Understanding science: The influence of computers in college physics classes

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Project Summary:

The growing role of computers in college physics is undeniable. Numerical data collection and analysis are performed effortlessly in the laboratory; beautiful simulations with idealized conditions are only a click away; abstract concepts that are notoriously difficult to visualize are represented in full-color animated displays. These computer uses aim to help students understand the content of physics by clearly presenting the outcomes of experiments. However, in the effort to present the *product* of science, there is a danger of misrepresenting the *process* of science. For example, after using software on simulations of atomic wave functions, students might have more familiarity with the representations, but they have not grappled with questions like “how do we know?” and “why do we believe?”[1] It might appear to the student that quantum mechanics is a “truth” because some authority (such as a computer) says so instead of recognizing it as a scientific model motivated by observations and having broad, but limited, predictive powers.

Understanding science extends beyond understanding the content to understanding what science is and how it is done. Understanding science can be represented by the need for physicists to define and approach unexplored phenomena, the need for engineers to solve problems without reliance on algorithmic solutions, and the need for pre-college teachers to recognize science as a process of inquiry, not a collection of facts and formulas. The goal of this project is to explore the influence of computers on student understanding of science when taking college physics.

One context of this investigation is computer simulations. The computer is often used to illustrate physical situations in cases where conducting the real experiment is impractical or impossible. Several studies have explored student understanding of science and computer simulations. Papert built on the work of Piaget to define an unconventional technological learning environment where the emphasis is on the intellectual development of the student.[2] Regarding Newton’s Laws, he describes a computer “microworld” where children become architects of their own learning instead of passive recipients of counterintuitive laws given from authority. White has shown how a set of interactive simulations can help sixth graders learn about the nature of scientific models in the context of force and motion.[3] Roth investigated how a computer simulation of Newtonian mechanics could be used to foster dialogue about the meaning of science to eleventh graders.[4] These are all pre-college studies that incorporated theories of cognition in the design of the curriculum. The situation in college physics is different. The topics and computer tools are more advanced and the students more mature. Also, the curriculum is almost exclusively centered on the content.[5] For example, in some classes students use the computer to “observe” particles in an ideal gas. Students see dots moving in a square and track the behavior of individual “particles.” Hopefully this helps students understand details of the kinetic model. However, what the students are doing is obviously *not* a real experiment. In fact, what they are watching is not observable in any lab. The series of experiments that have led to the detailed understanding of the particulate nature of gases is complex and highly inferential. Are students able to appreciate the observations that led to the kinetic model? Can they recognize the limitations of this model?

A second context is microcomputer-based laboratories (MBL). Here, students use computers for real time data acquisition and display. Students watch graphs of kinematic variables as they walk in front of a sensor. Quantities derived from the measured values, such as acceleration from a velocity-time graph, are easily accessible. Unlike simulations, with MBL, students make real measurements of the physical world and use them as the basis for making conclusions. It has been shown that MBL can help students learn physics.[6,7] However, in most MBL environments, what students are typically doing is very different from what practicing scientists do. Students have neither constructed nor motivated their technique for measurement, and most do not understand the one they are using. In this learning environment, what do students think an experiment is?

The methods of investigation for this project will include classroom observations and student interviews. Standard and non-standard classes, both with and without computers will be studied. In class, how the students interact with the educational software will be observed. The focus will be on classroom discourse. Do student dialogues indicate that they are interpreting simulations as models of idealized situations? In MBL, how do students try to make sense of the computer displayed graphs which come complete with spikes and misaligned zeros? Standard homework and examination responses will be analyzed to see how students approach solving scientific problems. Problems specially designed to probe student beliefs about the process of science in the context of the subject they are studying with the computer will be used. Can students solve problems which are extensions of the simulations they have studied? How do students solve real world kinematics problems when tools and representations different than the MBL's are used? Outside the classroom, task-oriented interviews will be conducted; students will be required to solve problems or make predictions for specific physical situations. Student beliefs will be inferred from the way they actually do science. Students will also be interviewed in a way that directly probes their beliefs about science. Students will be asked questions about the meaning of science and their interpretations of classroom experiences with the computer.

Finally, in the latter part of this project a small number of computer-based activities will be developed. The computer will be used to change the structure of the learning environment to one that helps students understand the way science is done.[8]

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[1] A.B. Arons, *A Guide to Introductory Physics Teaching* (John Wiley & Sons, Inc., NY, 1990), chapter 12.

[2] S. Papert, *Mindstorms: Children, Computers, and Powerful Ideas* (Basic Books, Inc., NY, 1980).

[3] B.Y. White, "ThinkerTools: Causal models, conceptual change, and science education," *Cognition and Instruction* (1993).

[4] W.-M. Roth, "Affordances of computers in teacher-student interactions: The case of Interactive Physics™," *J. Res. Sci. Teach.* **32**, 329-347 (1995).

[5] Recent examples of research into student understanding of the *content* of science in college level physics include: D.R. Sokoloff and R.K. Thornton, "Using interactive lecture demonstrations to create an active learning environment," *Phys. Teach.* **35**, 340-347 (1997); R.J. Beichner, "The impact of video motion analysis on kinematics graph interpretation skills," *Am. J. Phys.* **64**, 1272-1277 (1996); D.J. Grayson, "Using education research to develop waves courseware," *Comput. Phys.* **10**:1, 30-37 (1996).

[6] E.F. Redish, J.M. Saul, and R.N. Steinberg, "On the effectiveness of active-engagement microcomputer-based laboratories," *Am. J. Phys.* **65**, 45-54 (1997) and references therein.

[7] For studies that have shown that MBL could be used to foster scientific reasoning skills in pre-college environments, see Y. Friedler, R. Nachmias, and M.C. Linn, "Learning scientific reasoning skills in microcomputer-based laboratories," *J. Res. Sci. Teach.* **27**, 172-192 (1990) and Y. Friedler, R. Nachmias, and N.B. Butler, "Teaching scientific reasoning skills: A case of microcomputer-based curriculum," *School Science and Mathematics* **89**, 58-67 (1989).

[8] A. Collins, "The role of computer technology in restructuring schools," *Phi Delta Kappan* **73**, 28-36 (1991); R.D. Pea, "The collaborative visualization project," *Technology in Education* **36**:5, 60-63 (1993).