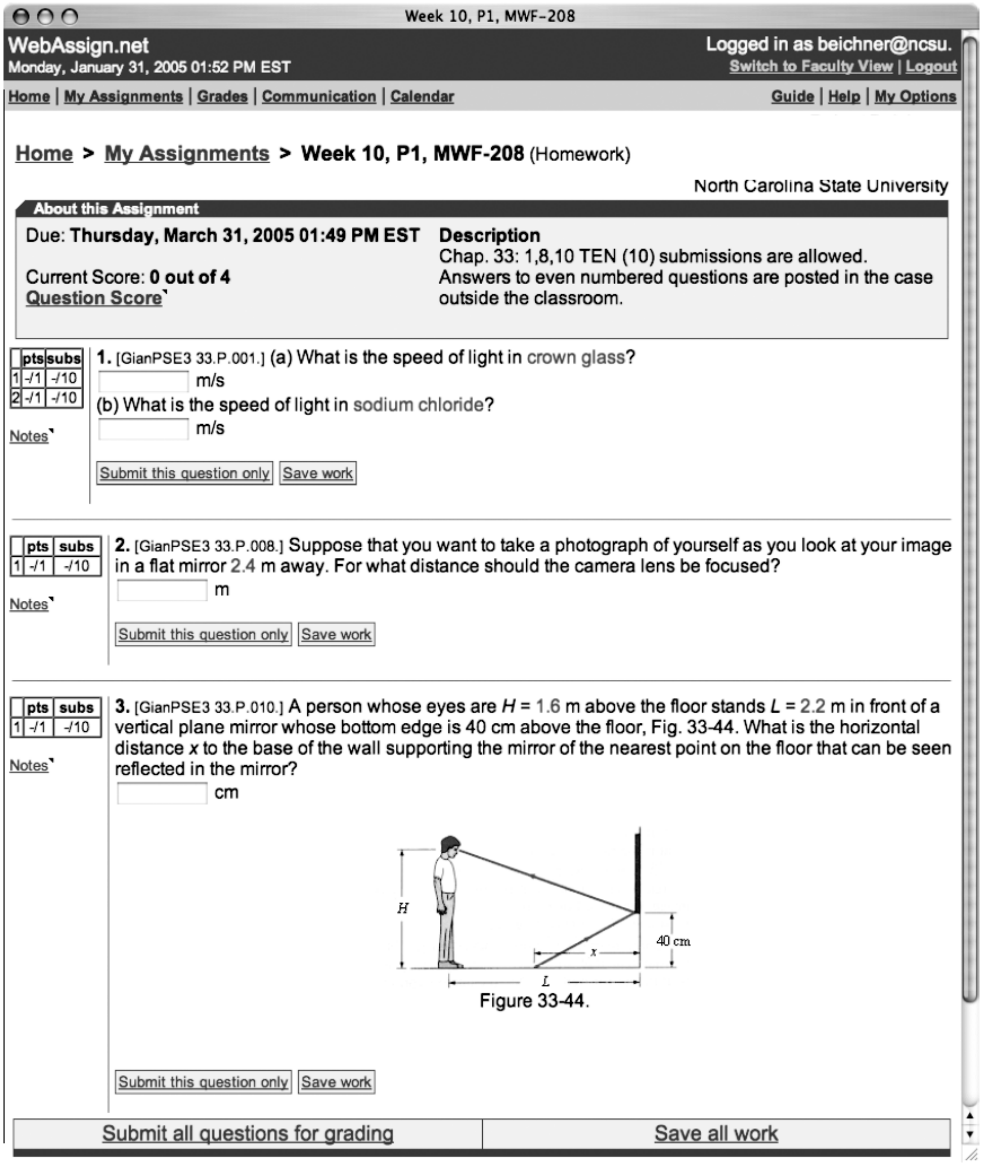


Figure 4. Sample *WebAssign* screen. The words and numbers in red or gray is randomized for each student.

programming expertise and the two created what has now become *WebAssign*,† the most popular web homework system in the US. There are currently more than 125,000 students using the system during any given semester. Hundreds of thousands of questions are in the now-commercial system, including problems from the major science textbooks. Figure 4 illustrates some simple questions displayed by the system. Much more complex presentations are possible. The system is flexible enough to support a wide variety of pedagogical applications (Titus *et al.* 1998), ranging from simple multiple-choice questions to peer-ranking of essays. Faculty member John Risley now runs the thriving business associated with *WebAssign*.

† See http://webassign.net for more information.

Because it permits question delivery to large numbers of students, the web has proven to be a useful tool for several other studies by group members. Scott Bonham[†] came to the group as a post-doc in 1997. He and graduate student Duane Deardorff[‡] collaborated on a direct comparison (Bonham *et al.* 2001, 2003) of web- and paper-based homework. He also led a review (Bonham *et al.* 2000) of different ways the web can be used for educational research. One of the more interesting projects of the group was led by Rhett Allain,[§] a graduate student who utilized *WebAssign* to collect conceptual essays and then compare student ranking of their peers' writing to the ranking of experts (Allain and Beichner 2000). Grad student Melissa Dancy[¶] wanted to know if animating questions from conceptual tests would change student answer choices. She animated (Dancy 2000) the Force Concept Inventory (Hestenes *et al.* 1992), the most widely used assessment instrument in introductory physics. Current graduate student Jeanne Morse[‖] is using the web to deliver a tutorial on various aspects of electric fields.

4. Student programming and visualization

One of the latest efforts of the group is an examination of how three-dimensional visualizations can aid student learning, particularly when students themselves do the programming. To this end, the *VPython* package[††] is being extended[‡‡] by faculty members Bruce Sherwood and Ruth Chabay, along with undergraduate Jonathan Brandmeyer. This powerful addition to the *Python* computer language allows students to easily generate a 3D world where they have to 'teach' the objects they create how to interact in physically realistic ways. A sample screen is displayed in figure 5. Graduate student Matt Kohlmyer is conducting a detailed protocol analysis of students as they write programs to simulate physical situations. The group is also beginning a study of how this type of capability affects students' ability to visualize abstract physical concepts like fields.

5. Classroom environment and pedagogy

At this point it should be clear that electronic technologies have provided a wide range of research and development possibilities for our group. Now I would like to refer back to our definition of technology—'a carefully considered means of accomplishing something'. Our two major curriculum development projects involve instructional technology extensively, both electronic and otherwise.

The *Matter and Interactions* (Chabay and Sherwood 2002) curriculum focuses on incorporating modern physics into introductory courses. Students learn that every problem can be started with one of only three fundamental principles and that the microscopic properties of matter produce its observable macroscopic characteristics. Graduate student Lin Ding is working to validate Chabay and Sherwood's Basic Electricity and Magnetism Assessment

[†]Dr. Bonham is now at Western Kentucky University, http://physics.wku.edu/~bonham/

[‡]Dr. Deardorff is now at the University of North Carolina at Chapel Hill, http://www.physics.unc.edu/~deardorf/

[§]Dr. Allain is now at Southeastern Louisiana University, http://www.phys.selu.edu/rhett/

[¶]Dr. Dancy is now at the University of North Carolina at Charlotte, http://www.physics.uncc.edu/physstaff/mhdancy/

[‖]Ms. Morse is at Sandhills Community College, http://www.sandhills.cc.nc.us/science/faculty.html

[††]Available for free download at http://vpython.org. It runs on Macintosh, Windows, and Linux platforms.

[‡‡]The original developers at Carnegie Mellon included Sherwood, Chabay, David Scherer, David Anderson, Ari Heitner, and Ian Peters.

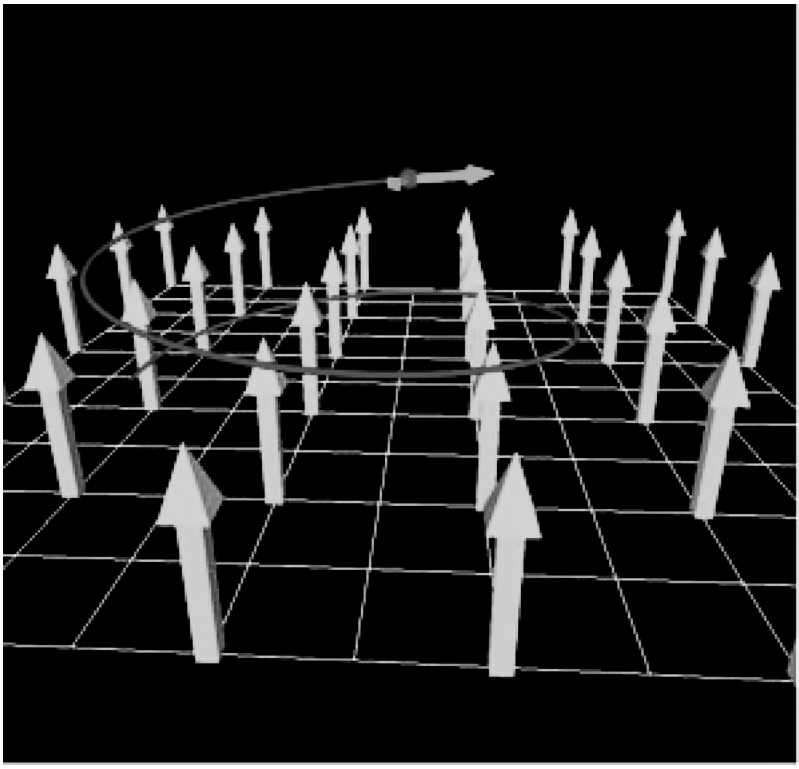
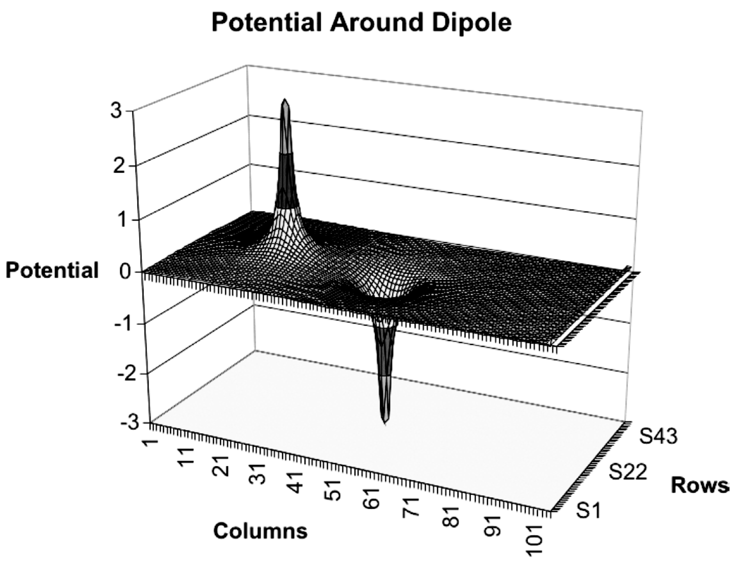


Figure 5. Sample output from a *VPython* program that shows a small red sphere (with the properties of a positive charge) as it moves in an upward pointing magnetic field. Students can easily zoom the view in and out as well as spin around to different viewpoints.

Figure 6. A SCALE-UP classroom has students seated at round tables, surrounded by whiteboards and computer projection screens. An instructor and assistant roam the facility, asking questions.

(BEMA) instrument, which will allow a close inspection of student learning with the new curriculum. *VPython* is used to promote student modeling of physical situations, classroom response systems are used in nearly every class, and there is a distance version of the course. For the distance course, highly compressed video files allow an entire semester of lectures to fit on 4 CDs or a single DVD. A simulated 'clicker' appears on the screen whenever a question is asked during the video. After student entry into the computer, a histogram of actual student answers from a real lecture is displayed. All aspects of the on-site and distance versions of the course and its delivery are carefully designed to maximize understanding, thus the entire curriculum is an example of 'technology'.



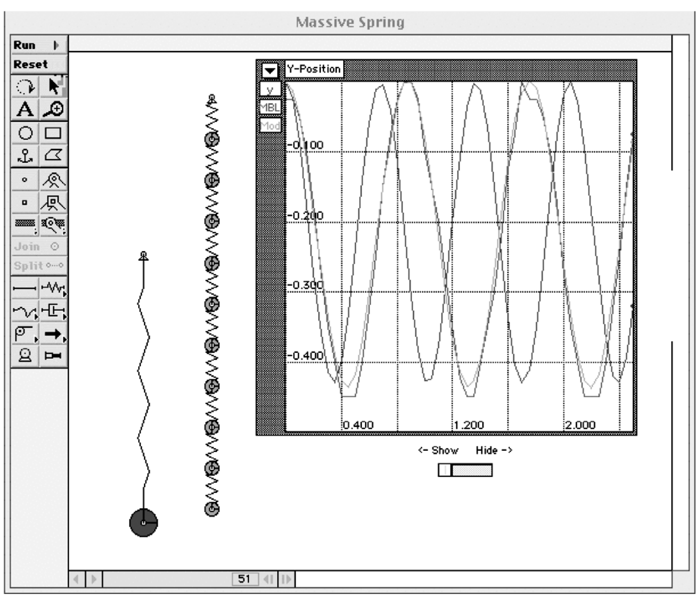


Figure 7. *Excel* and *Interactive Physics* allow students to explore physical phenomena.

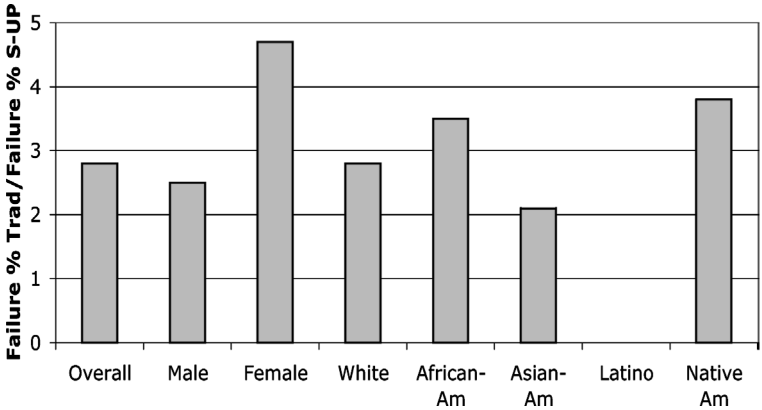


Figure 8. Ratio of failure rate percentages for 16,000 NCSU physics classes found by dividing the percentage of students failing in lecture/laboratory sections divided by the percentage failing in SCALE-UP sections. Here, failing means receiving a grade lower than C—in the mechanics course or less than a D—in the E & M course, the grades needed to receive credit for taking the course. The Latino rate cannot be calculated because no Latino students have failed in an NCSU SCALE-UP section.

The last major effort of the group that incorporates our extended idea of technology is the SCALE-UP project.† The name is an acronym for Student Centered Activities for Large Enrollment Undergraduate Programs. This author, former post-doc Jeffery Saul,‡ and John Risley, along with many of our group's graduate students, have developed and evaluated this extensively reformed approach to teaching and learning. The classroom has been redesigned to facilitate interactions between students and with the instructor. As figure 6 illustrates, students sit in teams of three at round tables. The teacher assigns activities and then walks from table to table, engaging students in conversations about their work. We consider the tables to be the most important 'instructional technology' that we use. Of course, we still have students working with computers. Besides work with *VPython*, they utilize *Excel* and *Interactive Physics* to model phenomena, as figure 7 shows.

Former graduate student David Abbott§ developed many of SCALE-UP's laboratory tasks. These mini-projects, combined with daily hands-on exposure to physical phenomena, have increased learning as measured by a wide assortment of assessments. Failure rates are significantly decreased, especially for women and minorities, as shown in figure 8 (Saul *et al.*, submitted). The curriculum has been adopted at quite a few schools in the US where it successfully helps students grasp physics concepts. We have data that indicate that on an array of normalized assessment instruments, students at multiple schools outperform their peers taking traditionally taught classes.

6. Summary

Instructional technology provides fertile ground for research on learning. When curricular materials are based on studies of student understanding, results can be significant. The Physics Education Research and Development Group at North Carolina State University has examined many different types of IT and created materials that have been extensively tested. We are one

†More information can be found at http://scaleup.ncsu.edu
‡Dr. Saul is now at the University of Central Florida, http://www.physics.ucf.edu/People/Faculty/saul.html
§Dr. Abbott is currently at Dartmouth College, http://www.dartmouth.edu/~physics/faculty/abbott.html

of many similar teams around the world. As more and more researchers make 'carefully considered efforts to accomplish learning', students will benefit.

For more information on any of the projects described here, please feel free to contact the relevant individuals.

Acknowledgements

Described here were the primary investigators/developers of instructional technologies in our group. We would be amiss if we did not also thank the non-mentioned group members who contributed daily to these IT efforts through conversations and suggestions. We would also like to thank the FIPSE program of the US Department of Education (PB116B71905 and P116B000659), the National Science Foundation (DUE-9752313, DUE-0127050, DUE-9981107, DUE-0320608, and DUE-0237132), the Spencer Foundation, Hewlett Packard, Apple Computer, and Pasco Scientific for their support.

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About the author

Robert Beichner's research focuses on increasing our understanding of student learning and the improvement of physics education. He developed the popular 'video-based lab' approach for introductory physics laboratories. He and his students have developed a series of tests aimed at diagnosing students' misconceptions about a variety of introductory physics topics. The SCALE-UP project is part of Dr. Beichner's efforts to reform physics instruction at a national level. Probably his most visible work along those lines has been the textbook that he co-authored with Raymond Serway, which was the top-selling introductory calculus-based physics book in the US, used by more than a third of all science, math, and engineering majors. He is currently the director of the PER-CENTRAL project, working to establish an electronic 'home base' for the Physics Education Research community. He is also the founding editor of the APS journal *Physical Review Special Topics: Physics Education Research*.