Changing practices in teaching and learning at MIT

Draft white paper written for
The Task Force on the Undergraduate Educational Commons

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I. Introduction and summary of recommendations

Many aspects of MIT's teaching mission have evolved rapidly in the past few years. This document attempts to characterize what is special about the teaching environment at MIT and what has led to these features, and to summarize recommendations for its future development.

Any consideration of teaching and learning has to be based ultimately on specified overall objectives. In this we are guided by the Task Force's identification of the underlying goals of an MIT education. These goals center on encouraging students to be reflective individuals, aware of the intended outcomes of their various learning experiences, able to use them in building up their own intellectual life, and conscious of their growing potency in their chosen fields.

In recent years it has been recognized (by the Boyer Commission in their report *Reinventing undergraduate education: A blueprint for America's research universities*,[1] for example, and locally by the Task Force on Student Life and Learning) that many features of the institutional environment contribute to student learning and therefore should not be considered independently of one another when speaking of teaching and learning practices. Nevertheless, in this document we will focus on activities centered around courses and not attempt a study of other parts of the MIT learning environment.

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[1] The Boyer Commission on Educating Undergraduates in the Research University was created under the auspices of the Carnegie Foundation. In 1998 they issued their report, Reinventing Undergraduate Education: A blueprint for America's research universities, http://naples.cc.sunysb.edu/Pres/boyer.nsf/. An excellent outline summary of Boyer report recommendations can be found at www.as.wvu.edu/~lbrady/boyer-report.html.

It is also clear that the renewal of undergraduate education we are witnessing at MIT is the local manifestation of a nation-wide movement. Nevertheless we will not attempt to survey or assess activities outside of MIT except insofar as they contribute to existing MIT studies and projects, nor will we attempt to assess the global impact of innovations centered here at MIT.

Summary of recommendations

These will be spelled out in more detail in Section VI. In brief, the considerations brought together in this paper suggest that MIT:

A. Reaffirm that teaching is an integral part of the academic profession. Make educational assessment an Institute policy. Enhance the sense of community among staff of a course. Encourage departmental responsibility. Strengthen the service component of the Teaching and Learning Laboratory.

B. Capitalize on the unity of the campus and the faculty, especially in the Undergraduate Educational Commons, by improving communication among various stakeholders. Create a corps of "Virtual Students," department members (perhaps postdoctoral fellows) tasked with knowing how departmental course material is used in downstream and parallel courses, and the detail of what is taught in upstream courses, explaining it within the department and explaining what the department does to others. Develop and announce detailed learning objectives for each subject. Explain the larger meaning of a subject. Connect contents and goals of a subject with the contents and goals of other courses in the students' past, present, and future at MIT.

C. Renovate classroom space, creating a variety of educational environments.

D. Consolidate what we have learned from the opportunities of the past six years, disseminating what works and incorporating it in our teaching program as broadly as possible, and preparing for the next steps in pedagogical innovation.

The next section summarizes some of the developments which have led to the unique teaching and learning environment at MIT. Section III is a series of brief illustrations of the range of pedagogical innovations created at MIT in the past six years or so. Sections IV outlines some principles and common practices which can be gleaned from recent experiences at MIT, both in teaching and in carrying out pedagogical innovations. Section V discusses the resources for support in the task of learning to teach. Section VI describes the series of recommendations outlined above.

II. Evolution of the MIT teaching and learning environment

The pedagogical environment at MIT has many unique elements which bear on the formulation and success of proposed reforms. A central feature, which should never be forgotten, is the pool of highly talented individuals making up this community. Against that background, its special character is due to a series of developments spanning many years.

We enumerate a few of these developments.

(1) As affirmed in the Report of the Committee on Educational Survey (the "Lewis commission," 1949), "... policies at MIT have from the very outset been governed by these principles of limited objectives and unity of the faculty." [2] These "limited objectives" were spelled out by the Task force on Student Life and Learning (1998) in the following terms: "MIT is devoted to the advancement of knowledge and education of students in areas that contribute to or prosper in an environment of science and technology."[3] These dual characteristics, of a unified faculty and a restricted educational mission, give an MIT education its unique character and strength. They underlie the existence of a specified core curriculum.

(2) UROP, the Undergraduate Research Opportunities Program, was initiated in 1969 with funds from Edwin Land by Margaret MacVicar in her first year as a postdoc in the Department of Physics. Today some 80% of MIT undergraduates participate at least once. For many students, their UROP represents a major part of their educational and motivational experience at MIT.

(3) The Margaret MacVicar Faculty Fellows Program, established in 1992 to recognize "faculty who have made exemplary and sustained contributions to the teaching and education of undergraduates at MIT." This high profile honor has had the effect of highlighting dedication to teaching as an important and well recognized value at MIT. As such it joins other important awards, such as the School of Science Prize for Excellence in Undergraduate Teaching and the Ruth and Joel Spira Award for Distinguished Teaching in the School of Engineering.

(4) The MIT Teaching and Learning Laboratory, founded in 1997 as part of the Office of the Dean for Undergraduate Education. "TLL's goals are to strengthen the quality of instruction at the Institute; better understand the process of learning in science and engineering; conduct research that has immediate applications both inside and outside the classroom; serve as a clearinghouse to disseminate information on efforts in science and engineering education nationally and internationally; and aid in the creation of new and innovative educational curricula, pedagogical methods, technologies, and methods of assessment." Among teaching and learning centers at universities around the world it exhibits a special strength and expertise in assessment.

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[2] Report of the Committee on Educational Survey, MIT, 1949, page 10, http://web.mit.edu/faculty/reports.
[3] Ibid.

(5) A number of departments, led by visionary faculty and supported by the MIT administration, have radically revised some or all of their undergraduate program. Perhaps most notable is the Department of Aeronautics and Astronautics, whose CDIO (Conceive, Design, Implement, Operate) educational process offers a model of carefully articulated curriculum, creative courses, and innovative pedagogical techniques.

(6) In the six years since 1999, MIT has engaged in a spectacular series of innovations in pedagogy, stimulated by large grants supporting a wide variety of projects:

- Project iCampus, and alliance with Microsoft to "conduct research and create new technologies that will improve information technology enabled teaching models and educational tools for university education."

- The d'Arbeloff Fund for Excellence in Education. "Projects funded in the program are designed to enhance and potentially transform the academic and residential experience of MIT's undergraduate students."[4]

- The Cambridge-MIT Institute. Funded by a grant from the British Department of Trade and Industry and private British donations, "CMI's mission is to deliver education and research to enhance the competitiveness, productivity and entrepreneurship of the UK economy. It focuses on the interface between academia and industry, and is concerned with improving the effectiveness of the knowledge exchange process." In addition to funding research projects and studies in innovations in knowledge exchange, CMI funds a variety of educational programs including a student exchange.

- The Singapore-MIT Alliance "is an innovative engineering education and research collaboration among three of the top engineering research universities in the world: National University of Singapore (NUS), Nanyang Technology University (NTU) and Massachusetts Institute of Technology (MIT). Founded in 1998 to promote global engineering research, SMA has provided thousands of students with an unsurpassed education through the most technologically advanced interactive distance education facilities available."

Some specific projects will be reviewed below, but the very existence of this new, substantial, and diversified support has in itself made clear the value placed on teaching at MIT. It has involved a much larger group of faculty in teaching innovations than ever before and brought faculty from different Departments and different Schools together to promote learning at MIT. It has stimulated the growth of a culture of professionalism around the exercise of teaching. It has led to the creation of new classroom space at MIT designed to facilitate various forms of active learning.

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[4] For history see Lori Breslow, "Educational innovation moving ahead at full speed," Faculty Newsletter XIII, No. 1, September 2000. A compilation of these Teach Talk articles can be found at http://web.mit.edu/tll/library/teach_talk.htm.

The availability in recent years of these new sources of grant support does not detract from the importance of support offered by the Class Funds and by the Schools, notably by the Curriculum Innovation Grant program funded by the Dean of the School of Engineering.[5] There are also Departmental teaching awards, such as the Bisplinghoff Faculty Fellowships in the Department of Aeronautics and Astronautics.

(7) OpenCourseWare, initiated by recommendation of the faculty in 1999 and funded by the William and Flora Hewett Foundation, the Andrew W. Mellon Foundation, and MIT, represents MIT's entry into web based dissemination of course material. It is distinguished from analogous initiatives elsewhere by the fact that it is entirely free to users. Translations and mirror sites are encouraged. As of June 1, 2005, it had published extensive material for some 1100 courses. As it has grown, it has become clear that OCW represents a powerful addition to the pedagogical armamentarium at MIT itself.

MIT has played a leading role in a variety of other collaborations designed to enhance the Information Technology infrastructure of university education. Among them are Stellar, a flexible course management system, and O.K.I., Open Knowledge Initiative, "an open and extensible architecture that specifies how the components of an educational software environment communicate with each other and with other … systems."

(8) A cycle of high-level committees has focused much faculty attention to reassessment of the undergraduate program at MIT:

- The Task Force on Student Life and Learning (1996--1998). The central contention of this task force was that "An MIT education should prepare students for life through an educational triad composed of academics, research, and community. Academics establish a place for rigorous study of the fundamentals of science, engineering, social science, and the humanities, as well as a format for developing problem-solving skills, familiarity with quantitative and qualitative analysis, historical and literary insight, and an understanding of the scientific method. Participation in research develops both the foundation for professional competence and the opportunity for learning-by-doing. Through interaction with faculty and students within the community, students become familiar with the responsibilities of citizenship, hone communication and leadership skills, and gain self-mastery. Although each component of the triad is a distinct area of a student's education, the contribution of each reinforces and adds to that of the others. To provide a uniquely excellent education, MIT must bring students and faculty together to learn from one another through academics, research, and community." [6]

This task force also found that "... information about educational experiments and teaching innovation is not adequately disseminated Institute-wide. In our discussions about educational innovation with faculty throughout the Institute, we found that many exciting experiments were taking place, ... However, very few of these are being assessed, recorded, and communicated to other faculty. There is a need to create and

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[5] Additional information about recent educational initiatives at MIT can be found for example in op. cit.

[6] This is the first Task Force principle, enunciated in Section 1.8 of the Final Report of the Task Force on Student Life and Learning, 1998, http://web.mit.edu/faculty/reports/.

support an environment of sharing and analysis of educational innovation." [7] The leadership of the Teaching and Learning Laboratory in the intervening years has improved the assessment of MIT educational experiments. We still face serious challenges in dissemination of proven good practice.

- The Educational Design Project (1998--1999). This subcommittee of the Committee on the Undergraduate Program focused on the first year undergraduate program. Its recommendations helped define the charge of the Task Force on the Undergraduate Educational Commons. It proposed to sanction a several experiments in freshman education, including what became 12.000. It envisioned a more dynamic freshman curriculum. And it declared that MIT should "make educational assessment an Institute policy."[8]

- The Task Force on the Undergraduate Educational Commons (2003--2006).

III. Pedagogical principles and practices

The variety of educational practice at MIT has been enhanced by the multitude of stimuli described in Section I. It provides an extensive body of useful experience in designing new curricula and in redesigning old ones. But this promise will only be fulfilled if the lessons are disseminated widely and deeply. This is a major task, which this report can only identify as a task. Nevertheless, it seems appropriate here to point out a handful of recent innovations and call attention to some of the lessons one can learn from them.

These lessons pertain to (A) the MIT implementation of various pedagogical principles, and (B) how to maximize the efficiency and effectiveness of educational innovation. [9]

A. Pedagogies that work

(1) Teach the student, not the material. This old chestnut is as true today as ever. A beautifully constructed account of some area of knowledge is useless if the students aren't thinking along with the instructor. It is worse than useless, because one of the few chances these students will have to start to understand this material will have been wasted. Teaching is about stimulating change in students, not about creating an edifice.

Teaching and learning constitute a form of interaction. The teacher must learn what his or her students know and enough about their interests to find ways to motivate them to integrate the subject at hand into their skill and knowledge base. "The most important single factor influencing learning is what the learner already knows. Ascertain this and

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[7] Ibid., Section 3.3, Finding 6.

[8] This is Recommendation 7 in the Preliminary Findings and Recommendations of the Educational Design Project, http://web.mit.edu/faculty/reports/.

[9] This section owes much to "Lessons Learned: Findings from ten formative assessments of educational initiatives at MIT (2000-2003)" by Lori Breslow and the staff of the Teaching and Learning Laboratory, April 1, 2004. http://web.mit.edu/tll/edresearch/reports/lessons.pdf.

teach him accordingly."[10] In addition to the students themselves, colleagues who have taught a course often have valuable insights into students in that course.

A lecture in an undergraduate course is different from a professional lecture, and some devices which are acceptable or even work well in the latter do not work well in the former. Skipping steps in a chain of reasoning or failing to think out usage of the blackboard provide some examples, but there are structural differences as well. These are illustrated by a study done by one MIT department comparing the structures of the lectures of a very highly regarded teacher with a faculty member whose student ratings were substantially lower. They found that the first professor broke the lecture up into three or four distinct pieces. The breaks between them were like station stops, allowing students who had for one reason or another fallen off the train to get back on. The other teacher gave carefully constructed lectures, with subtle trends brought out in the course of the 50 minutes and tied up neatly at the end. This technique works beautifully in a disciplinary lecture but it tends not to be appreciated by undergraduates.

They also studied how the various topics were treated: purely theoretically (letters only), completely specific special case (numbers only), or somewhere in between. The more successful teacher mixed the three approaches in such a way that it was clear what the special cases were exemplifying and what the theory was abstracting. The less successful teacher used the theoretical style most of the time, occasionally the intermediate mode, and almost never used completely specific examples. This does not reflect a good understanding of how human beings learn.

(2) Learning is active. There is much in common between William Barton Rogers's notion of "learning by doing," defined by the Lewis Commission as "education through first hand experience, with real situations," and the contemporary conception of active learning. A significant body of research supports the observation that learning is improved by integrating some form of response by the student (besides writing notes) into the classroom experience.[11] Active learning methods are "designed in part to promote conceptual understanding through interactive engagement of students in heads-on (always) and hands-on (usually) activities which yield immediate feedback through discussion with peers and/or instructors." [12] We will mention several specific active learning methods which have been widely used at MIT.[13]

(a) A mode of active learning which is relatively easy to implement in standard classroom space and which is widely used at MIT is the "Concept Quiz," brought to prominence by Harvard Physics Professor Eric Mazur.[14] Students are given numbered

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[10] David Ausubel, Educational psychology: A Cognitive Approach, Holt, Rinehart and Winston, Inc., 1968.

[11] These studies are reviewed briefly in Lori Breslow, "New research points to the importance of using active learning in the classroom," MIT Faculty Newsletter XII, No. 1, September/October 1999.

[12] Richard Hake, quoted in op. cit.

[13] For more, see Lori Breslow, "Active learning, Part II: Suggestions for using active learning techniques in the classroom," Faculty Newsletter XII, January/February 2000.

[14] Eric Mazur, Peer Instruction: A User’s Manual, Prentice Hall, 1997.

cards (perhaps eight, called "flashcards") or provided with a device resembling a very simple television remote control device (a Personal Response System, PRS). (At the moment the PRS technology is limited to classrooms of around 100 or fewer students.) Several times during the class, the lecturer stops and poses a question which challenges the students to bring together the material the lecturer has just spoken about. Up to eight answers are offered (ideally including "I don't know"), but if desired the drawbacks of a multiple choice question can be lessened by hiding the choices till the answer is asked for. The lecturer talks through the question and gives the students a moment to think about it. At a signal the students offer their answers. In case a PRS is used, a histogram of responses is made visible to the lecturer. In case flashcards are used, privacy is still largely preserved because the lecturer is the only one who can see all the cards. If the responses are for the most part correct, the lecturer has learned that the students are on top of the subject at hand and that it is safe to go on after a brief wrap up, which should include some comment about why chosen wrong answers are wrong. If there is scatter in the answers, the lecturer can invite the students to convince their neighbors of their answer. Discussion bursts forth and after perhaps 40 seconds it subsides and another poll is taken. The learning is visible and efficient.

Good concept quizzes are difficult to generate. Ideally, they: "Focus on a single concept; Are not solvable (in given time) relying solely on equations; Reveal common difficulties with the concepts; [and] Have more than one plausible answer based on typical misunderstandings."[15]

We learn from education research and from experience that scientific misconceptions can be deeply held, heavily protected, and very hard to alter. A central goal of a concept quiz is to bring misconceptions to the surface, where they can be seen and perhaps altered by the student.

This method is used systematically in the Aero-Astro Department and is widely used elsewhere in various forms at MIT. There are variations. For example, students can be instructed to pair up and synthesize their thoughts; either partner may then be asked to explain their solution to the class.

(b) Peer interaction offers an excellent form of active learning. MIT has a long history of use of small group or team work in classes, stimulated in part by the ubiquity of teams in engineering practice. Teams, by definition, are groups (of students, in this case) which collaborate for a significant length of time (a term, for example) on a single large project.[16] Small groups can have variable composition, a short lifetime, and can work on a variety of unrelated tasks in the lecture room, the recitation room, or outside of class.

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[15] David L. Darmofal, "Course development: An example from Aerodynamics," http://raphael.mit.edu/EngineeringEducation.html.

[16] For a review of team based courses at MIT, and the efforts made in them to create and maintain healthy and reflective teams see Lori Breslow, "Teaching teamwork skills," Faculty Newsletter X, Nos. 4 and 5, 1998.

(c) The teacher must also continually assess how successful his or her attempts to stimulate learning are. All too often we discover that some key idea has gone clean over the students' heads only when many of them blow a question on an exam, perhaps the final exam. Wouldn't it be better to discover this earlier, when it can be corrected in a timely way?

Concept quizzes are an excellent tool here. Another widely used technique is the end-of-the-hour "Muddy Card." Each student is given an index card or half sheet of paper. A few minutes before the end of the class, the lecturer instructs the students to write down what they found to be the muddiest point in the lecture. There are alternatives, such as "What was the most important point in the lecture?" or "What would you like to hear more about?" Promoted by Professor Frederick Mosteller[17] of Harvard University, this method is used systematically in the Aero-Astro Department and elsewhere at MIT.[18]

(d) A teacher can use the students to help improve teaching skills, but only if the teacher asks the students for their opinions. The MIT Office of Academic Services administers the term end Student Subject Evaluations "To increase student feedback to the faculty and departments and to provide an objective information source for both faculty and students. Greater awareness of student opinion can enhance the teaching and learning environment at MIT." Lecturers are asked to distribute these in class towards the end of term. For a more formative assessment, the TLL can help construct early or mid term questionnaires as well.

(3) Announce, teach, assess. Syllibi are best constructed around specified and testable learning objectives. Learning objectives are best thought of as verbs, not nouns. A carefully constituted learning objective specifies not only the content but also the depth of understanding expected.[19] Specified learning outcomes are prerequisites for a fair and objective assessment of student performance and of syllabus efficacy.

(4) Variety is spicy. Students appreciate variety, both within a lecture and from lecture to lecture. Teachers should seek variety, because different teaching challenges are optimally addressed by different pedagogical approaches. Variation of approach helps

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[17] Frederick Mosteller, "The "muddiest point in a lecture" as a feedback device," On Teaching and Learning, Vol. 3, 1989, http://bokcenter.harvard.edu/docs/mosteller.html.

[18] Many more feedback mechanisms are described in T. A. Angelo and K. P. Cross, Classroom Assessment Techniques: A handbook for college teachers, 1993, Jossey-Bass. This book led to the NSF supported website http://www.wcer.wisc.edu/archive/cl1/flag/ hosting FLAG, the Field-tested Learning Assessment Guide, which provides a convenient source for ideas of active learning techniques. Another resource is Barbara Gross Davis, Tools for Teaching, Jossey-Bass. Much of this book is available on the web at http://teaching.berkeley.edu/bgd/teaching.html. See also Lori Breslow, "Active learning, Part II," Faculty Newsletter XII, No 3, January/February 2000.

[19] Two standard taxonomies of conceptual depth which have been used to organize learning objectives are the Bloom taxonomy described in B. S. Bloom, M. D Englehatt, M. D. Furst, E. J. Hill, and D. R. Krathwohl, Taxonomy of educational objectives: Handbook I – Cognitive domain, McKay, 1956, and the SOLO (Structure of Observed Learning Outcomes) taxonomy due to J. B. Biggs and K. F. Collins, Evaluating the Quality of Learning – the SOLO Taxonomy, Academic Press, 1982.

reach students with varying learning styles. Due consideration to this variation must be given in the design of courses.

(5) Technology can enhance. The promise of computers as an educational tool has been trumpeted ever the earliest days of the computer revolution. "Some scholars assert that simulations and computer-based models are the most powerful resources for the advancement and application of mathematics and science since the origins of mathematical modeling during the Renaissance. The move from a static model in an inert medium, like a drawing, to dynamic models in interactive media that provide visualization and analytic tools is profoundly changing the nature of inquiry in mathematics and science."[20] The rapid increase in power, flexibility, and ubiquity of computers has increased this potential. Just as important is the insight we have gained into the limitations and optimal use of technology.

(a) Technology is most effective when it meets a need and fits naturally into the overall educational context. Absent these conditions it can be a distraction.

(b) Use of technology involves a change in what is taught, not just in how it is taught. For example, it is often possible to stress conceptual points more if direct graphical representations are easily available. Computational power brings a range of otherwise inaccessible examples into play.

(c) There is a high startup cost. Programming is expensive. As a result, the cost of altering functioning technological components can exert a conservative force on curricular development. There is also a price paid by the student, in learning to use the specific conventions attached to the technology. This has been a problem in integrating computational languages such as Matlab into basic courses.

(d) Aesthetics matter. Students use a device more willingly if it is attractive, simple, intuitive, and convenient.

(e) Technology is more than just computers. In many cases there is no substitute for hands on interaction with real artifacts, but these artifacts can be carefully designed to maximize their educational potential within a curricular framework.

(f) Information technology offers new avenues for enhancing communication. Email and websites have become ubiquitous. Online tutors are increasingly sophisticated at providing instantaneous feedback to students. Much can be learned about student understanding from logging various responses (via PRS to concept quizzes, for example).

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[20] John D. Bransford, Ann L. Brown, and Rodney R. Cocking, How People Learn: Brain, Mind, Experience, and School, National Academy, 2000, p. 215.

B. Design and implementation of teaching innovations

A few general lessons can be drawn from the educational experimentation at MIT over the past few years about how to carry out educational renovation.

(1) Specify desired learning outcomes and build the curriculum around these goals.

(2) Survey existing work. A first step in planning an educational initiative is to study the literature, and learn from similar initiatives at MIT and elsewhere. In the case of substantial innovations, this exploration may involve site visits and developing a relationship with teachers elsewhere.

(3) Build a design cycle into the introduction of the innovation. It is an iterative process and it takes time and feedback to get it right.

(4) Optimize classroom configurations. Modification of traditional classroom space may be called for.

(5) Build assessment into the process. It is possible to measure outcomes of pedagogical changes, but don't expect clean results and accept the use of qualitative measures. Learning goals specify what is to be assessed.

(6) Prepare the students and the teaching staff. The rationale for unfamiliar practices must be clearly and repeatedly explained to the students. Many new pedagogies require specialized training of the teachers, and the political and financial costs of this component must be considered.

IV. Recent examples at MIT

Here now are very brief accounts of a dozen educational innovations of various types carried out over the past six years at MIT. This is, needless to say, a very partial list, no more than a series of vignettes, chosen to exemplify the diversity of these innovations.

(1) TEAL (Technology Enabled Active Learning). This project[21], led by Professor John Belcher and funded principally by the d'Arbeloff Fund for Excellence, iCampus, and the NSF, has yielded radically revised versions of core physics courses (8.02, Electricity and Magnetism, and 8.01, Mechanics). This method demanded the construction of an entirely new type of classroom, in which students are assigned to groups of three, each one of which shares a laptop computer at large round tables accommodating three groups. The lecturer stands at a podium at the center of the room and directs events. Students spend much of the time working with extensive specially created computer simulations and often with an instrumented experimental apparatus at the center of their table. Course assistants patrol the room. The method replaces the lecture/recitation pattern with five

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[21] John W. Belcher, "The TEAL Project," http://web.mit.edu/jbelcher/TEALref/TEAL.pdf.

hours per week in this setting. PRS responses poll class comprehension and allow penalization of absences.

The development of this course illustrates many of the principles of pedagogical renewal described in III (B). The design was heavily influenced by experiments elsewhere (RPI and North Carolina State University). Careful assessments were part of the plan from the start, and they show increased learning gains by all sectors of the class. Rough edges were worked out over several iterations.

(2) Interactive web-based lectures in EECS. An iCampus funded project led by Professors Eric Grimson and Tomas Lozano-Perez replaced live lectures with web delivered narrated power point animations in 6.001 (Structure and Interpretation of Computer Languages) and two other EECS courses. These presentations are punctuated by required responses in which the student must supply a line or two of code which is instantaneously checked. Students may ask for hints of increasing breadth but they must have their work accepted in order to go on. Here too not all students were happy with the change, but carefully benchmarked evaluations show fairly dramatic improvement in learning gains.

(3) ""Colossal Failures in Engineering, a case study course in engineering challenges," a revised version [of which will be] taught in Spring 2006, will use a mix of lecture and group case study to assist students in understanding and analyzing complex socio-technical systems, as well as in grasping some of the engineering concepts underlying each system. The case studies will also illustrate the interdisciplinary nature of engineering with science, social science, economics, and politics. Embedding in these issues within popular case studies for discussion and analysis of major engineering failures will greatly enliven this material. To reinforce learning, discussions will be followed by student team completion of written analyses of several of the engineering case studies."[22] This project was supported by a Curriculum Innovation Grant from the School of Engineering.

(4) The d'Arbeloff Interactive Mathematics Project. Under this grant from the d'Arbeloff Fund for Excellence, a suite of student-controlled Java simulations ("Manipulatives" or "Mathlets") was created for use in 18.03, Ordinary Differential Equations. The goal is to provide a visual and kinesthetic handle for concepts usually approached purely formulaically. Each tool has a variety of settings and menu choices. Using them the student can for example vary the system parameters and observe the change in the shape of the solution. A uniform system of coordinate readouts, color coding, and mousekey functionality makes these applets very easy to use after the first encounter. These programs are used as classroom demonstrations and as the basis for homework, in which the student typically takes a measurement from the screen and then accounts for this empirical observation using the theory. The programs were developed through a detailed process of formative assessment.

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[22] Barbara Masi, MIT School of Engineering Teaching and Learning Trends: 2000-2005.

(5) 12.000, Solving Complex Problems, is a Freshman course also known as MissionX (where X is the year of graduation of the class) developed by Professor Kip Hodges with support from the d'Arbeloff Fund for Excellence in which student teams research aspects of a complex interdisciplinary problem and construct websites disseminating their findings. In Mission2009, for example, students study the origin and impact of the 2004 Indian Ocean tsunami and develop tsunami preparedness plans for specific developing countries. This course integrates its alumni still at MIT as well as MIT alumni in a large support community. In 2002 a learning community, Terrascope, was formed around the nucleus of 12.000 to support students wishing to continue the research and take a field trip over the Spring Break.

(6) 16.00, An Introduction to Aerospace Engineering and Design, offers freshmen a chance to work in a team to build a remote controlled lighter than air vehicle. These compete at the end of the term in a race. Developed by Professor Dava Newman, this course provides Freshmen with an experience of the CDIO cycle in miniature, and stimulates their excitement about engineering.

(7) 18.821, Mathematics Project Laboratory, is a new course developed by Professors Mike Artin and Haynes Miller using resources from a grant from CMI. Students form groups of three and work on a sequence of three projects chosen from a list of two dozen. Each project demands the collection of data, usually using a computer; detection of regularities in the data; and an attempt to account for these regularities by mathematical analysis. The groups meet regularly with a course assistant. The work is described in a briefing and written up in a report. At the end of the course each group delivers a paper in a class conference. The controlled research setting provides students with an experience of mathematical research.

(8) 16.100, Aerodynamics, is an upper level course in the Aero-Astro Department with around 40 students. A sequence of innovations over a five year span, led by Professor David Darmofal, resulted in a course featuring "Concept questions and mini-lectures in most class periods; Pre-class (graded) homework assignments; All exams are oral (a mid-term and a final); [and a] Semester-long, team-based design project."[23] These innovations were evaluated by giving very similar final exams three years apart. The gains were dramatic.

(9) 2.001, Mechanics and Materials I, was transformed into a technologically enriched active learning class thanks to an iCampus grant directed by Professors Mary Boyce and Sanjay Sarma. Desktop experiments are combined with computer tools and simulations, in a specially designed classroom. A web-based multimedia textbook was created. This project has affected the other Course 2 header subjects as well.

(10) Associate Professor Karen Willcox of the Aero-Astro Department led a project to investigate in detail the treatment of mathematical skills in undergraduate courses in her department. She asked: "What are the mathematical knowledge and skills we expect of

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[23] David L. Darmofal, op. cit.

our undergraduate students? How do we expect them to apply these skills (in the context of core undergraduate engineering subjects)? Where are they learning these skills? How are they learning these skills (language, examples, context)?"[24] She collected very specific data on this through interviews with Aero-Astro and Mathematics faculty and a study of class material. Analysis at this level of detail makes it possible to adjust curriculum to ease the students' difficulties in transferring concepts from one course to another, both within the major and from prerequisite courses taught by other departments into courses in the major. This data is now being incorporated into the OCW image of her course, as links to specific parts of Mathematics OCW courses. Conversely, Mathematics OCW courses will refer to OCW sites of user courses for examples of the mathematics in use.

(11) D-Lab, SP.721/11.190: Development, Dialogue and Delivery, is a series of courses and field trips in which students study and create technology appropriate for use in developing countries. It has been developed under the leadership of Amy Smith as part of the MIT International Development Initiative, and is co-sponsored by the Edgerton Center and the Public Service Center with support from the Lemelson-MIT Foundation and Modec International.

(12) The Meta-Media Project and the Cross-Media Annotation System. The Meta-Media software, created under a d'Arbeloff grant under the leadership of Professor Peter Donaldson, gives students quick access to a deep selection of material in a variety of media connected with a narrowly focused topic. It is designed to encourage an "iterated and intense pondering of some body of work." Its intent is pedagogical rather than archival. Students can annotate and build up a narrative within the program. It has been deployed in a variety of contexts, notably Shakespeare's plays. XMAS, the Cross-Media Annotation System, allows students to build multimedia essays with embedded links to media such as video. The impact of these technological innovations on student engagement and learning has been documented.

V. Learning to teach

Teaching is a skill. It is not innate (though it comes more easily to some than to others). Intimate knowledge of the content is a necessary condition to be successful at teaching it, but by no means sufficient. One learns to teach as one learns other skills. One needs

- guidance,
- a chance to observe good examples,
- opportunity to practice in a safe environment, and
- recognition of success.

[24] Karen Willcox and Gergana Bounova, AA Faculty Lunch talk, March 3, 2004. See also their "Mathematics in engineering: identifying, enhancing and Linking the implicit mathematics curriculum," http://raphael.mit.edu/willcox.html.

Local conditions at MIT lead to specific common shortcomings in teaching, identified in a presentation "What we know about teaching and learning" for the Task Force on the Undergraduate Educational Commons by Lori Breslow:

- speaking at a level above the heads of the students
- not connecting the physical phenomenon to its mathematical representation
- bowing to the "tyranny of the content," and
- not explicitly modeling problem-solving method.

At MIT the main source of support in the endeavor to learn to teach comes from the Teaching and Learning Laboratory (TLL). Founded in 1997, TLL offers a range of services: consultation, class videotaping and consulting, department-based workshops, microteaching workshops, classes for graduate students, and an orientation workshop for graduate teaching staff. In addition to providing these resources directly aimed at helping people improve their teaching, TLL also provides a range of assessment and evaluation services and a serves as a center for collaborative educational research at MIT. Overall it is distinguished among centers for teaching and learning at peer institutions by its focus on assessment and research, an orientation represented by its denomination as a laboratory.

There is a continuing need for improvement of Teaching Assistant training.[25] Pursuant to a Dean for Undergraduate Education Visiting Committee recommendation that TA training be strengthened, TLL carried out an investigation into what training is done and what could be done and issued a report in September, 2003.[26] This research uncovered striking failures to take advantage of the desire of TAs to be part of the course process. It was found that as a group they see their work as recitation leader as part of their professional experience, and flourish when they are treated as colleagues. On the other hand, "Between 60% and 80% of the TAs who responded to the survey did not get such basic information as a syllabus overview or instructions for grading from the faculty for whom they work,"[27] and "Approximately 85% of those surveyed reported that either they did not have the opportunity to meet with other TAs in their department, or they did not know if such opportunities existed."[28]

Roughly 70% of research institutions have mandatory TA training, usually organized by a centralized agency. The TLL report concluded however that "MIT departments have very distinct cultures and teaching priorities. Trying to centralize TA activities will be difficult given the autonomy of departments."[29] In view of this, the report recommended that human resources be developed within individual departments to foster better communication between faculty and TA and to support training individually suited to the

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[25] See for example Lori Breslow, "Working with TAs: Supervising TAs calls for faculty to be managers, team leaders, role models, and mentors," Faculty Newsletter XI, No. 2, Nov/Dec 1998.

[26] Report on TA training and development at MIT, Cindy Tervalon and Lori Breslow, TLL, 10 Sept 2003, http://web.mit.edu/tll/edresearch/reports/ta_survey.pdf.

[27] Ibid., p. 4.

[28] Ibid., p. 5. See also Lori Breslow and Cindy Tervalon, Strengthening TA training, Faculty Newsletter XVII, No. 5, May/June 2005.

[29] Tervalon and Breslow, op. cit., p. 5.

needs of the department. Another recommendation was that a web based TA resource be created, offering a variety of forms of guidance on a variety of challenges faced by TAs.

There are some fairly well established resources available to help learn the art of leading a recitation. One is Arthur Mattuck's classic "The Torch or the Firehose," a witty and insightful guide to the standard interactive lecture recitation teaching method. Another Institute wide resource is the annual MIT Orientation Workshop for Graduate Teaching Staff, sponsored by the Graduate Student Office and TLL. Many departments suggest or require their new TAs to attend this daylong event.

There are also some excellent departmental programs. The Department of Chemistry runs an intensive two day program "designed to introduce new teaching staff to the department's teaching philosophy, to build unity among the teaching teams, and to help the individual TA begin to create an effective, personal teaching style" which is required of all new TAs. The Department of Mathematics[30] runs a three part program for its new TAs: during the term before the graduate student begins teaching, he or she is assigned to a Recitation Leader who serves as his or her mentor. The TA attends several recitations led by the mentor and then teaches one, and receives feedback via a questionnaire filled out by the students and from the mentor. Next, attendance in three two-hour sessions of a Micro-teaching workshop is required. In this workshop, which TLL organizes elsewhere at MIT, the novice conducts a short fragment of a recitation while a group of faculty and the other TAs in training act as a class. The performance is taped for later study, and after the performance there is constructive critical discussion. The focus is on technique. In the third stage of this process a full recitation of the TA is videotaped and the tape is reviewed and commented on by a senior faculty member. New postdoctoral fellows in the department are strongly urged to participate in the second and third elements of this process and the response has been very positive.

For new faculty (but not new postdoctoral fellows) there is a general one-day orientation program, run by the office of the Provost. This represents an excellent opportunity to engage this group in the educational mission here at MIT.

The principle of active learning applies to faculty as well as to students. An excellent way to capture the lessons learned from the experience of teaching a subject is to write a term end reflective memo. Since others will most likely teach the course next, it is sensible to share this memo with colleagues. If it were a required part of an annual portfolio this sharing would happen more systematically. Making it a requirement would also overcome the natural term end inertia. The Aero-Astro Department currently does this.

All research universities face a dilemma in deciding how to weight teaching qualifications in salary determination and in promotion and tenure decisions. An expectation of an honest and organized presentation of teaching effort and effectiveness is a first step. For example, a statement of contribution to teaching research is part of the

[30] Lori Breslow, "Efforts to improve teaching gain momentum: Math's three-part program provides a coordinated effort," Faculty Newsletter X, No.1, Sept 1997.

annual review of faculty in the Aero-Astro Department. At MIT, School Councils are requiring increasingly precise and uniform information about teaching qualifications in support of promotion and tenure cases.

VI. Recommendations

It is recommended that the Faculty of MIT:

A. Reaffirm that teaching is an integral part of the academic profession. A faculty member is both a researcher and a teacher, and has a responsibility to strive for professionalism in both areas of academic life. There is much to learn about teaching, and the MIT faculty must embrace this challenge. To put this proposal into effect, it is recommended that MIT.

> **(1) "Make educational assessment an Institute policy."** This was a recommendation of the Educational Design Project and it deserves to be repeated. This recommendation has several aspects.
>
> > **(a)** Improve the breadth of coverage and the usefulness of the end of term class evaluations. One model, used successfully at Yale University, is to make course grades available online early in return for completing a web survey on the course. This has a number of advantages over the present system: all students are polled, not just those who happen to be in class when the survey is distributed; such a survey is easier to tailor to a given course; and comments are more easily accessible to faculty.
> >
> > **(b)** Encourage a cycle of feedback between student and faculty throughout the term. Make a midterm assessment an Institute policy.
> >
> > **(c)** Assess curriculum as well as teaching. Evaluating effectiveness of a given lecturer is important, but if we are to understand the effectiveness of the underlying curriculum we must assess it as well. An example of such a tool is SALG, "Student Assessment of Learning Gains."[31]
> >
> > **(d)** Endorse a systematic use of end of term reflective essays by faculty, identifying successful and less than successful aspects of each just completed course.
>
> **(2) Enhance community spirit within courses.** Define more clearly the educational responsibilities of the diverse groups contributing to the delivery of education in a class at MIT: lead professors, course administrators, recitation leaders, graders, students. These definitions will vary from department to

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[31] Elaine Seymour, Douglas J. Wiese, Anne-Barrie Hunter, and Susan M. Daffinrud, in "Creating a better mousetrap: On-line student assessment of their learning gains," http://www.wcer.wisc.edu/salgains/instructor/default.asp.

department and from subject to subject. Increase the team spirit binding these groups together in a common mission.

(3) Encourage departmental responsibility. Increase the responsiveness of each department to the teaching qualities of its members. Portfolios representing educational contributions should be part of the material supporting annual personnel reviews and in promotion and tenure cases. It is important that this material be presented in a uniform and unbiased manner. The Administration should encourage departmental activism by providing assistance to departments seeking to offer support to improve teaching.

(4) To tie all this together, **MIT should strengthen the service component of the Teaching and Learning Laboratory** to provide more systematic support for departmental efforts to help their teaching assistants and faculty reach their potential as teachers. Additional services should include support of development of resources within individual departments designed to encourage all faculty to continually reexamine their assumptions about teaching and to help graduate students maximize their potential as teachers. Create a layered web resource to help TAs progress as teachers, offering a variety of forms of guidance on a variety of challenges faced by TAs. More modest goals could include: provision of sample grading rubrics, model first day checksheets and midterm questionnaires, model contracts between the various estates represented in a course (Faculty, TA, Student).[32]

B. Capitalize on the unity of the campus and the faculty, especially in the Undergraduate Educational Commons, by improving communication among various stakeholders. This recommendation has various aspects.

(1) Create a corps of "Virtual Students" within departments or small groups of departments. A virtual physics student, for example, will be a member of the Physics Department, perhaps a postdoc, tasked with knowing how the physics which is taught in basic physics courses appears and is used in other corequisite and downstream courses across the Institute, at the level of language, notation, and examples. He or she will be responsible for conveying this information to teaching faculty in the Physics Department and also for conveying practice in the Physics Department to his or her peer virtual students in other departments. This knowledge will lead to better choice of examples, notation, and, in the long run, choice of subject matter better attuned to the needs of the students. Analogously, a Virtual Student in Mechanical Engineering will be an ME department member tasked with knowing in detail the syllabi, language, and exam content of prerequisite and corequisite courses from other departments (especially in Mathematics and Physics). Thus informed, lecturers in Mechanical Engineering will be better able to help students connect with their earlier (and

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[32] See for example Kenneth Miller, "Working with undergraduate and graduate TAs," a Harriet W. Sheridan Center for Teaching and Learning Teaching Tip, http://www.brown.edu/Administration/Sheridan_Center/teachtips/.

contemporaneous) learning. This group should meet regularly both privately and as a group. The Teaching and Learning Laboratory should coordinate this program.

(2) State each subject's learning objectives. This statement should be layered, providing several different levels of resolution. At the most detailed, very specific and directly testable objectives should be stated. Avoid a hidden curriculum (as described by Benson Snyder, who wrote *The Hidden Curriculum* while he was Dean for Institute Relations at MIT) determined by tested goals which differ from stated goals.

(3) Explain the larger meaning of a subject. How does the subject bear on questions and challenges students face in their lives and their careers? This is especially important in GIR subjects, which may have a more distant relationship to what interests the student than subjects in his or her major.

(4) Connect the content and goals of a subject with the content and goals of other courses in the students' past, present, and future at MIT. Students are often aware of conceptual communalities among courses and are puzzled when their professors ignore them. We fail to capitalize on the unity of the faculty and the campus.[33] OCW can play a significant role in allowing detailed reference to other MIT courses, and current efforts to incorporate those links within OCW itself should be encouraged.

C. Renovate classroom space, creating a variety of educational environments. Novel teaching methods will continue to result in calls for novel teaching spaces. At the same time, large lectures will continue to play a role in the MIT teaching mix, as will recitations. Neither of these forms is static, however, and renovation of all classroom space should take account of current practices in active teaching and use of technology. Involvement of faculty in all classroom design decisions is critical.

D. Consolidate what we have learned from the opportunities of the past six years, advertising what works and incorporating it into our teaching program as broadly as possible, and preparing for the next steps in pedagogical innovation. Capture the evaluations, publications and presentations reporting on this work, make it easily available through a central data base, and commission more. At the same time, we must acknowledge the importance of the very special opportunities of the recent past, and seek out the next round of stimuli.

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[33] See Lori Breslow, "What the students say," Faculty Newsletter X, No. 3, 1997, for anecdotes on this topic.

Further references

Benson Snyder, The Hidden Curriculum, Knopf, 1970.

Ken Bain, What the Best College Teachers Do, Harvard, 2004.

Richard J. Light, Making the Most out of College: Students Speak their Minds, Harvard, 2001.