Effect of Visualizations and Active Learning on Students' Understanding of Electromagnetism Concepts♦

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Models are playing an increasing role in science curriculum (Gilbert & Boulter, 2000) and science educators as well as instructors agree that students need to understand the importance of the models that they are taught (Treagust, Harrison, Venville, & Dagher, 1996) and to construct their own models (Justi & Gilbert, 2002). If students are to fully understand the nature and implications of a model, they must be taught it in an appropriate range of modes of representation (Boulter & Gilbert, 2000; Treagust et al., 1996). In order to construct a model of a phenomenon several modes of representation can be used: concrete, verbal, symbolic, mathematical and visual modes. In this study we use concrete and visual modes of representations: desktop experiments, graphs, diagrams, virtual models, and animations (Dori & Barak, 2000; Dori & Belcher, 2001) as well as the mathematical mode, while solving analytical problems of electromagnetism.

Introduction

The Technology-Enabled Active Learning (TEAL) Project at MIT (Belcher, 2001) involves the use of media-rich software for simulation and visualization in a freshman electromagnetism course. Visualization technology can support meaningful learning by enabling the presentation of spatial and dynamic images, which portray relationships among complex concepts. The objective of the project is to transform the way physics is taught in large enrollment physics classes at MIT in order to decrease failure rates and increase students' conceptual understanding. The problematics of passive learning in large classes was identified and researched over a decade

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ago (McDermott, 1991). The approach is designed to help students visualize, develop better intuition about, and conceptual models of, electromagnetic phenomena. The reform is centered on an "active learning" approach – a collaborative, hands-on environment, where students carry out desktop experiments, submit web-based assignments, and employ a host of visualizations. Patterned in some ways after the Studio Physics project of RPI (Cummings et al., 1999) and the Scale-Up project of NCSU (Beichner, et al., 2002), TEAL extends these efforts by incorporating advanced 2D and 3D visualizations that employ Java applets and enable students to get first-hand experience through experimentation, and immersion in various electromagnetic phenomena. The visualizations allow students to gain insight into the way in which fields transmit forces by watching how the motions of objects evolve in time in response to those forces. Such animations allow students to intuitively relate the forces transmitted by electromagnetic fields to more tangible forces, such as those exerted by rubber bands or strings, making electromagnetic phenomena more concrete and more comprehensible.

This study focuses on the value of concrete and visual representations in teaching abstract concepts, using advanced information technology.

Research Question

What is the effect of introducing 2D and 3D visualizations and desktop experiments on students understanding of electromagnetic fields?

Research Method

The experiment started with a pilot study, conducted in Fall 2000, and has continued throughout Fall 2001, involving about 350 experimental students. In Fall 2001, the physical infrastructure for teaching the course in the TEAL Studio format was in place. The setting includes 12 round tables with nine students seated around each table and working in teams of three on a laptop. The experimental group of Fall 2001 included about two thirds of upper classmen, who had failed either the mechanics course or the electromagnetism course. One third was comprised of freshmen that studied physics in high school at the advanced level and advanced placed mechanics course. The control group of Spring 2002, which took the electromagnetism course in the traditional large lecture and recitations, consisted of about 120 volunteers, of whom 90% were freshmen, while the rest were upper classmen.

We expand the extent of the TEAL Project such that full implementation of the course takes place in Spring 2003, encompassing about 600 students and six new instructors.

The assessment of the project included examining students' conceptual understanding before and after studying the TEAL electromagnetism course. We developed pre- and posttests consisting of conceptual questions from standardized tests (Maloney, et al., 2001), as well as questions designed to assess the visualizations and experiments. The tests included open-ended and multiple choice questions that require qualitative and quantitative responses. We also investigated the effect of this environment on students' preferences regarding the various teaching methods using a survey and focus group discussions.

Findings

Figures 1 and 2 present the Fall 2001 experimental group and Spring 2002 control group results, respectively.

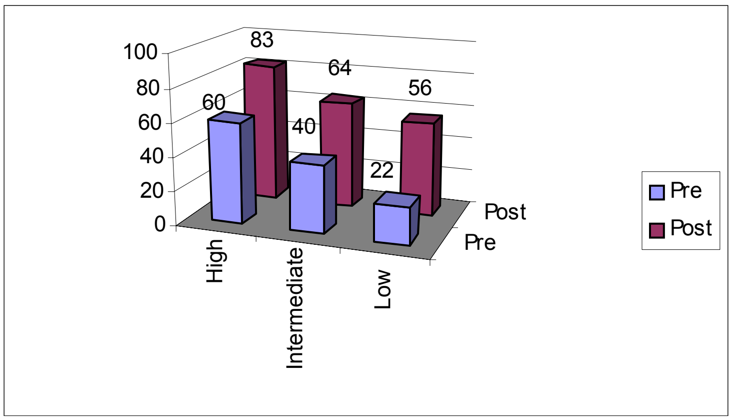

Figure 1. Fall 2001 experimental group results in the pre- and posttests

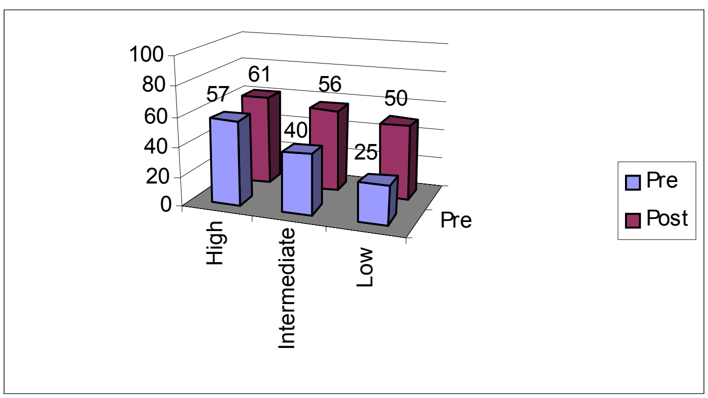

Figure 2. Spring 2002 control group results in the pre- and posttest s

Our findings indicate that students who studied in the TEAL format (N = 174) significantly improved their conceptual understanding of the various complex phenomena associated with electromagnetic fields. The improvement of the Fall 2001 TEAL students from the pretest to the posttest was significantly higher than that of the control group of Spring 2002 (N = 120). As figures 1 and 2 show, the net gain of the low-achieving students was the highest, probably because their starting point was the lowest, so they had the most room for improvement. To analyze the effect of the TEAL classroom and learning materials on high achievers, we examined the relative improvement measure $\langle g \rangle$, according to Hake (1998). The relative improvement of the experimental group was significantly higher ($p < 0.05$) than that of the control group. Within the experimental group, the high achievers' relative improvement was significantly higher than each of the intermediate and low achiever groups.

In response to the question "Would you recommend this course to a fellow student?" presented in the end-term survey, a strong majority of the students responded positively (see Table 1).

Table 3. Students' responses to the question "Would you recommend this course to a fellow student?"

Answer Type	**Frequency**	**Examples**
Yes	45%	
Yes, with explanation	26%	Yes. The interactiveness makes it much more interesting and easy to learn when compared to traditional lecture style. Definitely. My impression of 8.02T *[the E&M TEAL course]* is that it conveys the concepts of electricity and magnetism in a much more visual and hands-on way than the standard 8.02 *[the E&M traditional course]* class.
Maybe, yes but…	22%	I would recommend it to any student who is not planning on majoring in course 8 [physics], or who doesn't need to take more advanced physics classes. I feel like 8.02T [the TEAL course] was a good class for non-physics majors because it was interesting, and the pace was good.
No	4%	
No, with explanation	3%	No. I was looking for a more complicated physics class. I wanted more conceptual work, and in-depth approach.

Table 1 lists the frequency of positive and negative answers without and with explanations, with sample explanations for both types. Typical explanations included the elements of interactivity, visualization, and desktop experiments, which the technology helped enable.

Discussion

Science educators are facing increasing demands as they are asked to teach more content more effectively and to engage their students in scientific practices (Edelson, 2001). The National Science Education Standards (National Research Council [NRC], 1996) expressed strong disapproval of the traditional emphasis on memorization and recitation. They stressed the need to foster conceptual understanding and give students firsthand experience of questioning, evidence gathering, and analysis that resembles authentic scientific processes.

In the TEAL project, direct hands-on exposure to the phenomena under study, visualization of electromagnetic phenomena, and active learning in a collaborative setting, were combined to achieve the desired effect on the students' learning outcomes. Our results indicate that students significantly improved their conceptual understanding of the subject matter. The net gain and relative improvement of fall 2000 and 2001 TEAL students' conceptual understanding has been found to be significantly higher than that of both the 2001 and 2002 control groups. This research has shown that the two central themes in the course, 2D/3D visualizations along with collaborative desktop experiments, significantly enhanced students' ability to transfer the concepts of electromagnetic field lines and associated phenomena from the abstract level to the concrete level, thereby contributing to better conceptual understanding of these physical phenomena.

References

Beichner, R.J. et al. (2002) Scale-Up Project www.ncsu.edu/per/scaleup.html

Belcher, J. (2001). Studio Physics at MIT. MIT Physics Department Newsletter, Fall 2001.

Boulter, C. J., & Gilbert, J. K. (2000). Challenges and opportunities of developing models in science education. In J. K. Gilbert & C. J. Boulter (Eds.), Developing Models in Science Education (pp. 343-362). Dordrecht: Kluwer.

Cummings, K., Marx, J., Sornton, R. & Kuhl, D. (1999) Evaluating Innovations in Studio Physics. Physics Educational Research, American Journal of Physics Suppl. 67, S38-S45.

Edelson, D.C. (2001). Learning-for-use: A framework for the design of technology –supported inquiry activities. Journal of Research in Science Teaching, 38, 355-385.

Gilbert, J. K., & Boulter, C. J. (Eds.). (2000). Developing Models in Science Education. Dordrecht: Kluwer.

Hake, R.R. (1998). Interactive-engagement versus traditional methods: A six-thousand-students-survey of mechanics test data for introductory physics courses. American Journal of Physics, 66, 67-74.

Justi, R., & Gilbert, J. K. (2002). Modelling, teachers' views on the nature of modelling, and implications for the education of modellers. *International Journal of Science Education, 24*(4), 369-387.

Maloney, D.P., O'Kuma, T.L., Hieggelke, C.J. & Van Heuvelen, A. (2001). Surveying students' conceptual knowledge of electricity and magnetism. Physics Educational Research, American Journal of Physics Suppl. 69, S12-S23.

McDermott, L.C. (1991). Millikan Lecture 1990: What we teach and what is learned – closing the gap. American Journal of Physics, 59, 301-315.

NRC - National Research Council. (1996). National Science Education Standards. Washington,D.C.: National Academic Press.

Treagust, D. F., Harrison, A. G., Venville, G. J., & Dagher, Z. (1996). Using an analogical teaching approach to engender conceptual change. International Journal of Science Education, 18(2), 213-229.