How Much Have They Retained?
The Retention of Concepts from a Freshman Electromagnetism Course by MIT Upperclass Students

Yehudit Judy Dori1,2, Erin Hult1, Lori Breslow1, and John W. Belcher1
1Massachusetts Institute of Technology, Cambridge, MA 02139, USA
2Technion, Israel Institute of Technology, Haifa 32000, Israel

Abstract
During the last four years, the introductory freshmen electromagnetism course at MIT has been taught using a studio physics format entitled TEAL—Technology Enabled Active Learning. TEAL has created a collaborative, hands-on environment where students carry out desktop experiments, submit web-based assignments, and have access to a host of visualizations and simulations that help them develop stronger intuition about electromagnetic phenomena. Pre- and posttests administered to students who took the course in the TEAL format and to those who took it in a traditional lecture-recitation format indicated that TEAL students gained significantly better conceptual understanding. This study focuses on the extent to which both groups retained conceptual understanding approximately a year after finishing the course. We also analyzed the perceptions of both research groups about how the pedagogical methods used in the electromagnetism course helped them in their learning in advanced courses.

Our research has indicated that the long-term effect of the TEAL format on students' retention of concepts was more noticeable than that of the traditional learning format. The significance of this research is that it is the first of its kind to provide college students' learning outcomes in both cognitive and affective domains based on a longitudinal study.

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Corresponding author:
Prof. Yehudit Judy Dori
Department of Education in Technology and Science
Technion - Israel Institute of Technology, Haifa 32000, Israel.
Phone: +972 4 8293132 Fax: +972 4 8295634 yjdori@tx.technion.ac.il
http://edu.technion.ac.il/faculty/jdori
http://caes.mit.edu/people/dori.html

Studies of how much conceptual understanding college students retain from their science courses are quite rare. Related studies include Barufaldi and Spiegel (1994), and Martenson, Eriksson, and Ingelman-Sundberg (1985). According to Halpern and Hakel (2002), educators need to provide students with education that lasts a lifetime. This implies, obviously, that instructors need to adopt learning principles for long-term retention so that their students remember what they have learned beyond the end of the semester.

The introductory freshmen electromagnetism course at MIT has been taught using a new approach—Technology-Enabled Active Learning (TEAL)—during the last four years (Dori & Belcher, 2004). The objective of the TEAL Project has been to reform a large enrollment, required physics class in order to increase students’ conceptual understanding of electromagnetism and decrease failure rates in the course. The problems with passive learning in large classes were identified and researched over a decade ago (McDermott, 1991). The TEAL approach has been to use active-learning methodologies and educational technology to help students better visualize, develop stronger intuition about, and create more robust conceptual models of electromagnetic phenomena. The effort was designed to create a collaborative, hands-on environment, where students carry out desktop experiments, submit web-based assignments, and have access to a host of visualizations and simulations of electromagnetic phenomena. Patterned in some ways after the Studio Physics project of RPI (Cummings et al., 1999) and the Scale-Up project of NCSU (Handelsman et al., 2004), TEAL extends these efforts by incorporating advanced 2D and 3D visualizations that employ Java applets. Visualizations can support meaningful learning by enabling the presentation of spatial and dynamic images that portray relationships among complex concepts. 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.

This study focuses on the extent of retention of conceptual understanding about electromagnetism (E&M) by undergraduate students who took a course in the TEAL format (Dori et al., 2003) in comparison to the retention of students who took in the course in a traditional setting. We also examine the long-term perceptions of upper class
students from both research groups about how the pedagogical methods used in the particular class they took helped them to retain knowledge.

Research Questions

1. What is the effect of the TEAL project on the retention of students’ conceptual understanding of electromagnetism, and how does it compare to retention of students taught in a traditional teaching method?
2. How do students perceive the contribution of studying E&M in one format or the other to their learning in advanced courses?

Research Settings

The TEAL experiment started with a pilot study conducted in Fall 2000 and continued throughout Fall 2001. It evolved into large-scale implementation (approximately 500 students) in Spring 2003. The TEAL setting includes 12 round tables with nine students seated around each table and working in teams of three on a laptop. The assessment of the project included examining students' conceptual understanding of electromagnetic phenomena before and after the course. We also investigated, through a survey and focus groups, the effect of this learning environment on students' preferences regarding the various teaching methods. The project and findings related to students' learning outcomes have been described in Dori and Belcher (2004). Overall, the results indicated the TEAL students gained better conceptual understanding in comparison to students who studied in traditional settings.

Research Instruments and Methods

In order to address the first research question, we administered the same questionnaire (with 25 conceptual questions) that had been used for the pre- and posttests in the original experimental (TEAL) and control (traditional) E&M courses. The tests consisted of multiple-choice conceptual questions from standardized tests (Maloney et al., 2001; Mazur, 1997) augmented by questions of our own devising. This retention test was given to volunteer students from both the experimental and control groups after about a year. Mean scores, standard deviations, and t-tests were calculated for the pre-, post-, and retention tests of each research group.
For the second research question, the students responded to the following open-ended question: “Please elaborate on the contribution of studying E&M in the TEAL format or in the traditional format to your learning in advanced courses.” Each response was classified into one or more categories compiled from the students’ comments.

Findings

Table 1 presents results of the comparison between experimental and control upper class students on the three test types. There was no significant difference between the two research groups in the pretest. However, in both the posttest and the retention test, TEAL students significantly outperform their control peers. The average E&M course net gain (Post – Pre score) of the experimental students was 36 (out of 100) compared with a net gain of 16 for the control students. The average retention net gain (Retention – Pre score) of the experimental students was 23 compared with a net gain of 15 for the control students.

Table 1. Mean scores, standard deviation, and t-test of pre, post and retention tests by research group

| Test type | Research group | N  | Mean Score | S.D. | t Value | Pr > |t|    |
|-----------|----------------|----|------------|------|---------|------|------|
| Pre       | experimental   | 120| 33         | 13   | -0.68   | n.s.*|
|           | control        | 52 | 32         | 9    |         |      |
| Post      | experimental   | 120| 69         | 16   | -8.03   | <.0001|
|           | control        | 52 | 48         | 16   |         |      |
| Retention | experimental   | 120| 56         | 15   | -3.37   | <0.005|
|           | control        | 52 | 47         | 15   |         |      |

Table 1. Mean scores, standard deviation, and t-test of pre, post and retention tests by research group

Figure 1 shows the reactions of students in both the TEAL (i.e., experimental) and traditional (i.e., control groups) in response to the open-ended question. The percentages shown are equal to the number of students within a research group making a comment in a particular category divided by the number of students in the corresponding group. The two groups made very similar numbers of positive comments per student, with 1.03 positive comments per student in the TEAL group versus 1.04 in the traditional group.

Figure 1. Comparison of students’ positive attitudes toward studying E&M in the TEAL vs. the traditional format

Figure 1 shows the reactions of students in both the TEAL (i.e., experimental) and traditional (i.e., control groups) in response to the open-ended question. The percentages shown are equal to the number of students within a research group making a comment in a particular category divided by the number of students in the corresponding group. The two groups made very similar numbers of positive comments per student, with 1.03 positive comments per student in the TEAL group verses 1.04 in the traditional group. The largest discrepancies between the two groups appear in the categories of enjoyment and confidence, group and instructor interaction, interest and motivation, lecture and explanations, visualization and experiments, and multiple methods and conceptual understanding. The strengths of the experimental approach over the traditional approach highlight the additional elements in the experimental course: group work, visual and hands-on activities, and the incorporation of multiple methods in building conceptual understanding. On the other hand, the control group made positive comments more frequently regarding enjoyment, interest and quality of lectures.
The difference in the types of comments made by the two groups suggests the students may be resistant to departures from traditional methods. For example, one control group student commented, “I liked taking E&M in big lecture format. This seems like a traditional part of an MIT education.” Despite the fact that the smaller lecture size appealed to some experimental students, others in the experimental group expressed interest in the traditional format, “I would have preferred the regular lecture method of studying, for I felt that I got very little out of doing the in-class labs, so it would have been more beneficial to have seen the lab done by a professor and spent the time we wasted on going over material and examples.” However, a substantial percentage of experimental students commented that group or instructor interaction, one of the new elements of the course, had made a positive contribution to the experience. In response to the question on preparation for advanced courses, 11% of the experimental students vs. only 4% of the control group students praised group or instructor interaction. The topic of visualizations and experiments was indicated as a contributing factor by 14% of experimental students vs. 8% of the control students. Multiple methods and conceptual understanding, which were primary goals of the TEAL project, were cited by 11% of the experimental students as opposed to none of the control group. One experimental student commented, “TEAL demanded active classroom participation which would have been absent in the traditional setting. I enjoyed each session's multiple choice problems that asked for every student's input with the remote control. This forced me to quickly absorb what was said in lecture and review material on a small scale. The hands on experiments also helped to visualize the concepts and theories and made formulae less tedious.” In the control group, many students commented on the ability of the lecturer, who was renowned as an excellent teacher, to make the course interesting and enjoyable. One control student wrote, “The professor was an engaging instructor who made learning theory an experience of its own.” Comments such as this suggest that the personality and experience of the lecturer play a major role in the attitudes of students toward any course. The experimental group was taught by six different lecturers, most of whom did not participate in developing learning material for TEAL and were new to the TEAL format.
Figure 2 illustrates the percentages of the experimental and control groups making all positive, all negative, both, or neutral comments in response to the question stated above about the contribution of each format to preparation for advanced courses. The percentage shown is the number of students in a research group making, for example, all positive comments divided by the number of total students in that group. The neutral category consists almost entirely of students commenting exclusively that they had no further courses that required the material from the introductory E&M course.

**Summary and Discussion**

Our findings reinforce the notion by Halpern and Hakel (2003) who claimed that learning occurs under varied conditions and that key ideas have “multiple retrieval cues” that allow them to be retrieved. They go on to say that some learning situations and methods require a greater investment of effort than others on the part of the student and the instructor alike. Consequently, some learning situations may be less enjoyable for students, leading to lower instructors' ratings. This is indeed part of what happened in our study: While TEAL students learning gains were significantly higher than their peers', they responded with a higher number of negative comments. Students' resistance to changes introduced by the TEAL project was a major source of some dissatisfaction they voiced. This is expressed by one of the TEAL students who wrote: “I think there are too many variables to hold a firm position either way. A lot depends on the instructor and on the format of the course that semester. It also depends a lot on how a particular student
prefers to learn—obviously we are all accustomed to lecture format, and some people like that while others might like TEAL.”

Currently, the TEAL format is being introduced also to the mechanics course (which precedes the E&M course), so freshmen will get accustomed to the new approach and will probably be less resistant because it will no longer be perceived as a major change. Our research has indicated that the long-term effect of the TEAL format on students' retention of E&M concepts was more noticeable than that of the traditional learning format. Responding to the open-ended question, experimental students noted teamwork, visualizations, hands-on activities, and the incorporation of multiple methods as positive factors that enhanced their conceptual understanding and its retention.

The significance of this research is that it is the first of its kind to provide college students' learning outcomes in both cognitive and affective domains based on a longitudinal study over a period of four years.

References


