CSMT: Teaching Physics Concepts with Activity-based Learning

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CSMT: Teaching Physics Concepts with Activity-based Learning

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Why use technology?
Even at the good universities, most physics students don’t understand the concepts – rather they are very skilled at memorizing and using formulas. In my experience, only 20 percent of physics students in a traditional physics program can give conceptual answers that go beyond the mechanics of solving physics problems. In most physics courses, students listen to lectures about already proven theories – they don’t “do” real science. In contrast, physicists are actively engaged in predicting and testing models that explain the real world.

I left a career as a research physicist to become an educator, developing learning technology and directing the Center for Science & Mathematics Teaching, which I founded in 1986, because I believed then and even more so now that students learn best when they can ask and answer the questions that interest them. The real text of physics is the physical world – if the student isn’t actually doing something, which includes active thinking, the student probably isn’t learning.

The strategy
My colleagues and I developed the first Microcomputer-Based Laboratory (MBL) tools – and we continue to develop them – because we know through research that activity-based materials improve students’ learning. Personally, one of the reasons I developed these materials was to reach “science anxious” students, many of whom belong to the traditionally underserved student populations: women, minorities, under-prepared students. These activity-based learning technologies work very well because they put the students back into control.

As we’ve continued to develop our materials, we’ve formed five productive working collaborations with a variety of different groups, such as Workshop Physics and coalitions of different educational institutions, to broaden our activity-based physics outreach efforts to faculty and students. These collaborations allow us to develop new materials and evaluate their effectiveness in different audiences.

We also partner with publishers and a software company to produce the MBL materials. One of the reasons we moved to commercial distribution of our materials was due to the reality that most people have less time than money. We’ve always showed how activity-based learning materials could be made, but in fact most people will not take the time to do it. Instead, we try to distribute materials ready for use for as close to the cost of making them as possible.

To help faculty introduce more successful methods into their teaching, we provide national and international workshops, along with “Chautauqua short courses” (sponsored by the National
Science Foundation and free for college professors), that demonstrate the materials and explain the reasoning and research behind them. We have developed evaluation tools that help professors evaluate their students’ learning and guide instruction during a course as well as after. We also conduct studies and evaluations, to assess the effectiveness of our tools and to better understand how students learn – and why some students do not learn.

The courses
These materials can be integrated into any science course.

The learning technology
*Microcomputer-Based Laboratory (MBL) tools:* All of the software, hardware, and curricular materials we have developed for physics and other science faculty are MBL tools and curricula. This means that students learn science by doing science – they conduct experiments and take measurements using sensors interfaced with computers. The MBL hardware and software allow students in science labs to control their own explorations by taking real-time measurements and immediately generating graphs of physical quantities as they make the measurements. Some of the quantities that can be measured include: position, velocity, acceleration, force, light intensity, sound pressure, radiation, current, voltage, temperature, pH, and four specific ions.

Included in the activity-based materials are materials that change traditional labs into “guided discovery” labs, which emphasize concepts as well as the mathematical equations – the guided discovery labs are designed to teach students the fundamental concepts that we know are essential from our research in physics learning. You can visit our Website for more information on all of the materials and projects listed below and more: [http://ase.tufts.edu/csmt/](http://ase.tufts.edu/csmt/)

All of the MBL software, hardware, and curricular materials we developed are manufactured and sold for extremely reasonable prices by Vernier Software. The following is a representative sampling; visit Vernier’s Website for a complete list: [http://www.vernier.com](http://www.vernier.com).

*Logger Pro (software):* Logger Pro works with sensors available from Vernier and enables the students to do real-time physics experiments by storing the measurement data they collect in data tables as the measurements are being graphed. Students can use the analysis tools – derivatives, integration, statistics, curve fitting, and interpolation – in the software to analyze their data.

*LabPro (hardware):* LabPro is an extremely flexible, hand-held interface that can work with Windows or Macintosh computers and Texas Instrument calculators; it automatically calibrates sensors to gather data, and it can even gather data remotely for import later to a computer or calculator. LabPro Science Packages are also available for physics, biology, chemistry, and water quality; these include the interface, data-collection software, sensors, and lab manuals.

*Tools for Scientific Thinking (curricular materials):* These materials are designed to use the MBL tools in activity-based learning experiments; extensive testing shows that these materials can dramatically improve students’ conceptual understanding. The materials target two areas: “Motion and Force” and “Heat and Temperature.” The curriculum guides for the two areas provide a series of guided investigations for use in the lab. Teacher guides and word processing files, for modifying the labs to a particular class, are also included.
**MBL Interactive Lecture Demonstrations (curricular packages):** These are the MBL tools I would recommend first to faculty if they intend to try something but don’t know what to try. These are a series of short experiments, seven or eight in one class period, and they’re sequenced to teach the fundamental concepts – they’re done very quickly and very intensely, to fit easily into a typical lecture. These could move more slowly, but in fact they’re designed to move rapidly to accommodate the fact that professors don’t like to give up lecture time.

**RealTime Physics (experiments packages):** These collections are groups of guided experiments that cover the essential concepts within the areas of Electric Circuits, Mechanics, and Heat and Thermodynamics. The Mechanics and Heat and Thermodynamics packages are offered through Wiley Publishing: [http://ase.tufts.edu/csmt/html/soft.html](http://ase.tufts.edu/csmt/html/soft.html).

**Workshop Physics:** The Workshop Physics project has developed tools and materials for those faculty who are ready to give up lecturing entirely. You can get more information at the Workshop Physics Website: [http://physics.dickinson.edu/](http://physics.dickinson.edu/).

**The project support**
I founded the Center for Science and Mathematics Teaching in 1986 with a FIPSE (Fund for the Improvement of Post-Secondary Education) grant from the U.S. Department of Education. Since then, the CSMT’s operations have been funded by the National Science Foundation, the U.S. Department of Education, additional FIPSE grants, the Commonwealth of Massachusetts, Apple Computer, NYNEX, and many others.

**The results**
The reactions from the students are generally fantastic – they’re usually very happy with this.

We are constantly evaluating our tools and curricula, in addition to conducting new educational and cognitive learning research to discover how good students learn and why poor students don’t. The bottom line: activity-based learning, using MBL tools and materials, greatly improves students’ learning and understanding of scientific concepts. The National Science Foundation commissioned a study by external experts on the impact of the CSMT. The study showed that the work of the Center and our major collaborators is reaching some 20 percent of physics students nationwide. We’ve published many articles based on our research; a list of the citations is available on our Website: [http://ase.tufts.edu/csmt/](http://ase.tufts.edu/csmt/).

One telling example is a study we conducted at Rensselaer Polytechnic Institute in Troy, New York, one of the top engineering schools in the country and the nation’s first technological university. Before using our materials, 30 percent of physics students at RPI had a reasonable understanding of the concepts. After using our Interactive Lecture Demos, 60 percent of the students understood the concepts. We have other cases, such as the Tufts algebra-based physics class, that show as high as an 80-90 percent success rate after using the Interactive Lecture Demos.

Sometimes the professors think these materials are too easy, but they’re not – they’re not easy at all. Knowing physics is knowing the concepts; the mathematical stuff is rote. Some professors, in spite of the fact that they should know better, lose track of the fact that the stuff of physics is understanding the subject conceptually. It’s not solving algebra problems. It’s connecting the calculations to the physical phenomena and moving beyond that to understand
how the physical phenomena work. Scientists model the physical world and then see if their
model works. This is what students should study.

I challenge physics faculty to check that their students are learning what those faculty think the
students are learning. And if the students aren't learning, the faculty should try to make some
changes.

If you have any questions about our work or materials, you can contact me at csmt@tufts.edu.

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| Center for Science and Mathematics Teaching:  
  http://ase.tufts.edu/CSMT/ |
| Vernier Software:  
  http://www.vernier.com/ |
| MBL Interactive Lecture Demonstrations (curricular materials):  
  http://www.vernier.com/cmat/ild.html |
| Logger Pro Info and Demo:  
  http://www.vernier.com/soft/lp.html |
| Lab Pro Info:  
  http://www.vernier.com/pkgs/packlp.html |
| Tools for Scientific Thinking (curricular materials):  
  http://www.vernier.com/cmat/tst.html |
| RealTime Physics (experiment packages):  
  http://www.vernier.com/cmat/rtp.html |
| Workshop Physics:  
  http://physics.dickinson.edu/PhysicsPages/Workshop_Physics/Workshop_Physics_Home.htm |