LESSONS LEARNED

Findings from Ten Formative Assessments of Educational Initiatives at MIT (2000-2003)

Lori Breslow, Ph.D.
and
The Staff of the Teaching and Learning Laboratory

April 1, 2004

T|L|L
Teaching
& Learning
Laboratory

Table of Contents

LESSONS LEARNED

Findings from Ten Formative Assessments of Educational Initiatives at MIT

(2000-2003)

The Staff of the Teaching and Learning Laboratory

In 1999, MIT received two generous grants that allowed it to embark on a wide scale series of innovations in undergraduate education. The first was from then chairman of the MIT Corporation, Alex d'Arbeloff, and his wife, Brit d'Arbeloff; they created the d'Arbeloff Fund for Excellence in Education (http://web.mit.edu/cet/init/darbeloff.html). The d'Arbeloff grants have been devoted primarily to strengthening the first-year experience at MIT. The second grant, from the Microsoft Corporation, funded iCampus (http://mit.edu/icampus), a five-year, $25 million research alliance whose purpose is to improve higher education through the use of information technology. Since 1999, MIT faculty, staff, and students have undertaken approximately forty experiments in educational innovation supported by these two sources of funding.

The Teaching and Learning Laboratory (TLL) was asked to manage the assessment of these initiatives. Of course, the Institute has evaluated its educational efforts throughout its history, but it wanted these new initiatives to be studied in a more systematic way. We have undertaken that work over the last four years. Each senior TLL staff member (of which there are four) is responsible for at least one, but in some cases as many as three, assessment projects per year. In addition to this in-house effort, we have collaborated with assessment and evaluation consultants who work under the direction of either TLL's Director or Associate Director for Assessment and Evaluation. Of the ten research projects undertaken, six have been completed and four are in their second or third years.

Following the lead of the newly formed Center for the Advancement of Scholarship on Engineering Education (CASEE), we have grouped these ten projects into "strands." A strand is a line of inquiry that a number of individual projects can contribute to. Although it is difficult to categorize ten distinct projects, as we have reviewed them over the last several months, we have come to see they can be placed in one of two strands: (1) those that used active learning pedagogies; and (2) those that focused on educational technology. In at least one notable exception—the Technology-Enabled Active Learning (TEAL) project—those two factors were of equal importance, so that TEAL is included in the discussion of both strands. In other projects, both active learning and educational technology played a part, but one was in service to the other. (Please see Appendix A for a description of each individual project.)

This report, then, summarizes the most important findings from the educational initiatives MIT has undertaken over the last several years. It should be noted that we have not described every finding for every project; we are only reporting the findings that we believe are the most striking, and that have the most relevance for undergraduate education in science, engineering, and technology. We should also make clear that the initiatives listed in Appendix A do not encompass all of the activities that are being carried out at the Institute to strengthen undergraduate education. A number of other initiatives are currently underway, and several others are in the planning stage.

As we have done this work over the last four years, we have also identified what we believe are several "best practices" for the design and implementation of reforms in teaching and learning in higher education. We thought readers would be interested in those observations, and we have included them in the second to last section of this report. We have also learned some lessons about how to do our own work in assessment more effectively; these are included as well. Finally, we believe the studies we have done over the past several years have set the stage for a second phase of research at MIT into pedagogical innovation, educational technology, and how improvements in those two areas impact learning. The conclusion to this report lays out the priorities for research and assessment as we move forward.

STRAND A: FINDINGS RELATED TO THE USE OF ACTIVE LEARNING PEDAGOGIES

Major findings:

- The use of active learning pedagogies resulted in increased learning gains in two courses that specifically measured learning.

- Students need to be prepared and instructors need to be trained for the change from lecture-based classes to those that employ active learning pedagogies.

Preliminary finding:

- Some elements of active learning may be more appropriate for some students than for others, and better for some cognitive tasks than for others.

We realize that "active learning" is a term that has many meanings in the educational community; similarly, it covers an array of pedagogical techniques at MIT. As an umbrella, we use Hake's (1998, p. 65) definition for what he calls interactive engagement, a set of pedagogical methods:

> . . . designed at least in part to promote conceptual understanding through the interactive engagement of students in heads-on (always) and hands-on (usually) activities which yield immediate feedback through discussions with peers and/or instructors.

A number of studies have reported favorable results in achievement, attitudes toward learning, and persistence in continuing in science and engineering courses when active learning techniques are employed (see, for example, Springer, et al. [1997]). We wanted to test if that held true for the kinds of students we teach at MIT. We believe that exploring whether or not active learning improves conceptual understanding in top tier students is important for science and engineering education and for teaching the next generation of practicing scientists and engineers.

Finding #1: Active Learning Pedagogies Increase Learning Gains

Two assessments undertaken at the Institute have explicitly measured learning gains: the TEAL project, which introduced both active learning pedagogies and educational technologies into the required freshmen physics course in electromagnetism (Physics II [8.02T]); and the course Biomedical Signal and Image Processing, which is taught in the Harvard-MIT Division of Health Science and Technology (HST 582J). These two studies demonstrate that learning does improve when active learning pedagogies are employed in MIT courses.

Dori and Belcher (2004, p. 27) employed pre- and post-tests to compare learning gains in the TEAL Physics II (8.02T) class taught in the spring semester 2003 to an 8.02 class taught in the conventional lecture/recitation mode in spring 2002. A variety of statistical tests were used to analyze gains in learning, including ANOVA, General Linear Model, GENMOD, and t-test. For one analysis, students were divided into low, intermediate, and high groups based on their scores on the pre-test, and those scores were turned into a normalized learning gains score.[1] Figure 1 illustrates the TEAL students in all three groups outperformed their traditional 8.02 counterparts at statistically significant levels.

Figure 1: Learning Gains in TEAL Physics II (8.02)

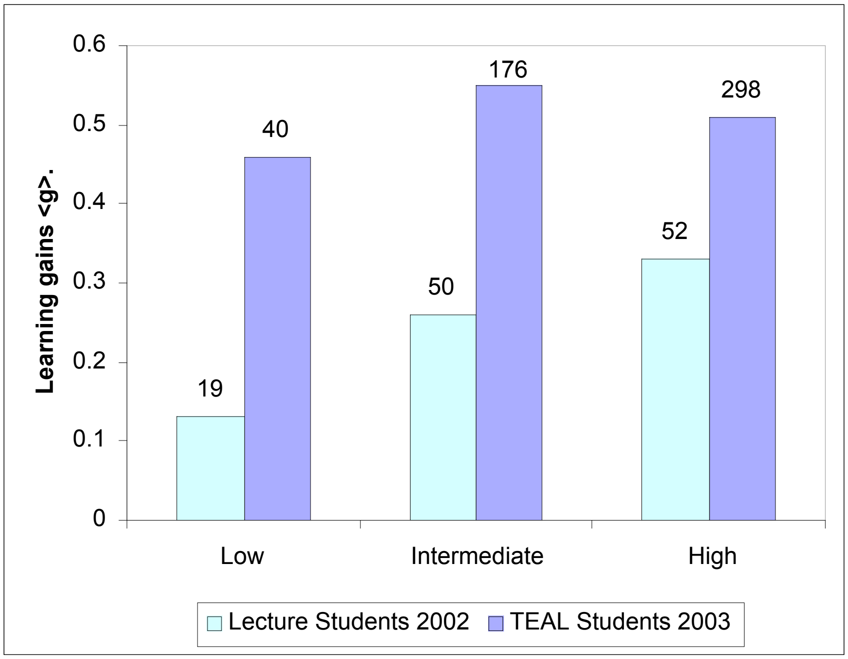

Figure 1. Relative improvement of conceptual understanding of spring 2003 TEAL students vs. the spring 2002 control group students. Figures above the columns represent number of pre- and post-tests completed. Source: Dori and Belcher (2004).

In addition, the failure rate of students in 8.02, which had historically varied between 7% and 13%, fell to a few percentage points for students taught in the TEAL format (Belcher, 2003, p. 8). In order to counter the argument that the lower failure rate might be due to the use of easier exams in TEAL, it should be noted that a senior faculty member who had taught 8.02 courses in the lecture format for many years judged TEAL exams to be comparable in difficulty to those he and other physics faculty have traditionally given.

In the case of the course in biomedical signal and image processing, instructors taught the topic of Fourier spectral analysis in a traditional lecture mode one year and with a module based on the "How People Learn" educational model the next. (HPL is a problem-based methodology developed by Professor John Bransford, who is at the University of Washington.)

Assignments and exams were graded according to a rubric that was developed to rate the students' understanding of thirteen key concepts. Eleven of the thirteen concepts were combined into four categories with two concepts remaining independent. These groupings of the original concepts were analyzed by means of MANOVA. Figure 2 summarizes the results that show the treatment group demonstrated at statistically significant levels deeper understanding than the comparison group in three of the four groupings and in one of the two single items.

Figure 2: Learning Gains in HST 582J

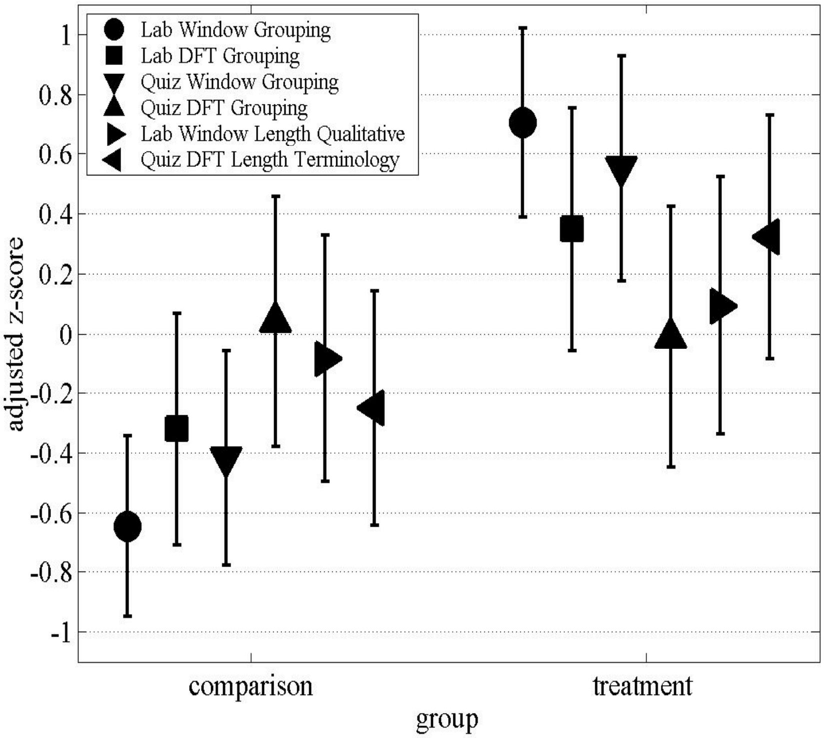

Figure 2: The treatment group's understanding of key concepts as contrasted to the comparison group's understanding of those same concepts. The plot shows mean adjusted z-scores for the four concept groups and the two concepts that remained independent. Error bars illustrate 95% confidence intervals. Source: Greenberg, Smith, and Newman (2003).

Finding #2: Both Students and Instructors Need to Be Prepared

While the two studies described above sought to measure gains in learning, a number of other studies done at TLL focused primarily on the students' attitudes toward the shift from lecture-based courses to those that employed active learning techniques. Here the results were mixed with some courses receiving positive reviews and others coming under a fair amount of criticism. We believe one of the variables that made a difference in how the course was received was the way in which the pedagogy was implemented. That is, for the most part, the courses under study were designed well, but there was some difficulty in implementing one or more of their components. And further we have seen that those problems often stem from two factors: (1) the instructors did not receive enough training in how to use active learning techniques; and/or (2) the students were not adequately prepared for the shift in roles and responsibilities that active learning requires.

The addition of problem-based tutorials in a required electrical engineering course, Circuits and Electronics (6.002x), is an innovation that has been received positively. In these tutorials, practicing engineers, most of whom are MIT alumni, coach six to eight students as they solve open-ended problems related to the concepts they have learned in lecture that week. The students gave the course high marks for meeting its objectives, were satisfied with their learning, perceived a boost in their own confidence as a result of the class, and felt they would have a long-term advantage over students in the traditional 6.002 course (Clay, 2003). In this particular case, the faculty members in charge are very available to students to answer questions and solve problems, the tutors receive training in how to manage a problem-based tutorial as well as feedback on their performance, and the students self select for the class based on their understanding of how it will operate. We believe all these elements contribute to the course's favorable reviews.

Another class that relies on active learning methods is Mission 200X (the X stands for the year the students will graduate), a first-semester freshmen course that emphasizes project-based learning and teamwork. The feedback on this class has been mixed. For example, when students compared Mission 2005 to their other first semester classes, 50% or more rated it higher than those other classes for: (1) giving them independence/autonomy; (2) helping them learn to work productively in a group; (3) giving them a sense of accomplishment because there was a final product; and (4) actively involving them in their learning. On the other hand, less than one-third rated the course higher for improving their problem-solving ability; being a worthwhile use of their time; and helping them become more independent learners (Lipson, 2002, p. 2). Among the recommendations for strengthening the course, the lead investigator has suggested, "Offer more structure and guidance, especially in the beginning to help students with teamwork, problem-solving, research, inter-team communication, mentor relationships and journals" (Lipson, 2002, p. 2).

On the other end of the spectrum, the first large-scale implementation of TEAL in spring semester 2003 met with outspoken student criticism. In fact, dissatisfaction was so high at one point that students submitted a petition to the physics department "ask[ing] MIT to halt the proposed expansion of the program, questioning its efficacy" (LeBon, 2003, p. 1). In focus groups held before midterms that year, students complained in particular about the mandatory attendance policy that required them to be present for in-class experiments and other active learning exercises. This policy represented a dramatic shift in MIT norms. Most, if not all, lecture-based courses do not require attendance, and, in fact, attendance is typically at 50% or below by the end of the semester even for MIT's best lecturers. The TEAL students were annoyed that they had to spend five hours a week in the classroom. As one of them said, "8.02 is far more than a 12 unit course; it's more like an 18 unit course."

Students also complained about having to turn in reading questions before lectures. This was a policy that was put in place so they would have some familiarity with the material before coming to class, so that time in class could be used to delve more deeply into ideas. In response to this requirement, one student groused, "By the time I've done the reading questions, I've already taught myself the material. So why should I come to class?" In fact, in reviewing our notes from the focus groups, we saw a fair number of comments that sprung from the fact the lecturer was not simply feeding students information as they were used to. For example, another student who commented on being required to do the reading before coming to class said, "Go back to the standard way of lecturing first, and then I'll do the reading." Another wanted "the instructors [to] do problems for us during class." And in the same vein, yet another student suggested, "Teach the material and then do problems in the workshop."

To be fair to the students, implementation problems in 8.02T did sometimes make class time unproductive. Again, some of those problems could be traced to the faculty's unfamiliarity with the new format. Teaching in TEAL is very different from lecturing; many other skills come into play. As Professor John Belcher, TEAL's designer and lead instructor, wrote in *The MIT Faculty Newsletter* (2002, p. 9):

> Although we did train the faculty in the teaching methods in the course, with hindsight our training was not thorough enough to prepare them for the new environment in the d'Arbeloff Classroom both in terms of the technology in the room and the teaching methods used in "interactive engagement."

However, before the start of the spring semester 2004, faculty and teaching assistants went through more extensive training, and the instructors were given advice on how to explain to students not only what TEAL would entail, but how this kind of instruction would benefit them. There have been no complaints about TEAL as of the middle of the spring term 2004.

Another example of the interrelationship among instructor training, student expectations, and the acceptance of active learning techniques occurred in a large enrollment mathematics class, Differential Equations (18.03). In that course, the faculty member wanted to bring group work into the recitations. That is, rather than having the recitation leader (RL) solve problems on the board, the students were to put themselves in groups of three or four and work on problems that had been formulated by the faculty member. While the RLs got a short training workshop at the beginning of the semester, in our opinion, there was not enough training, and the instructor did not mandate that group work be used in the recitations. Although several of the RLs were excellent at leading group work, many were only adequate, and some were quite poor.

When students were asked on an end-of-the-semester course evaluation about their preferences for pedagogical style, only 19% preferred group work, 31% were neutral, and a full 50% of the students stated they wanted to see the RL solve problems on the board. When a follow-up question asked students why they didn't like group work, they reported in large numbers (62%) that they learned best when they saw an example worked out clearly (Breslow, 2002a, pp. 4-5). Since most of the RLs and students were used to this kind of teaching, it is not surprising that they preferred it.

We believe the experiences of the courses we have assessed in the past several years point to the fact that the shift from passive lecture mode to active learning methodologies requires that both teachers and students be helped to meet new expectations and take on new roles. As Lipson (2002, p. 1) writes in her assessment of Mission 2005:

> The data indicate that introducing entering freshmen, schooled in traditionally structured educational settings, into an unstructured classroom format that relies on the students themselves to structure the experience can be a difficult transition for many students.

Studies at other universities (Mayo et al, 1995; Solomon and Finch, 1998; Dolmans, et al., 2001; Maudsley, 2002) support this view.

Finding #3: Elements of Active Learning May Not Be Applicable for All Cognitive Tasks and for All Students

This last finding is tentative although we believe it makes sense intuitively. For example, another reason students in 18.03 gave for not liking group work was that they needed to think about a mathematics problem on their own before they could talk about it with anyone else. One student, for instance, said math was "very personal"; another talked about the need to "think independently" when working on problems (Breslow, 2002a, p. 11). And, in fact, classroom observations bore this out. Students who were asked to work together tackled the problems on their own before conferring with one another. And some students never did get to the point of talking to their classmates. Learning mathematics, no doubt, uses a host of cognitive skills that are different from, for example, brainstorming a design problem, which may lend itself more naturally to teamwork.

In a similar vein, the assessment of the introduction of active learning methods and wireless laptops into a beginning course in programming, Introduction to Computers and Engineering Problem Solving (1.00), in the department of Civil and Environmental Engineering found that different students had different reactions. When the researchers broke down students by year in school and experience in programming, they found seniors had higher positive attitudes toward active learning than other students, and students with low prior programming experience were more positive about both active learning and laptops than those with high prior programming experience (Barak, Lipson, and Lerman, 2004, pp. 19, 22). These preliminary findings remind us that a "one size fits all" approach doesn't work in education, and that even though many of us are philosophically committed to active learning, we should not and cannot jettison more conventional means of teaching.

STRAND B: FINDINGS RELATED TO THE USE OF EDUCATIONAL TECHNOLOGY

Major findings:

- The most successful educational technologies have met a specific instructional need that has been unmet or poorly met by traditional media.

- Too much technology can be detrimental.

- There are important relationships between educational technology and the learning environments in which they operate:

    - The use of educational technology has been most effective when there are strong connections between the technology, the learning goals, the pedagogical methods employed, and the other components of the learning environment.
    - The same technology will have differential effectiveness depending on the educational context within which it is embedded.
    - Educational technology exerts its impact by changing the properties of information in the learning environment.

With the support of the Microsoft funding, MIT has been able to design and implement over twenty experiments involving educational technology since 1999. The individual iCampus experiments have contributed to one of two kinds of efforts: developing web-based services for higher education and creating edtech applications for use in the classroom. iCampus has funded projects undertaken by cross-departmental groups of faculty, individual faculty members, and students. It continues to fund new projects each year. We at TLL have been directly involved in assessing six iCampus projects and peripherally involved in assessing a half dozen more that have been studied by other educational researchers at the Institute. We are also advisors to what is perhaps MIT's most ambitious project in educational technology, OpenCourseWare, but the findings from OCW's first evaluation are not being considered in this report.

Although commonplace knowledge, it still needs to be said: Edtech is just in its infancy, but holds promise for improving higher education in a number of ways. As the iCampus website proclaims, the alliance's goal is to "use its resources to create significant, sustainable positive change in higher education" with the stress on both "significant" and "sustainable" (http://web.mit.edu/icampus). We began with a strategic plan for assessing MIT's efforts in educational technology that sought to determine its impact in three areas: conceptual learning, interaction and engagement, and resource allocation (see Breslow, 2002b). Four years later, we have made some progress in the first two areas, but we have also made discoveries we did not anticipate. We believe this reflects the unchartered territory we have been trying to map. We hope that in another four years we will be able to report that we have an even more sophisticated understanding of the role technology plays in higher education. What follows, then, are the results of our efforts to date.

Finding #1: Edtech Is Most Successful in Meeting Unmet or Poorly Met Educational Needs

We believe Marshall McLuhan was right: media are not neutral conveyances. They have their own biases, grammars, and limitations. While one particular technology may do some things well, another is best suited to a different set of tasks. To illustrate this idea, the media critic Neil Postman (1985, p. 7) once pointed out that smoke signals aren't the optimum way to communicate philosophical arguments. "Puffs of smoke are insufficiently complex to express ideas on the nature of existence," Postman wrote, "and even if they were not, a Cherokee philosopher would run short of either wood or blankets before he reached his second axiom."

We have found the same principle holds true for educational technologies: use them to do what they are naturally suited to do. The opposite is also true: if a more traditional technology is a good match for a particular educational need, then perhaps the situation is best left as is.

For example, faculty teaching an upper-level physics class, Exploring Black Holes: General Relativity and Astrophysics (8.224), conducted an experiment in which MIT alumni, most of whom lived outside the Boston area, were enrolled remotely in the class. They created a discussion board for the course in order to allow the students and alumni to explore ideas with one another. (The students were required to post to the board three times a week.) The hope was that these discussions would help the students learn the material, as well as promote interaction between the alumni and the undergraduates. Interviews with both students and alumni revealed the alumni found the discussion board, which was the only interaction they had with the instructors and the other students, highly functional, amazingly interactive, and easy to use. But for the undergraduates, posting to the discussion board was time consuming and unhelpful—except when they needed the faculty to answer a question quickly. As the lead investigator wrote (Tervalon, 2002, p. 7), "For the undergraduates, whose lives are immersed in the university experience, the use of the discussion boards in lieu of face-to-face interactions feels artificial and forced."

While in this example, a conventional medium—that is, face-to-face interaction—was the better one to use, our assessments have uncovered six situations in which an educational technology has accomplished a pedagogical goal more successfully than traditional media. These situations are:

Using online lectures to teach students basic concepts*:* In 2000, Professors Eric Grimson and Tomas Lozano-Perez began to put lectures for the 350-student course Structure and Interpretation of Computer Programs (6.001), online. Each semester, Grimson and Lozano-Perez saw attendance at the lectures drop off significantly as the term progressed even with excellent lecturers; they felt a radical change was needed. The online lectures, which are composed of narration, text, and slides that mimic board work, are broken down into three or four segments with problems that require students to write lines of code embedded in between. The students can use "hint" and "check" buttons that allow them to revise their answers until their code passes the "check" test, and then they submit it. Weekly problem sets also use the hint and check buttons, and are submitted and graded electronically.

Interestingly, at the students' request a small number of live lectures were reinstated in the spring semester 2001. The students felt they weren't getting the chance to know faculty—even though faculty members taught weekly recitations. (There are now five live lectures during the semester; each one introduces a new topic of the course.) The online lectures enable the students to learn at their own pace and on their own schedule and give them the opportunity to obtain immediate electronic feedback on their own progress—something traditional lectures could never do.

A study conducted in the spring semester 2002 assessed how well the online lectures taught both broad programming concepts and detailed material in comparison to the live lectures. Six live lectures were matched with six online lectures based on the type of content covered. Questions on quizzes and exams were created specifically to assess how well the students learned material from both delivery systems. Additional data on student satisfaction, academic motivation, and cognitive style was collected. As the investigator explains and is shown in Figure 3:

> The online presentation of information appears to be more successful than auditorium-style lecturing. Online lecture broad knowledge and online lecture detailed knowledge showed significant differences from the null hypothesis of average performance. Live lecture broad knowledge tested significantly below the average and live lecture detailed knowledge was not significantly different from the average (Newman, 2002, p. 7).

Figure 3: Student Performance as a Function of Live versus Online Lectures in 6.001

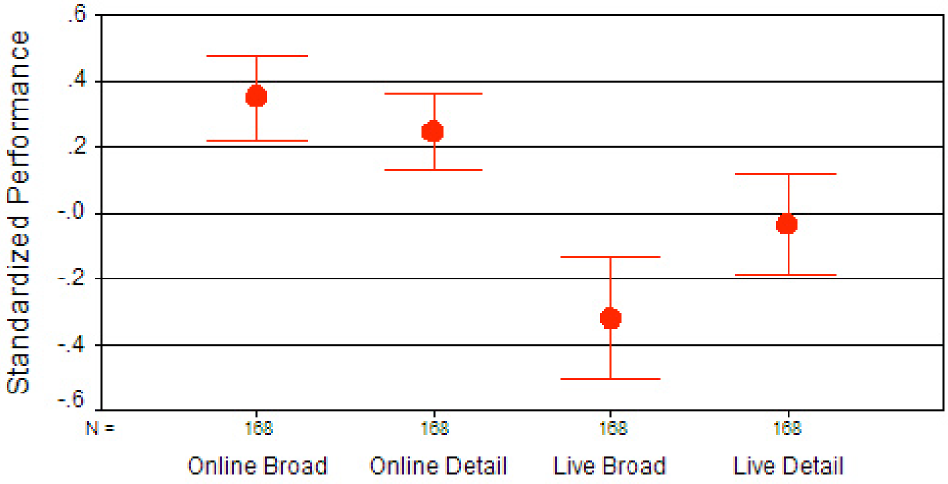

Figure 3: Student performance on 6.001 exam and quiz questions specifically written to test their understanding of categories of material (broad concepts and detailed information) presented in two formats (live lectures and online lectures). Circles represent group mean z-scores, and vertical bars show 95% confidence intervals. Source: Newman (2002).

The faculty member currently teaching the course, who was skeptical about going online at first, admits he is now a convert. "The students are viewing the lectures and doing the problems conscientiously," he said. And although he does not have data to support this conclusion, he feels the students understand the subject matter in the course more thoroughly than they did when 6.001 was lecture based.

Using visualizations to help students see what cannot otherwise be seen: An important feature of the TEAL project is the development and use of simulations and animations that model electromagnetic phenomena. It is not hard to understand why electromagnetism is a difficult subject for students to master as they have only the most indirect experience with it in the physical world. The TEAL visualizations allow students to literally see electric and magnetic fields and understand how they exert the forces they do.

For example, in teaching Faraday's Law, students do a desktop experiment in which a loop of wire falls along the axis of a magnet so they can observe the resultant eddy current in the loop, something predicted by Faraday. Then they can access a Java applet in which they can perform the same experiment "virtually" and "see" both the eddy current and the field it produces. As Dori and Belcher (2004, p. 13) write:

> The Java applet calculates the motion of the falling wire loop and also calculates and plots the magnetic field lines of both the magnet and the eddy current in the loop. Using sliders and field text at the bottom of the screen, a student can change two parameters in the simulation.

As they change those two parameters, students are asked to answer a series of questions that help solidify their understanding of the fundamental principle in electromagnetism that asserts that changing magnetic flux produces an electrical field and thereby a current.

Another example of using technology to help students conceptualize a complex phenomenon is the instructional module developed to teach Fourier spectral analysis in Biomedical Signal and Image Processing (HST 582J). This is an important but difficult idea for students to master because of the number of variables that are interacting. The online module consists of an input window that allows students to observe those key variables and change their parameters. An output window illustrates the effects of these choices and then displays the final results. This tool is used both in a web-based tutorial the students must complete, as well as in class during the lecture on spectral analysis. In both situations, students are aided by being able to observe the phenomenon (Greenberg, Smith, and Newman, 2003).

As reported above, our assessments have shown positive learning gains in both 8.02T and HST 582J that are due in some measure, we believe, to the utilization of the technologies discussed above.

Using visual technologies to help students strengthen their literacy in non-text-based media: Two technologies developed at MIT, the Cross Media Annotation Tool (XMAS) and the MetaMedia framework, move students away from a reliance solely on text-based resources and expand their access to graphic, video, and audio materials. Multimedia archives allow humanities students to have access to materials found in various locations around the world. Students can annotate the material, embed it in essays and projects, and share the annotated documents with others. These capabilities allow students to research, develop, and collaborate on multimedia essays or presentations with learners across the globe (http://metaphor.mit.edu/).

When students who were using MetaMedia in 2002 were interviewed, they confirmed that the applications helped them learn. Effects ranged from improved listening comprehension, vocabulary building, speaking ability, and understanding the culture (for the language) to the ability to create better presentations, do better literary analysis, and conduct better research (for literature applications). Students were less certain of the impact on their cognitive skills—e.g., thinking abilities, media literacy, close reading skills, and hypothesis making. While the assessment did not test for learning gains in these areas, on interview, faculty felt that these abilities had been improved. Since the interviews were done when students were using version 1 of MetaMedia, an assessment studying version 3 is being carried out in spring semester 2004. A follow-up investigation of XMAS is also being planned for spring semester 2004.

Using wireless laptops to learn programming: In Introduction to Computers and Engineering Problem Solving (1.00), students are given wireless laptops to do both in-class exercises and homework assignments. Carrying out active learning exercises in class via wireless laptops not only allows the 1.00 students to practice what they have just heard in mini-lectures, but it permits instructors and teaching assistants to answer questions as soon as students ask them. Students also bring their laptops to office hours so they can show the instructor or teaching assistant the problem they are having writing their code.

Online surveys administered at the end of the fall 2002 and spring 2003 semesters assessed students' attitudes toward both active learning pedagogies and the use of wireless laptops. Based on the responses of slightly over 70% of the students, the investigators concluded, "[The students] believed that having their own laptops in the class was very useful, and they did not want to be taught in a desktop laboratory as was done in the past" (Barak, Lipson, and Lerman, 2004, p. 19).

Making laboratory facilities available remotely*:* iCampus has funded a project called iLab since summer 2002. iLab provides online access to remote laboratories for classes that cannot provide them themselves either because of cost or lack of space. iLab began with a microelectronics WebLab; there are now seven online laboratories (http://icampus.mit.edu/projects/iLab.shtml). Students log into a website and start a program that allows them to configure and execute experiments. Currently, WebLab is being used in the course, "Microelectronic Devices and Circuits" (6.012). With over one hundred students enrolled, the course would not include a lab component if not for WebLab. Although no assessment has been done of the iLab courses, it is clear that in this case technology makes possible access to an educational experience that would not be available to students otherwise.

Improving feedback*:* Finally, edtech has the ability to change the nature of feedback, a crucial component of the learning process. Not only can both students and instructors receive feedback more quickly, but the feedback they get can be personalized to their own needs.

For example, in TEAL a personal response system (PRS) allows the instructor to ask the class a multiple-choice question about a concept just discussed. The students punch in their answers on hand-held devices that transmit to a central computer using infrared signals. A histogram showing the number of students who chose each answer is generated on a screen, so both the instructor and the students can gauge if the material was understood. Depending on the results of the "voting," the instructor can re-teach the material; give students a hint and ask them the question again; ask them to talk to other students about their answers; or continue on if most of the class got the answer right. (See p. 14, however, for problems that needed to be addressed regarding the use of the PRS system.)

As discussed, the online lecture system in Structure and Interpretation of Computer Programs (6.001) permits students to "check" the code they have written immediately, and, in fact, the students do not submit their code until it has passed various "check" tests. The assessment of 6.001 done in the fall semester 2002 found that the check button was "universally applauded" (Newman, 2002, p. 9), and the instructor currently teaching the class reports the students really "love" it. (Most get 95% or above on the problems that have check buttons.) As explained above, the feedback on these embedded problems, as well as the problem sets that are due once a week, is immediate, so students know right away if there are gaps in their understanding.

Although we have not specifically focused on technologies that provide instantaneous feedback in our assessment studies, both Mazur (1997) and Hake (1998) report on the advantages of pedagogies that allow students to get immediate feedback through discussions with peers. Our hypothesis is that tools that make feedback more readily available and more easily accessible enhance the learning process, although there may be a point at which too much feedback overwhelms the learners, the instructor, or both. This is a topic for future investigation.

Finding #2: Too Much Technology Can Be Detrimental

Students need time to learn how to use a technology: how to access the application and make it operate, its features and functions, its purpose in the course, and how to best integrate it into their learning experience. Sometimes students have to do two things at once: learn the application and learn the course material. Introducing too much technology can overwhelm students as they grapple with the technology. In this scenario, they spend so much time learning to use the application that the technology never becomes a tool for understanding the course material. Students who took courses using MetaMedia and XMAS reported a period of adjustment during which they had to become familiar with the technologies and comfortable with the pedagogies that employed them.

All new applications go through various upgrades, each one improving functionality and usability. Rarely is a technology introduced without at least some initial obstacles. The web-based module on Fourier spectral analysis for Biomedical Signal Image and Processing (HST 582J) went through an elaborate formative assessment. Necessary changes were identified and made. The functionality and features of MetaMedia and XMAS have also been through several upgrades. Students proposed a number of enhancements to the interface features and controls. In Exploring Black Holes (8.224), several changes were made to the layout of the discussion board within the first weeks of the semester. The original designed proved to be too cumbersome; students needed a clear and simpler layout of the discussion threads.

TEAL uses a variety of very sophisticated classroom technologies, which often take a fair amount of practice for the *instructors* to master. Besides the visualizations and personal response system described above, there are PowerPoint presentations, and students work on laptops in groups of three to do desktop experiments and other in-class assignments.

In the spring semester 2003, when there was a great deal of dissatisfaction with TEAL, the PowerPoint presentations were particularly singled out for criticism. The students complained the lecturer only read what was on the overheads, and, as a result, they couldn't follow the thread of his argument. (The students pointed out that if a lecturer writes out a proof on the blackboard, for example, it is easier to follow him because the logic of the proof is unfolding in real time.) One student spoke for many when she said, "Sometimes the lecturer skips over points on the overhead saying, 'You know that,' but I don't know that." And another said, "Sometimes I feel as if I'm just sitting there watching a slide show."

The PRS system also was criticized. One student confided that answering the questions became a game. "The PRS is a joke," he said. "At my table people just push buttons; sometimes they want to see how many times their answer is registered." There were also problems with the way in which the PRS system was integrated into learning. For example, one student pointed out if at least 60% of the class got the question right, the instructor moved on. "What about the 40% who didn't understand the concept?" she asked. But perhaps the most telling comments about the use of technology came in the summary comments the students made. "There are too many ways to get information," said one. "It's confusing, and there's repetition."

It is important to mention that in response to this feedback, the TEAL instructional staff has made improvements. The PowerPoint overheads have been simplified, and the number of slides has been cut down. More training is given to the faculty in the use of technology. Instructors now explain why the right PRS question is correct, and the others aren't. All this has made a difference: there have been few, if any, complaints about 8.02T this term.

As a final example, although students enrolled in 1.00 have enjoyed the use of their wireless laptops, at times they can be a serious distraction. As to be expected, some students use their laptops to send or read email messages or access websites when they are supposed to be paying attention to the instructor's explanations.

Finding #3: There Are Important Relationships Between Educational Technologies and the Learning Environments in Which They Exist

One way to understand the impact of educational technology is to look more broadly at how specific tools operate within the learning environments in which they are used. Just like the phonetic alphabet and the book before them, educational technologies exert their influence by shifting the nature and uses of information within the wider system. In the initiatives we have been examining, those systems are the places—and here we use the word "places" to refer both to physical spaces and the social norms that govern them—where learning typically takes place. In a university setting, those places certainly include the classroom, library, and laboratory, but they can also be a faculty member's office, a dorm room, or the local Starbucks.

All of these learning environments are defined by the way in which information exists within them. To use a simple example, in a lecture-based classroom information primarily flows one way—from instructor to student. This creates a different kind of environment, with different norms and different kinds of learning, than a classroom in which students interact with one another, and information flows from many different sources to many different receivers. As the educational literature has shown, learning increases in classrooms where information flows among students (Springer, et al., 1997).

This broader perspective has led us to three conclusions about the impact of educational technologies:

Educational technology is most effective when connections are strong between the use of the technology, the learning goals, and other pedagogical methods employed: In other words, educational technology is most successful when it is aligned with the other components of the learning environment. Most of the projects we have studied began with the instructor's conviction that some sort of educational technology would allow students to become more actively engaged with the subject matter of the course, and that, in turn, would foster deeper understanding. Instructors who use educational technology in courses like 1.00, 6.001, 8.02T, HST 582J, as well as those who developed tools like XMAS and MetaMedia, have found this to be true. The degree to which the educational technology achieved its aim is due in large measure to the fact that it worked in concert with the instructor's learning objectives and the other pedagogical methods employed.

For example, a specific goal of the TEAL project is to increase students' conceptual and analytical understanding about the nature and dynamics of electromagnetic fields and phenomena. The animations and visualizations, desktop experiments, and PRS system are all used to further that aim. For example, Dori and Belcher (2004, p. 8) offer this explanation of the benefits of the desktop experiments:

> Thornton and Sokoloff (1990) found strong evidence for significantly improved learning and retention by students who used MBL [micro-based laboratory materials] compared to those taught in lecture. Desktop experiments provide for integration of data acquisition with tools for data analysis, modeling,
>
> and computations, enabling the student to use models as a bridge between the mathematical function that reproduces a result and the underlying physical concepts that give rise to such relationships (Scheker, 1998).

But getting the technology, pedagogy, and learning goals aligned is no easy matter—especially when other components of the system such as the students' knowledge base or the instructional preferences of the faculty are added to the mix. Like a recipe that can be ruined by adding too much salt or leaving out the pepper, the learning environment can be put out of kilter if the ingredients are not just right.

We have several examples of this. As explained above, in Introduction to Computers and Engineering Problem Solving (1.00), students have access to their wireless laptops both when they are doing in-class exercises, and when the instructor is lecturing. According to classroom observations done in the spring semester 2003, during the active learning sessions, 94% of the students, on average, used their laptops to solve the problems presented in class. However, during lecture, when about 80% of the students had their laptops on their desks, the machines sometimes "were used for non-directed, non-learning purposes such as reading e-mail or surfing the web" (Barak, Lipson, and Lerman, 2004, p. 35). And why shouldn't that be the case? It would be a surprise if the mix of the pedagogy (lecture) and technology (wireless laptop) resulted in anything else.

In the Mission 200X courses, the first semester freshman year class that emphasizes project-based learning and teamwork, students were given access to an online synchronous discussion tool called Unchat to encourage collaboration and discussion outside the classroom within teams, between teams, and with mentors and other outside experts. But the students never fully utilized Unchat because technical problems were a major barrier to its use. It was more trouble than it was worth for intra- and inter-team communication—the students could accomplish that more easily by meeting with each other inside or outside of class—although Unchat did prove useful in one specific situation when students needed to communicate with off-campus experts.

It may be naive to think we will ever get to the point where we will know with some certainty which uses of edtech will be effective and which will not. But our assessments have shown that instructors and developers who analyze the major elements in the learning environment, and who think about how those elements are likely to interact, have a good chance of achieving positive results.

The same technology will have differential effectiveness based on the educational context within which it is embedded and may benefit some groups of students more than others: PIVoT, the Physics Interactive Video Tutor, was designed to be a web-based multi-media supplement to Physics I (Newtonian mechanics [8.01]). It includes video lectures, video help sessions, a physics textbook, FAQs, practice problems, simulations, and a discussion board. An assessment (Lipson, 2000), conducted during fall semester 2000, examined PIVoT's use at three different schools: MIT, Rensselaer Polytechnic Institute (RPI), and Wellesley. Each school utilized PIVoT within a different pedagogical environment. MIT's Physics I class used PIVoT in a loosely coupled way as a voluntary supplement within a traditional lecture/recitation format; its use was not required for any specific homework assignments. RPI conducted an experiment in its studio-based mechanics class in which some sections used PIVoT while others did not. The sections that used PIVoT assigned some homework problems related to specific video lectures and help sections. Wellesley also used PIVoT in this tightly coupled way but within a traditional small lecture format; some of the weekly homework problems were practice problems from the PIVoT website.

For the assessment, online surveys were administered to MIT students, and similar paper surveys were given to students in the two other schools. Only RPI gathered pre- and post-test data using two conceptual diagnostic exams, the Force Concept Inventory (FCI) and the Force and Motion Conceptual Evaluation (FMCE). The survey data suggest two relationships. The first was between the pedagogical format used in the course and the students' opinion of PIVoT. For example, RPI students were less likely than MIT and Wellesley students to say PIVoT helped them better understand physics concepts, which may be because RPI's studio-based course offered a variety of other interactive ways to learn. The second relationship was between PIVoT and the students' level of preparedness. As an example of this, the less prepared MIT students were significantly more likely than the better prepared MIT students to think PIVoT helped their conceptual understanding. This may be because the traditional large lecture/recitation format is less conducive to helping weaker students learn.

Interestingly, although RPI PIVoT users had significantly higher gains on the Force Concept Inventory than non-users, the data showed that improvement in conceptual understanding was not uniform for all PIVoT users when high school preparation was factored in. Students with stronger high school preparation derived greater benefit than those with weaker preparation. Perhaps in the RPI format, students with better preparation were more able to take advantage of the multiple learning options that PIVoT provided, while those with less preparation made less use of those options. The assessment report emphasized that this finding requires further study.

Edtech exerts its impact by changing the properties of information in the learning environment: Educational technologies are information carriers, packaging, transporting, and disseminating information throughout the system. They are one kind of tool in an array of devices that are used to build and maintain the learning environment. (The spoken word and text-based materials, of course, are the other primary tools.) But as noted above, these technologies are not neutral conveyances. Different technologies use different symbol systems to encode information, they move information at different speeds, the change the amount of information in the system and the direction in which it moves, and they make information accessible to different groups of people. In doing so, they influence the very nature of the system in which they exist.[2]

These effects can be paradoxical. For example, a tool like MetaMedia changes the amount of information available to students. No longer confined to using texts, students can now access both still and moving images. We would argue that this is a positive change because instructors now have ways to strengthen students' media literacy. However, this also means the instructor must provide the students with guidelines on how to judge the quality of images, how to place them in context, how to use them appropriately for a given assignment, etc. At a time when instructors often complain there is not enough time to "cover the material," this increase in the number of ideas that must be addressed creates its own problems. On the other hand, the student, who already has available a library full of texts, now has to examine, evaluate, and, ultimately, utilize new and different kinds of information.

Perhaps one of the most dramatic ways in which technology is affecting the learning environment is by changing the relationship between student and teacher. We have

already described how educational technology influences the shift away from passive learning, as exemplified by the lecture, to the use of more active learning pedagogies in which students construct their own knowledge. (This is not to say that educational technologies are a necessity for active learning, but many of the innovations at MIT have revolved around building technologies to facilitate and improve active learning.)
The irony is that over and over again we have seen that students do not always take this change well. They do not necessarily want the faculty to give up their role as information providers, and they do not want to take on the role of knowledge builder. This was most evident in the comments of the students who participated in the TEAL focus groups in spring 2003 (see p. 6 of this report).

The shift from passive recipient of information to active user requires a major re-conceptualization of who is responsible for what, under what circumstances, and to what end. This kind of substantial redefinition of roles takes both time and effort. The ability of educational technology to deliver more information, in more forms, anytime and anywhere is going to be one of the prime movers in redefining that relationship whether students and their teachers are ready for it or not.

As stated in the beginning of this section, we realize the potential of educational technologies is yet to be realized. We expect that major changes will occur in the technologies themselves and the uses to which they will be put. Some technologies will wither away while others will be transformed and used in ways that we may not yet imagine.

OBSERVATIONS ON DESIGN, IMPLEMENTATION, AND ASSESSMENT

Major findings:

- *Design:* Educational innovation can be thought of as a design problem: innovators wish to improve upon instructional practices but must work within a set of constraints. Best practices to accomplish this goal include:
    - Formulating objectives in terms of learning outcomes.
    - Researching what is already known or has been done in relation to the innovation.
    - Identifying constraints in time, funding, and space.
    - Planning for the pull of the status quo.
- *Implementation:* Educational innovation is an iterative process.
- *Assessment:*
    - Differences between research in the “hard” and “soft” sciences must be made explicit.
    - The full-range of assessment methodologies should be used because the educational environment is “noisy.”
    - Assessment should be formative in line with the philosophy that educational innovation is an iterative process.

Below are specific lessons we have learned about the design, implementation, and assessment of educational innovations.

Best Practices in Design

We believe one of the reasons that MIT faculty, administration, and students have embraced educational reform so successfully is that it parallels what they do best: tackle a hard problem and find a first-rate solution for it. In many ways, educational innovation can be thought of as a design problem because innovators want to achieve certain objectives but must work within certain constraints in order to do so. Interestingly, educational innovation can also be thought of as research: that is, a "hypothesis" is formulated about how learning can be strengthened, an "experiment" is created to test the "hypothesis," and the results are analyzed. Educational innovation is a natural process for the scientists and engineers who make up the MIT community.

Our collaboration with faculty over the past four years has led us to identify two specific "best practices" in the design of new learning experiences.

The very first thing we do when we begin to work with faculty members is to ask them to define their objectives, so we can collaborate on developing an assessment plan that will help us judge if those objectives are being met. But we have noticed that this is a hard task for some faculty. For example, if the project relates to a specific course, many MIT instructors, like most academics, will think of their objectives in terms of the topics that need to be discussed during the semester. It can take a shift in thinking to define objectives in terms of learning outcomes, which, we would argue, is the better way to conceptualize them. Of course, those learning outcomes must include the knowledge the students will gain from the course, but they may also include skills the students should master, or the attitudes or habits of minds that the instructor hopes to foster. Many MIT faculty members begin projects from this perspective, but for others the lure of content is hard to resist. We want to reinforce the notion that developing learning objectives, as we have defined them, and using them as the springboard for educational reform is good instructional practice.

Another practice we think is beneficial is to start an educational initiative by researching what is already known or what has already been done that relates to it. There is a growing body of literature in higher education, and it includes both research in learning and descriptions of innovations already implemented. Just as scientific research begins with what is known, so should our work in educational reform.

Best Practices in Implementation

If there is one thing we have learned as we have worked with faculty, staff, and students on these projects, it is this: It takes time to get it right. We found that our first efforts in assessment—though not necessarily planned this way—tended to focus on the design components of the initiative. We then fed the results of our studies back to faculty and instructional staff so they could strengthen the design. Just like any other kind of creative work, the process of improving education is iterative.

The development of TEAL is a good example of this kind of evolution. TEAL was piloted in Physics II (8.02T) in the fall semesters 2001 and 2002. Student feedback, along with other assessment data, was gathered. Although students reported they were satisfied with the course, a number of changes were made based upon that feedback.

As stated above, the first full-scale implementation of 8.02T occurred during spring semester 2003, and within a month of the beginning of the semester, it was clear that many students were unhappy. TLL staff led “emergency” focus groups of students before spring break that year, and based on what we heard, the TEAL instructional staff made changes in the second half of the semester. (We have seen this need for mid-course corrections in other projects as well.) More importantly, still additional alterations were made in TEAL in the spring semester 2004 based on the data from 2003, which is one reason, we believe, that TEAL has been so well received this year.

The point is that the TEAL project has been “under development” for almost five years. (This includes the year before the first pilot was launched when many of the curricular components were created.) We do not feel this is an unusual amount of time to make the kind of educational change that TEAL represents.

Best Practices in Assessment

And what have we discovered about our own work that will help us improve as we go forward?

We know that the role of assessment is to provide credible and viable data that describe and explore the educational experience, serve as feedback on innovations, and support claims about best practices. We know—and enjoy—working closely with faculty to formulate questions that resonate with them, make the data viable, and make the results valuable. We recognize that for successful collaboration, TLL researchers must honor the demands placed on faculty members' time and take responsibility for the implementation of the assessment plan. We keep faculty informed of our progress, seek their advice on any key issues, and provide summaries of data analysis along the way. We try our best to do all that with minimal burden placed on faculty.

We also know that educational research differs from the kind of research that most MIT faculty members do in several fundamental ways: different data counts as evidence; different methodologies are considered legitimate; and different kinds of results are seen as valid.

For example, in the lab, a relatively high degree of control of the phenomena under study can be exercised. Variables can be isolated and controlled for, physical processes can be replicated in time and space, and measurements can be precise. But the process of educational research is—for lack of a better word—messier. The impact of educational innovation is often difficult to see because treatment effects are usually small or medium in size. Detecting these effects is sometimes problematic because students as subjects are "noisy." Moreover, the learning environment does not lend itself easily to randomized experiments. Placing students in one of two learning settings in which the treatment setting is hypothesized to provide a stronger learning experience may be good science, but it does not reflect ethical behavior. In quasi-experimental designs, the problem may be lack of a comparison group due to the absence of base line data, or the inability to control enough "outside" factors to be able to see the influence of the treatment. In other situations, the treatment effect may be so well integrated into the course that it is difficult to isolate quantitatively.

All of this has led us to two more "best practices." First, we make these differences between research in the "hard" and "soft" sciences explicit to the faculty with whom we work. We have found that this helps faculty members understand what can and cannot be done in educational research. Second, whenever possible, we triangulate the data. Specifically, we have found in cases where the "noise" level of the learning environments is sufficiently strong to weaken the effectiveness of quantitative assessment, qualitative methodologies, including observation, focus groups, and interviews, are useful. For example, in Circuits and Electronics (6.002x), student interviews and surveys were used to assess student acceptance of the case method, and in 8.02T, focus groups, questionnaires, and pre- and post-tests were used to evaluate the impact of the TEAL experience.

Most of the studies we have done in the last four years are formative assessments that generate feedback rather than make formal judgments. We would not have it any other way because this assessment method is in line with the philosophy that educational innovation is an iterative process. Our assessments have, and for the foreseeable future will continue to, result in recommendations, suggestions, or, when possible, alternate solutions to problematic educational issues. We want our findings, whether they are negative or positive, to lead to actions that move current initiatives forward or point to new directions. We believe formative assessment fails if the results discourage rather than encourage advancement. It is our hope that the collaboration between faculty members, administration, students, and TLL educational researchers will continue to energize innovation and bring about positive change.

NEXT STEPS

We have already started what we consider to be "round two" of evaluating educational innovations at MIT: We are working to discover what the longer term effects of some of the earliest initiatives may be. To that end, Dr. Alberta Lipson has been interviewing the students who were enrolled in Mission 2004, the first Mission class, and who are now seniors. (Please see Appendix B for a list of researchers who have contributed to TLL's assessment efforts and their affiliations.) Dr. Lipson is interested in finding out what the impact of Mission 2004 has been on the development of those students' teamwork, communication, and problem solving skills, as well as their attitudes toward their experience at MIT.

Professor Yehudit Dori has had former 8.02T and conventional 8.02 students take an exam to test their retention of concepts in electromagnetism twelve to eighteen months after they finished Physics II. The results of the two groups will be compared to see if there is a significant difference between them. And Mr. Tom Clay is interviewing the students who took the first experimental version of 6.002x to find out their opinions a year later about working in tutorials with practicing engineers.

While we intend to continue these longitudinal assessments, we are also excited about starting new research. Dr. Rudi Mitchell, who began as TLL's Associate Director of Assessment and Evaluation only two months ago, has just completed meeting with over three dozen faculty, administrators, and instructional staff to find out what kinds of questions they would like us to explore. Among their answers include:

- What are the relationships among pace, quantity, and quality of student learning?
- How well do the concepts/skills covered in a given course transfer to future subjects?
- How do on-line simulations affect student cognition?
- Are the educational technologies and active learning methods developed at MIT generalizable?
- Does active learning stimulate higher-level thinking?
- How do students learn in study groups formed outside of class?
- What is the relationship between space and learning? How do spaces (outside of formal settings) become venues for learners?
- What role do recitations play in student learning?
- What are the factors that contribute to the acceptance of innovative educational initiatives?
- How can faculty members stimulate students to become reflective learners?

Finally, TLL staff members have their own research questions they are exploring, including: how do we strengthen students' abilities to work in interdisciplinary classrooms and laboratories? what are the impediments to students collaborating effectively in teams, and how can we overcome them? and, how can we best describe the cognitive, metacognitive, and experiential aspects of MIT student learning? There is no end of interesting projects to pursue!

The other major "next step" we will be taking is to disseminate these findings through a variety of venues both at the Institute and in the wider educational community. (Please see Appendix C for a list of papers and presentations that have reported our findings to date.) In that way, we hope to contribute to DUE's goal of supporting more educational innovations at MIT, and we hope other institutions can profit from the work to which MIT faculty, administration, staff, and students have been so devoted.

Endnotes

[1] Hake (1998) computer learning gains using the following formula:

$$\text{Learning gains} <g> = \frac{\%\text{Correct}_{\text{post-test}} - \%\text{Correct}_{\text{pre-test}}}{100\% - \%\text{Correct}_{\text{pre-test}}}$$

[2] This analysis follows work done in the 1970s and 1980s by media researchers primarily at New York University. Christine Nystrom (1973) and others postulated that information has five properties in human communication systems: the *symbol systems* used to encode information; the *direction* in which information flows; the *amount* of information available in the system; the *velocity* at which information moves; and the *accessibility* of information to different parts of the system. These properties are interrelated so that a change in one produces a change in some or all of the others.

Works Cited

Barak, M., Lipson, A. and Lerman, S. (2004). "Wireless Laptops and Active Learning: Developing a Sustainable Curriculum for a Java Programming Course," submitted to the *International Journal of Human-Computer Studies*.

Belcher, J. (2003). "Improving Student Understanding with TEAL," *The MIT Faculty Newsletter,* 16(2):1,8-11.

Breslow, L. (1986). "Media Ecology: An Interdisciplinary Approach to the Study of Communication," paper presented at the *Association for Integrative Studies Conference,* Bowling Green, OH: Bowling Green State University.

Breslow, L. (2002a). "Report on the Use of Group Work in 'Differential Equations' (18.03) Recitations Spring Semester 2002," unpublished assessment report.

Breslow, L. (2002b). "Strategic Assessment at the Massachusetts Institute of Technology," *Proceedings of the e-Technologies in Engineering Education Conference*, published online at http://www.coe.gatech.edu/eTEE.

Clay, T. (2002). "Overview Report on MIT MetaMedia," unpublished assessment report.

Dolmans, D., Wolfhagen, I., van der Vleuten, C., and Wijnen, W. (2001). "Solving Problems with Group Work in Problem-Based Learning: Hold on to the Philosophy," *Medical Education*, 35(9):884-889.

Dori, Y. and Belcher, J. (2004). "How Does Technology-Enabled Active Learning Affect Undergraduate Students' Understanding of Electromagnetism Concepts?" under review at *The Journal of the Learning Sciences.*

Greenberg, J. E., Smith, N. T., and Newman, J. H. (2003). "Instructional Module in Fourier Spectral Analysis, Based on Principles of How People Learn," *Journal of Engineering Education,* 92(2):155-164.

Hake, R. R. (1998). "Interactive-Engagement versus Traditional Methods: A Six-Thousand Student Survey of Mechanics Test Data for Introductory Physics Courses," *American Journal of Physics,* 66(1):64-74.

LeBon, L. E. (2003). "Students Petition Against TEAL," *The Tech,* 123(14):1,17 March 21, 2003.

Lipson, A. (2000). "An Examination of Student Usage Patterns and Attitudes Toward PIVoT: A Pilot Study," unpublished assessment report.

Lipson, A. (2002). "A Formative Assessment of Mission 2005," unpublished assessment report.

Maudsley, G. (2002). “Making Sense of Trying Not To Teach: An Interview Study of Tutors’ Ideas of Problem-Based Learning,” *Academic Medicine,* 77(2):162-172.

Mayo, W. P., Donnelly, M. B., and Schwartz, R. W. (1995). “Characteristics of the Ideal Problem-Based Tutor in Clinical Medicine,” *Evaluation and the Health Professions,* 18(2):124-136.

Mazur, E. (1997). *Peer Instruction.* Upper Saddle River, N.J.: Prentice Hall.

Newman, J. (2002). “6.001 Report on the Outcomes of Online Learning,” unpublished assessment report.

Nystrom, C. (1973). “Towards a Science of Media Ecology: The Formulation of Integrated Conceptual Paradigms for the Study of Human Communication Systems,” doctoral dissertation, New York University.

Postman, N. (1985). *Amusing Ourselves to Death.* New York: Viking Penguin, Inc.

Scheker, H. P. (1998). “Integration of Experimenting and Modeling by Advanced Educational Technology: Examples from Nuclear Physics.” In Fraser, B. J. and Tobin, K. J. (eds.), *International Handbook of Science Education*, pp. 383-398. Dordrecht, The Netherlands: Kluwer Academic, as cited in Dori and Belcher (2004).

Sokoloff, D. R., Thornton, R. K, and Laws, P. W. (1999). *Real Time Physics Active Learning Laboratories*. New York, NY: Wiley, as cited in Dori and Belcher (2004).

Solomon, P. and Finch, E. (1998). “A Qualitative Study Identifying Stressors Associated with Adapting to Problem-Based Learning,” *Teaching and Learning in Medicine,* 10(2):58-63.

Springer, L., Stanne, M. E., and Donovan, S. S. (1997). “Effects of Small-Group Learning on Undergraduates in Science, Mathematics, Engineering, and Technology: A Meta-Analysis,” Research Monograph No. 11, Madison, Wisconsin: University of Wisconsin—National Institute for Science Education.

Tervalon, C. D. (2002). “Student Views of 8.224: A Qualitative Case Study,” unpublished assessment report.

Appendix A
TLL Assessment Projects 2000-2003

Strand A: Active Learning

Project Name	**Biomedical Signal and Image Processing (HST 582J)**
Investigator(s)	Julie Greenberg, Natalie Smith, John Newman
Faculty	Julie Greenberg
Scale and Scope	This study examined the introduction of a module on Fourier spectral analysis, based on the “How People Learn” (HPL) educational model, into the course, Biomedical Signal and Image Processing. The study compared a group of students who were taught that topic with the module with students taught the material using traditional methods.
Outcome Measures	Rubrics developed to score understanding of key concepts showed that students who used the module demonstrated better understanding of the majority of key concepts relative to students who learned with traditional pedagogical methods.
Impact	The results of this study were published in the *Journal of Engineering Education*, April 2003. The Harvard-MIT Division of Health Science and Technology (HST) is extremely committed to educational innovation and has appointed Dr. Greenberg Director of Educational Initiatives. The division is involved in a proposal to the NIH for a new interdisciplinary educational effort, the Center for Studies in Endothelial Biomedicine.
Status	Study is completed.
Funding Source	Internal

Project Name	**Circuits and Electronics (6.002x)**
Investigator(s)	Thomas Clay, Rudolph Mitchell, Lori Breslow
Faculty	Harold Abelson, Gerald Sussman
Scale and Scope	This assessment evaluated the use of problem-based tutorials in a required electrical engineering course, Circuits and Electronics (6.002x). In these tutorials, practicing engineers, most of whom are MIT alumni, coach six to eight students as they solve open-ended problems related to the concepts they had learned in lecture that week.
Outcome Measures	Students and tutors both reported high levels of satisfaction in interviews and surveys done in spring 2003. Relatively minor changes were made in the course this year based on the assessment results (e.g., two-hour instead of one-hour tutorials).
Impact	Twice the numbers of students have chosen to be in the course this semester. The department is exploring using case-based tutorials in other courses.
Status	Assessment continues in the spring semester 2004, focusing on: scability, impact on student attitudes toward new modes of learning, and the longer term impact on students who took the course in 2003.
Funding Source	Internal

Project Name	**Differential Equations (18.03)**
Investigator(s)	Lori Breslow
Faculty	Haynes Miller
Scale and Scope	This project investigated the introduction of an active learning pedagogy into 18.03 recitations during the spring semester 2002. Specifically, the students were asked to work in groups on problems instead of watching the recitation leader solve problems at the board.
Outcome Measures	Classroom observations, interviews, and surveys showed modifications of usual group work methods were needed for the cognitive tasks associated with learning mathematics. Satisfaction increased when students were allowed to work on problems individually before discussing them with other students.
Impact	Results of this and other experiments in active learning have been reported in the department although the department has not chosen to use these pedagogies on a broad scale.
Status	Study is completed.
Funding Source	Internal

Project Name	**Introduction to Computers and Engineering Problem Solving (1.00)**
Investigator(s)	Miri Barak, Alberta Lipson
Faculty	Steven Lerman, Jud Harwood, George Kocur
Scale and Scope	Instructors in 1.00 changed the course from a lecture/recitation format to a studio-based model. A unique feature of this class is that students are loaned wireless laptops for the semester, which allows them to participate in programming exercises and interactive problem solving during class time. An assessment was carried out that included online surveys, class observations, and student and TA interviews to gauge student attitudes toward the new pedagogical model and understand how the laptops were being used.
Outcome Measures	Based on the responses of slightly over 70% of the students to online surveys at the end of the fall semester 2002 and spring semester 2003, the investigators concluded, "[The students] believed that having their own laptops in the class was very useful, and they did not want to be taught in a desktop laboratory as was done in the past" (Barak, Lipson, and Lerman, 2004, p. 19).
Impact	Because the study indicated students in 1.00 view laptops as an integral part of their learning, students may be given laptops in additional courses.
Status	Assessment continues in the spring semester 2004.
Funding Source	Internal

Project Name	**Kinetic Processes in Materials (3.21)**
Investigator(s)	Alberta Lipson
Faculty	Samuel Allen, Craig Carter
Scale and Scope	In spring 2002, student satisfaction with the teamwork component of the course was assessed by an online survey and a focus group.
Impact	The instructors continue to use student teams, and the results of the assessment have helped them to refine how they implement teamwork and assess the work of the student teams.
Status	Study is completed.
Funding Source	Internal

Project Name	**Mission 200X (12.000)**
Investigator(s)	Alberta Lipson
Faculty	Kip Hodges
Scale and Scope	Mission 200X (the X stands for the year the students will graduate) is a first-semester, freshmen course that emphasizes project-based learning and teamwork. The assessment sought to determine the strengths and weaknesses of that approach for freshmen, and the overall impact of the class on the students. Methodologies included interviews and surveys of the students, the undergraduate teaching fellows who work with the teams, and alumni/ae mentors.
Outcome Measures	When students compared Mission 2005 to their other first semester classes, 50% or more rated it higher than those other classes for: (1) giving them independence/autonomy; (2) helping them learn to work productively in a group; (3) giving them a sense of accomplishment because there was a final product; and (4) actively involving them in their learning. On the other hand, less than one-third rated it higher for improving their problem-solving ability; being a worthwhile use of their time; and helping them become more independent learners (Lipson, 2002, p. 2).
Impact	MIT has recently begun a wide scale review of its General Institute Requirements. Mission 200X and other educational reforms have helped the GIR Task Force understand that along with subject content, new pedagogies—like project-based learning and teamwork—need to be considered.
Status	Members of the first Mission class (Mission 2004) were interviewed in their sophomore year to determine what impact Mission 200X had on their learning skills, and now, as seniors, they are being interviewed and surveyed again to assess longer term influences.
Funding Source	Internal

Project Name	**Technology-Enabled Active Learning (TEAL)***
Investigator(s)	Yehudit (Judy) Dori
Faculty	John Belcher
Scale and Scope	The TEAL project has transformed freshmen physics (both mechanics [8.01] and electromagnetism [8.02]) from a lecture/recitation format to a studio physics model that combines short presentations with in-class desktop experiments and conceptual and algorithmic problem solving done in three-student teams. Students were surveyed to determine their preferences for the range of pedagogical innovations introduced by TEAL. Two quasi-experimental studies using pre- and post-tests were done to compare the conceptual understanding of students who studied in the TEAL format to those who learned in the conventional lecture/recitation mode.
Outcome Measures	Learning gains for conceptual understanding were larger for students who studied in the TEAL format than those who learned in conventional lecture/recitation mode.
Impact	After introducing the TEAL format in the course on electromagnetism (8.02), it was expanded to the mechanics course (8.01). In addition, results have been submitted to *The Journal of the Learning Sciences* and reported at professional conferences.
Status	We are now analyzing preliminary data from a study that has compared retention of concepts by TEAL students to retention of concepts by conventional students approximately a year after taking their courses. An additional study of these two groups will be done spring semester 2004.
Funding Source	Internal

Strand B: Educational Technology

Project Name	**Exploring Black Holes: General Relativity and Astrophysics (8.224)**
Investigator(s)	Cindy Dernay Tervalon, Rahul Sarathy
Faculty	Edmund Bertschinger, Edwin Taylor
Scale and Scope	This study examined an experiment to enroll off-campus alumni along with undergraduates in a physics course in the fall semester 2001. The alumni took the course using distance learning technologies. The assessment entailed interviewing both the undergraduates and the alumni and conducting a content analysis of the discussion board used throughout the semester.
Impact	The results were reported at the American Association of Physics Teacher Winter Meeting, January 2003. The assessment has also helped the instructors improve the usefulness of the discussion board. Finally, based upon this work, Cindy Dernay Tervalon has played an important role in an Institute-wide committee that is examining multiple uses of discussion boards at MIT.
Status	Study is completed.
Funding Source	Internal

*Please see Strand B: Educational Technology for a description of the assessment of the educational technology utilized in TEAL.

Project Name	**PIVoT (Physics Interactive Video Tutor)**
Investigator(s)	Alberta Lipson
Faculty	Richard Larson
Scale and Scope	The use of PIVoT, a web-based learning environment designed to be a multimedia supplement for students taking Newtonian mechanics, was studied in entry-level physics classes at MIT, Rensselaer Polytechnic Institute (RPI), and Wellesley during the fall semester 2000.
Outcome Measures	The survey data suggested two relationships. The first was between the pedagogical format used in the course and the students' opinions of PIVoT's usefulness. For example, the RPI students were less likely to say PIVoT helped them understand basic concepts than the MIT or Wellesley students, perhaps because RIP course is studio based. The second relationship was between PIVoT and the students' level of preparedness. As an example, the less prepared MIT students were significantly more likely than the better prepared MIT students to think PIVoT contributed to their conceptual understanding.
Impact	This was the first multi-setting investigation of an educational technology, and it yielded valuable information about the importance of understanding educational context when examining the effectiveness of educational technology.
Status	Study is completed.
Funding Source	Internal

Project Name	**Structure and Interpretation of Computer Programs (6.001)**
Investigator(s)	John Newman
Faculty	Eric Grimson, Tomas Lozano-Perez
Scale and Scope	Faculty who teach 6.001 developed a series of online lectures composed of narration, text, and slides that mimic board work. Questions and problem sets were embedded in the online material as well. In response to student feedback, five live lectures were reinstated in the spring semester 2001, and the students are now taught with a combination of online and live lectures. Student satisfaction with this change was assessed. A quasi-experimental investigation compared the effectiveness of live lectures to the online version in presenting both broad concepts and narrow, detail-laden information for students with different cognitive styles as measured by a standardized instrument.
Outcome Measures	The quasi-experimental investigation showed that students were more successful in answering exam questions related to material (both conceptual and detailed) presented in the online lectures than in material presented in the lives lectures.
Impact	The course continues to be taught online. Hint and check buttons have been incorporated into online material in other courses.
Status	Study is completed.
Funding Source	Internal

Project Name	**Technology-Enabled Active Learning**
Investigator(s)	Yehudit Dori
Faculty	John Belcher
Scale and Scope	A number of educational technologies are incorporated into the TEAL format, including visualizations of electromagnetic phenomena, online experiments, online problem sets, and the use of a personal response system (PRS). Students were asked about their attitudes toward these technologies. In addition, a special classroom was built for the TEAL project. In it are 13 round tables sitting nine students each, with every three sharing a laptop. Around the perimeter of the room are white boards and projection screens. A video camera points at each table for student presentations. In the middle of the room is the lecturer's "command center" from which he/she can control the technology and present short explanations of the concepts under discussion. Small separate studies examined the use of the PRS system in this and other classes, and the functionality of the classroom (please see below).
Impact	As described above, TEAL has had important consequences for MIT and undergraduate physics education. After introducing the TEAL format in the course on electromagnetism (8.02), it was expanded to the mechanics course (8.01). In spring semester 2005, another 150 students will be taught 8.02 in the TEAL format, and in order to accommodate them, a second TEAL classroom is being built. Many faculty from other departments at MIT, as well as from around the world, come to visit the TEAL classroom every year.
Status	Please see the status of the TEAL assessment under the Active Learning strand.
Funding	Internal

Project Name	**Use of Personal Response Systems (PRS and PDA) in Six Classes**
Investigator(s)	Alberta Lipson
Faculty	Multi-faculty study
Scale and Scope	Two focus groups were conducted with the faculty who use person response systems (PRS and PDAs) in their classes. In the most sophisticated system, after students send their answers to a conceptual question the instructor has asked, a histogram is generated of their answers. This gives the instructor instant feedback so he/she can gauge student understanding.
Impact	PRS systems continue to be used in MIT classes.
Status	The study is completed.
Funding	Internal

Project Name	**d’Arbeloff-TEAL Classroom Observation**
Investigator(s)	Lori Breslow, Alberta Lipson, Cindy Dernay Tervalon
Faculty	Multi-faculty study
Scale and Scope	A set of classes conducted in the d’Arbeloff-TEAL Classroom (26-152) were observed to assess the room’s functionality and to make recommendations for a second TEAL-like classroom.
Impact	A second classroom is scheduled to open in the fall semester 2004.
Status	The study is completed.
Funding	Internal

Appendix B
Names, Titles, and Affiliations of Project Investigators

Miriam Barak, Ph.D.	Postdoctoral Associate, Center for Educational Computing Initiatives, MIT
Lori Breslow, Ph.D.	*Director, TLL*
Thomas W. Clay	Principal, Tom Clay & Associates, Consultant
Cindy Dernay Tervalon, M.Ed.	Assistant Director, TLL
Yehudit Dori, Ph.D.	Associate Professor, Department of Education in Technology and Science, Technion, Israel Institute of Technology
Julie Greenberg, Ph.D.	Director of Educational Initiatives and Lecturer, Harvard-MIT Division of Health Sciences and Technology (HST), and Research Scientist, Research Laboratory of Electronics, MIT
Alberta Lipson, Ph.D.	Associate Director for Educational Studies, TLL
Rudolph Mitchell, Ed.D	Associate Director for Assessment and Evaluation, TLL
John Newman, Ph.D.	Former Associate Director for Assessment and Evaluation, TLL
Rahul Sarathy	S.B. ‘03, Mechanical Engineering /Management, MIT

Appendix C
Dissemination of Findings

Publications

Dori, Y. and Belcher, J., “Effect of Visualizations and Active Learning on Students' Understanding of Electromagnetism Concepts,” *National Association for Research in Science Teaching (NARST) Proceedings 2003.*

Dori, Y. and Belcher, J., “How Does Technology-Enabled Active Learning Affect Undergraduate Students’ Understanding of Electromagnetism Concepts?” in review at *The Journal of Learning Science,* March 2004.

Barak, M., Lipson, A., and Lerman S., “Wireless Laptops and Active Learning: Developing a Sustainable Curriculum for a Java Programming Course,” *International Journal of Human-Computer Studies,* submitted March 2004.

Greenberg, J. E., Smith, N. T., and Newman, J. H., “Instructional Module in Fourier Spectral Analysis, Based on Principles of How People Learn,” *Journal of Engineering Education,* 92(2):155-164, April 2003.

Breslow, L., “Strategic Assessment at the Massachusetts Institute of Technology,” *Proceedings of the e-Technologies in Engineering Education Conference*, published online at http://www.coe.gatech.edu/eTEE, 2002.

Breslow, L. “Strategic Assessment at MIT,” *The MIT Faculty Newsletter,* 14(3): 5-9, January-February 2002.

Presentations

Dori, Y. and Belcher, J. “Improving Students' Understanding of Electromagnetism through Visualizations—A Large Scale Study,” National Association for Research in Science Teaching (NARST) Annual Meeting, Vancouver, British Columbia, April 2004.

Dourmashkin, P. “Technology Enabled Active Learning at MIT,” Meeting of the American Physical Society, Denver, CO, May 2004.

Belcher, J., “Using Visualization in Teaching Introductory Electromagnetism at MIT,” Invited talk at the 2003 Gordon Research Conference on Science Education and Visualization, Queen's College, Oxford, UK, July 2003.

Dori, Y., “The Relationships between Visualizations of Scientific Phenomena and Understanding Science,” Invited talk at the 2003 Gordon Research Conference on Science Education and Visualization, Queen's College, Oxford, UK, July 2003.

Breslow, L., “Taking Stock of Technology: MIT’s Effort in EdTech,” Invited talk, Worcester Polytechnical Institute, Worcester, MA, April 2003.

Dernay Tervalon, C. and Sarathy, R., “Assessment of Exploring Black Holes, 8.224,” American Association of Physics Teachers Winter Meeting, Austin, TX, January 2003.

Breslow, L. and Dourmashkin, P., “How Faculty Developers Can Work with Departments of Physics,” American Association of Physics Teachers Winter Meeting, Austin, TX, January 2003.

Belcher, J., “The Medium Extends The Message: Teaching E&M Using Visualization,” American Association of Physics Teachers Winter Meeting, Austin, TX, January 2003.

Breslow, L., “Thinking Strategically about Assessment,” e-Technologies in Engineering Education Conference, Davos, Switzerland, August 2002, and New England Association of Schools and Colleges Annual Conference, Boston, MA, December 2002.

Dori, Y. Invited talk at the 2001 Gordon Research Conference on Science Education and Visualization, Mt. Holyoke College, South Hadley, MA, August 2001.

Belcher, J., “Using Visualization in Teaching Electromagnetism,” contributed talk at the 2001 Gordon Research Conference on Science Education and Visualization, Mt. Holyoke College, South Hadley, MA, August 2001.

Publicity about TEAL in Non-Journal Publications

“TEAL Teaching: TEAL Is Transforming Physics Education,” MIT’s *Spectrum* Magazine, Winter 2004.

Belcher, J., “Increasing Student Understanding with TEAL,” *The MIT Faculty Newsletter,* (16):2, October/November 2003.

Dori, Y., Belcher, J., Bassette, M., Danziger, M., McKinney, A., and Hult, E., “Technology for Active Learning,” *Materials Today*, December 2003, pp. 44-49.

Belcher, J., “Studio Physics at MIT,” *MIT Physics Department Newsletter,* 2001.