WRESTLING WITH PEDAGOGICAL CHANGE:

THE TEAL INITIATIVE AT MIT

By Lori Breslow

In the late 1990s, the physics department at the Massachusetts Institute of Technology had a problem. The department was responsible for teaching the two required physics courses that are part of the General Institute Requirements (GIRs), MIT's core curriculum—Physics I (mechanics, or in MIT parlance, 8.01) and Physics II (electricity and magnetism, 8.02)—and the failure rate in both was dismal. Often as many as 15 percent of the students didn't pass mechanics on their first try, and 10 percent didn't get through electricity and magnetism. The department head, Marc Kastner (now dean of the School of Science at MIT), and the associate department head for education, Thomas Greytak, were under pressure from the senior administration, as well as faculty in other departments, to fix the problem.

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At about the same time, another physics faculty member, John Belcher, who had been teaching 8.02 for some thirty years and who had won awards for that teaching, was getting frustrated by the lack of attendance in his class. It often dipped as low as 40 percent by the end of the semester, which, while not unusual for a large lecture course at MIT, troubled Belcher.

He also knew that the concepts associated with electromagnetism were particularly difficult for students to grasp: The phenomena are complex, not to mention invisible to the naked eye. In an effort to help his students, Belcher had begun to experiment with animations that would allow the students to "see" what they otherwise had to grasp either mathematically or intuitively.

While Kastner and Greytak were searching for a way to improve freshman physics and Belcher was experimenting with ways to teach electromagnetism, MIT acquired two substantial sources of funding for undergraduate education. In the fall of 1999, Alex d'Arbeloff, then chairman of the MIT Corporation, and his wife, Brit d'Arbeloff, donated $10 million to establish the d'Arbeloff Fund for Excellence in Education, which was intended to focus on the process of educational innovation. That same autumn Microsoft announced it was giving MIT $25 million to underwrite a collaboration between the Institute and Microsoft Research to develop educational technology for higher education. Belcher, with Kastner's and Greytak's backing, now had two substantial funding sources to draw from in tackling the problem of freshman physics.

The account of how TEAL was born and managed to survive demonstrates just how difficult substantial educational reform can be.

This is a story about the transformation of the two foundational physics courses at MIT from lecture/recitation to the kind of interactive teaching and learning that educational reformers hold up as a model of best practices. Named TEAL—Technology Enabled Active Learning—the format is still used in Physics I and II at MIT today.

At a time when everyone from Margaret Spellings to Derek Bok is decrying the state of teaching and learning in US colleges and universities, the account of how TEAL was born and managed to survive demonstrates just how difficult substantial educational reform can be. TEAL's story is especially important because calls for reform in STEM teaching have been particularly urgent and persistent, with long-time advocates observing that the most pressing need has been for improvement in introductory science courses, because they can make or break a student's interest in science, mathematics, or engineering.

TEAL is a textbook case for what it takes to reform such courses. The ingredients for successful pedagogical change were present (departmental and institutional support, a faculty champion, funding), as were some typical roadblocks (critical faculty, conservative students, a reformer's burnout). As is true of most stories, TEAL's has its protagonists and antagonists, its high and low points, its challenges and victories. Whether it will have a happy ending remains to be seen—in part because the very definition of what would be a happy ending depends upon whom you ask.

A New Way to Teach Introductory Physics

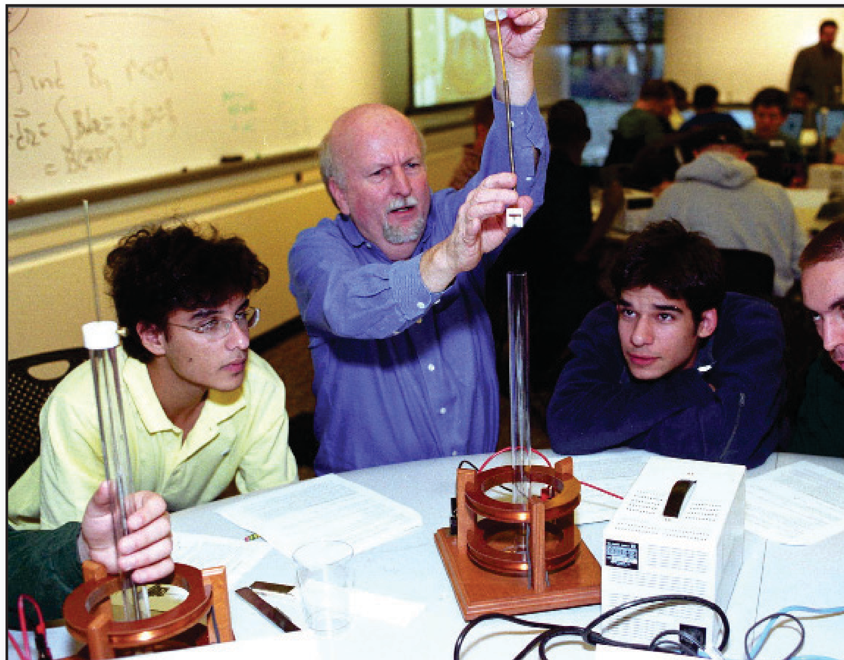
When a high percentage of students fail a class, it is often the students themselves who are blamed—they aren't prepared, they don't work hard enough, they try to get by with rote memorization. Science-education reformer Carl Wieman calls this the "students-these-days" defense.

But to its credit, the physics department did not lay the failure rate in Physics I and II at the feet of the students. Instead, Kastner and Greytak commissioned a well-respected researcher from MIT's management school to interview a sample of undergraduates to hear their views on the problem. The results were inconclusive. The most consistent comment the interviewers heard was that doing the homework was the key to receiving a passing grade, but that observation didn't give Kastner and Greytak much to go on as they sought to improve the courses.

Meanwhile, they had heard about new ideas in physics education, including the use of personal response systems (clickers), the introduction of small-group problem solving, and the inclusion of simple experiments to anchor the conceptual material. Belcher, too, had heard about the move in physics education from lectures to active learning, including the development of "studio physics."

Jack Wilson and Karen Cummings are generally credited with creating the first studio physics model at Rensselaer Polytechnic University in the mid-1990s, building upon materials developed in the Maryland University Project in Physics and Educational Technology (MUPPET); their own Comprehensive Unified Physics Learning Environment (CUPLE); cooperative learning techniques pioneered by Uri Treisman and others; and Workshop Physics, created by Priscilla Laws and her colleagues (Laws wrote about Workshop Physics in an article that appeared in *Change* in 1991). [Editor's note: the National Center for Academic Transformation (http://www.thencat.org) uses this model in its course redesign project; see the interview of Carol Twigg in the May/June 2007 issue of *Change*.] Belcher patterned TEAL after RPI's model and after SCALE-UP (Student-Centered Active Learning Environment for Undergraduate Programs), devised by Robert Beichner at North Carolina State University.

At the heart of TEAL is the merger of lectures, problem solving, and hands-on laboratory experiments. The traditional five hours of lecture/recitation per week are replaced by two two-hour sessions and a one-hour problem-solving session. During the two-hour classes, students hear one or more short presentations, often accompanied by either slides or whiteboard work; then they solve a small-group problem, answer a clicker question, or work on a desktop experiment. The specific contribution TEAL has made to studio physics is the addition of two- and three-dimensional visualizations that illustrate electromagnetic phenomena (e.g., electromagnetic field lines) to help students develop intuition about and conceptual models of physical reality (for some examples of the visualizations, go to http://web.mit.edu/8.02/www/802TEAL3D).



Working with students in the TEAL classroom.

Students are assigned to teams of three, which work collaboratively on problems and experiments. (The teams are composed of students with a range of knowledge and abilities.) Each team has a desktop computer at its disposal, with the required software already loaded. The computers are "locked" so students cannot get to the Internet or their e-mail during class. An interactive teaching model like TEAL is based on the premise that students are learning because they are doing something (solving a problem, running an experiment, analyzing data) with the concepts they are being introduced to. Therefore, students are required to come to class in order to get an A; more on this below.

With support from the d'Arbeloff Fund, MIT transformed the former physics library into a 3,000-square foot classroom for TEAL. The classroom holds thirteen round tables with nine students at each table, so that the room accommodates just over one hundred students. The instructor's "command center," from which he or she can control all the technology in the room, was purposely placed in the middle to move the faculty member from a position of authority at the front of the classroom.

Numerous whiteboards and video screens around the perimeter of the room enable the students to see PowerPoint slides, visualizations, or demonstrations, no matter where they are sitting. Whiteboards are also mounted on pillars throughout the room for small-group work. A video camera is trained on each white board; if the students are asked to present their work to the entire class, they have only to flip a switch to appear on all the screens.

The first TEAL classroom, which opened in fall 2001, cost approximately $1.5 million. A second classroom opened in fall 2004.

Belcher, along with Peter Dourmashkin, a senior lecturer in physics, and David Litster, a physics faculty member, piloted a version of Physics II: Electricity and Magnetism (8.02) in the TEAL format in fall 2001 and fall 2002, with two sections of about seventy students each. The course was "off term," which meant that most of the students were either freshmen who placed out of Physics I or upper-class students who had not passed 8.02 previously. Both times students reported that they were satisfied with the class on the course evaluations and surveys that were part of the project's assessment.

The 8.02 course went "on term" in spring 2003, with six hundred students enrolled. While Belcher and another experienced instructor taught the pilot versions, now six new instructors—some of whom had never taught a class remotely like TEAL—were thrown into this new environment.

The Pushback

MIT's spring semester usually begins in the first week of February. On Valentine's Day 2003, the student newspaper, *The Tech,* carried a story with the headline "All-TEAL 8.02 Leads to Freshman Gripes." The story began, "Despite high hopes and initial success, the mainstream Physics II (8.02), now taught in the [TEAL] format has left many students unhappy . . . and unsure of what to expect for the rest of the semester." The article went on to chronicle student complaints about the group work; the sacrifice of theory to application; and the novelty of the pedagogy, which was so different from any other course they had.

Despite a vigorous defense of TEAL by a *Tech* columnist two weeks later, there was enough rumbling that in early March, Belcher asked researchers from the Teaching and Learning Laboratory to organize focus groups to get a fuller picture of the students' concerns. While the focus groups showed there was support for some aspects of TEAL, they also surfaced a variety of complaints: The experiments were "busy work," the PowerPoint slides were overwhelming, and the group work was at best annoying and at worst counterproductive. "The other members of my group are more advanced than I am," said one student. "They do the work, and I fall further behind." Students also objected to the fact that TEAL had done away with recitations. It was in those smaller classes, they said, that they actually learned the material, not to mention how to do the homework problems.

By the third week in March, student discontent had reached a fever pitch, and 173 current and former students presented Kastner with a petition objecting to TEAL. "We, the undersigned, are unhappy and dissatisfied with 8.02 TEAL," the petition began. They went on to protest that the course "does not provide . . . the intellectual challenge and stimulation that can be expected from a course at MIT." The students accused the TEAL faculty, and, by implication, the administration that allowed TEAL to replace lectures, of compromising "the quality of our education…for the sake of 'trying something different.'"

The petition asked that the lecture version of the course be reinstated and that students be allowed to choose whether they

The first TEAL classroom.

took 8.02 in the studio physics format or in the lecture/recitation model. The students were particularly critical of the plan to transform Physics I (8.01) into a TEAL course.

Kastner and Greytak supported Belcher and TEAL. The dean for undergraduate education, Robert Redwine, met with unhappy students but maintained his support as well. (Redwine, who is also a physics professor, has since served as course co-administrator for 8.02.) MIT's then-provost, Robert Brown (now president of Boston University), backed Kastner and Greytak. Both institutional and departmental leaders were willing to ride out the student discontent while the TEAL team worked out the bugs in the course.

Belcher sent a formal response, signed by all the 8.02 instructors, to the student who had spearheaded the petition drive. "Although the intellectual level of 8.02T is appropriate and ambitious," he wrote, "moving to a class size of around 600 students is always a challenge, and the present format does need fine-tuning." He promised to use spring break to improve the course.

What caused the furor? Several things. First, if the commonly accepted wisdom that students are inherently conservative is true, then TEAL was a sure-fire way to get them angry. What was particularly goading was the grading system. As explained above, in TEAL students have to come to class in order to garner enough points to receive an A. This was not the case for any other course in the science core. At MIT, freshmen learn very quickly from upper-class students how to survive the rigors of an MIT education, including optimizing your time, which, in turn, means going to as few classes as possible.

Student resentment about the attendance requirement was compounded by the fact that in spring 2003, the MIT faculty changed the policy regarding first-year grades. Previously, students were not "on grades" for their entire freshman year; only the fact that they passed a course was recorded on their transcript. But starting in spring 2003—and the timing could not have been worse for TEAL—a grade of A, B, or C was recorded for courses taken in the spring semester. (A grade of D or F still meant the course did not appear on the transcript.) Now it mattered if you received an A, B, or C in 8.02, and you could only get an A if you came to class.

The second problem, as Belcher noted in an article he wrote for the *MIT Faculty Newsletter*, was that, as many educational innovators have discovered, the most "perilous part of any innovation is the attempt to move from small-scale innovation to large-scale implementation." "Many of [the] missteps," he wrote, "had to do with insufficient training of both students and instructional staff for teaching and learning in this new format."

He pointed out that the students needed more training in how to work in groups and that poorly functioning teams needed more support. Faculty needed help in their transition from lecturer to facilitator and in using the complicated technology in the TEAL classroom.

There was yet one more factor that contributed to the uproar. There was speculation that a physics faculty member who was well known for his success in teaching traditional introductory physics played a role in the petition drive. Whether out of genuine concern for the students' education or out of fear that lectures would become passé, this faculty member reportedly roused the students to the point that their dissatisfaction with TEAL became a public furor.

Another Bout of Criticism

One of the sororities at MIT has a tradition of dubious quality called the "Big Screw." Students nominate faculty and administrators who have "screwed them over" and then "vote" by making contributions to a charity of the nominee's choosing. The faculty or staff member who raises the most amount of money "wins" and receives a giant screw as a prize. Belcher and one of his TEAL co-instructors were nominated for the "Big Screw" in spring 2003; they did not win.

By fall 2003, however, the commotion over TEAL died down, and there were no additional articles in *The Tech*. It was not until a year later that another article appeared announcing Physics I would go "all TEAL" in fall 2005, and it only merited a place at the back of the paper. The article noted that "addressing students' complaints . . ., the general format has shifted to better accommodate student needs."

Changes had been made in TEAL as a result, in part, of the extensive assessment done by Belcher and his colleague, Yehudit Judy Dori, a professor of science education at the Technion in Israel. They were particularly interested in whether TEAL improved conceptual understanding of electromagnetism. They modified the Conceptual Survey in Electricity and Magnetism and used it in a pre-test/post-test design to compare students who took TEAL in spring 2003 with a cohort that took the course in the lecture/recitation format in spring 2002.

In each of three groups (high, intermediate, and low scorers on the pre-test), students who took electricity and magnetism in TEAL had higher scores than students who were in the lecture/recitation version of the course. Although the opponents of TEAL were quick to point out there were weaknesses in the study, the overall conclusion that interactive engagement improves learning has been borne out by other physics-education researchers, including Richard Hake, Eric Mazur, and Edward Redish. In addition, class attendance was higher in TEAL, and the failure rate dropped to a few percentage points.

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Despite favorable assessment data, in spring 2005 a report of a physics department external review committee made note of the student complaints. One member of the review committee was particularly harsh in his condemnation of TEAL. While Kastner made it clear to MIT's senior administrators that the department was committed to TEAL, that condemnation was the last straw for Belcher, who had been previously stung by the vehemence of the student criticism. He announced he would no longer be involved with TEAL, and another faculty member, Eric Hudson, assumed his role as course administrator. In this regard, TEAL did not follow the typical course of educational reform: Even though the original champion stepped down, the innovation continued.

Perhaps it was just as well that Belcher distanced himself from TEAL, because in spring 2006, seemingly out of nowhere, a critical article again appeared in *The Tech* that singled out the Belcher/Dori study. The student writer asserted, for example, that the only reason TEAL students outperformed the lecture students was that the former were required to come to class. Two more articles appeared the next week: One defended TEAL, and one balanced its advantages with a description of continuing student complaints.

Kastner and Greytak felt they needed to address those complaints. Kastner scheduled a special departmental meeting for the end of May to discuss TEAL and whether the lecture/recitation format should be re-introduced as an option. Thirty-five faculty members attended. According to one person who was present, the faculty were almost evenly divided in their support for and opposition to TEAL.

Kastner took those results to Physics Council, which is composed of the heads of the major departmental divisions and laboratories. In an e-mail that went to all faculty in the middle of June, he and Greytak announced that Physics Council had decided *not* to re-introduce the lecture/recitation option. Citing course evaluation scores that were not significantly different between TEAL and "conventional" 8.02, they explained there was concern that if a lecture/recitation model were to be offered, the majority of freshmen would choose lectures. "Offering an alternative," they concluded, "would be tantamount to abandoning TEAL even though we believe that it is the best way for most MIT freshmen to learn E&M."

In recent interviews about that decision, both Kastner and Greytak said they believed the department had made a commitment to TEAL that they felt personally responsible to honor. Physics Council mandated a review of TEAL within two years, during which time, Kastner and Greytak wrote, "We will make every effort to make TEAL appealing to more of our freshmen."

It fell to the department head who succeeded Kastner, Edmund Bertschinger, to make good on that promise. In fall

2007, Bertschinger convened what he called a "broadly composed committee," including both supporters and opponents of TEAL, and charged it with assessing the format and making recommendations about its future. "I made it clear," he said, "that the committee was to advise me, and that I was under no obligation to follow all or, for that matter, any, of the recommendations that were made."

The committee worked throughout the academic year, at times with a good deal of acrimony. Although he admitted he has an "appreciation for TEAL that not all faculty share," Bertschinger said that "if the committee had recommended termination, I would have looked for an exit strategy." In fact, the committee's final report, while reflecting the strong views of its membership, did not recommend abandoning TEAL. In the end, Bertschinger and his associate department head for education decided not to make any "dramatic changes," although Bertschinger said, "TEAL continues to be a work in progress."

At MIT, the students receive their class ring, the Brass Rat, after they have survived their freshman year. Each class decorates the shank of their ring, and the Class of 2011 chose to include a TEAL clicker on theirs. The students in one of MIT's *a cappella* groups did a "pessimistic take" on 8.02 in its annual "Bad Taste" concert in spring 2009. And a January 2009 *New York Times* article on TEAL once more caused a flurry of letters, both pro and con, in the *Tech*.

But as of this writing, Physics I and II are taught in the TEAL format. Belcher, who received a faculty chair for his work, has returned to TEAL as an 8.02 instructor. At least for now, TEAL has been absorbed into the culture of MIT.

What Can Be Learned?

As I was finishing this article, a colleague sent me an editorial about STEM teaching and learning that had just been published online in *Nature*, reporting on the results of a survey of 450 science faculty from over 30 countries. More than half of the respondents rated science education in their country as "mediocre, poor, or very poor." More to the point of this article, the respondents agreed the situation could be improved by strengthening the quality of college-level teaching in the sciences.

But here is the rub: A substantial majority of respondents said that while science education in their country was a problem, their own teaching was "highly effective." How is wide-scale reform to be achieved if those to whom we look to lead it do not see a problem with their own practice?

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TEAL prevailed because everything was in place that was needed for an initiative of its scale to succeed. First, the reform was centered in a department. The introductory physics courses, Physics I and Physics II, were "owned" by the physics department, and their problems were the department's problems. (It didn't hurt that senior administrators, as well as faculty in other departments, were pressuring physics to decrease the number of failures in those courses. As even beginning students of organizational studies know, external threats to an organization are an excellent inducement to change.)

As research by Graham Gibbs, Christopher Knapper, and Sergio Piccinin (among others) has shown, efforts to improve teaching and learning in research-intensive universities are more likely to originate within a department, and institution-wide initiatives are more likely to emerge from department-based efforts than the other way around. Elaine Seymour puts it another way. "The department," she writes, "is the rock against which teaching innovations . . . are most apt to founder" (p. 96).

More specifically, Belcher had the support of the head of the physics department, the associate head for education, the dean for undergraduate education, and the provost. At critical junctures, particularly when the students were in an uproar, they were all willing to defend TEAL. Later, Bertschinger did the same.

The second thing in TEAL's favor was that it had a faculty champion; without such a defender, reform projects stand a much higher chance of failing. Belcher's established record of research (he was one of the principal investigators on Voyager, the spacecraft that explored the outer planets) was vital for TEAL's survival. Seymour's research shows that the research credentials of the reformer are more effective in persuading other faculty about the worth of a teaching innovation than either the data that support its efficacy or videotapes that demonstrate its merits or show that students like it.

It is not surprising, though, that Belcher got burned out—both by the amount of work he had to put into TEAL and the energy it took to fight its detractors. Reforms often wither away if the innovator moves on, but TEAL continues today because other faculty members who fervently felt it was the right way to teach were willing to take over.

Finally, the fact that MIT had at its disposal $35 million for educational innovation didn't hurt TEAL's chances for success.

But if the first lesson that TEAL teaches is that a lot has to go right for educational reform to succeed, the second lesson is that a lot can go wrong. The literature confirms that all the problems TEAL experienced were to be expected, given how bold an educational innovation it was.

While TEAL had its supporters among the faculty, it also had its detractors who sought—with various degrees of effort—to undermine it. Some faculty simply believed TEAL was bad pedagogy. One well-respected faculty member who had extensive experience teaching Physics I wrote a long critique of TEAL that began, "What I don't like about the TEAL format is that it seems to be effectively based on the premise that lectures are obsolete." Lecturing, in this faculty member's view, allowed the instructor to "lay out the logic of physics —the beautiful way in which just about everything that we teach in the freshman year can be seen as the logical consequence of a few fundamentally simple ideas." Other faculty argued that TEAL was not rigorous, that it was lowering the standards to which physics at MIT should adhere, and that it was turning students off from science entirely.

The faculty censure was to be expected—those who have been successful within the status quo often feel threatened by change—but Belcher was completely surprised by the vehemence of the students' reaction. "I thought things were going smoothly," he said, looking back on the spring 2003 semester when TEAL went on term. "I had no idea of the train wreck that was coming." Yet other reformers, like Harvard physics professor Eric Mazur, to name one, have described the fervent pushback they received from students angry about fundamental changes in pedagogy.

As noted above, Belcher identified missteps in the initial implementation of TEAL, particularly the insufficient training of both students and the faculty. Students were not prepared for the new way they were expected to learn, and the faculty did not do a good job of telling them—and telling them again—the reasons for the changes and how they could benefit from them.

Some faculty intuitively knew how to make the transition from lecture to the TEAL format; others were flummoxed but learned; some never mastered the new method. With an all-but-mandatory attendance requirement, students who were unlucky enough to end up in a section taught by a weak instructor were particularly frustrated.

Finally, TEAL is a fairly complicated instructional system; as one student said, "There are so many moving parts." TEAL's complexity probably made it more difficult to get through what Mazur has called the "period of problems, adjustments, mismatch, and to some extent a period of frustration and pain" that follows the introduction of any new way of doing things.

What TEAL demonstrates is that successful educational innovation requires an enormous amount of effort and a good deal of luck. For TEAL, the stars were in alignment—the ingredients required for major pedagogical reform were there. But the question that higher education needs to ask itself is, why does this have to be so hard? C

Resources

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