10 Lessons of an MIT Education

An essay by G-C Rota

Lesson One: You can and will work at a desk for seven hours straight, routinely.

For several years, I have been teaching 18.03, differential equations, the largest mathematics course at MIT, with more than 300 students. The lectures have been good training in dealing with mass behavior. Every sentence must be perfectly enunciated, preferably twice. Examples on the board must be relevant, if not downright fascinating. Every 15 minutes or so, the lecturer is expected to come up with an interesting aside, joke, historical anecdote, or unusual application of the concept at hand. When a lecturer fails to conform to these inexorable requirements, the students will signify their displeasure by picking up their books and leaving the classroom.

Despite the lecturer's best efforts, however, it becomes more difficult to hold the attention of the students as the term wears on, and that they start falling asleep in class under those circumstances should be a source of satisfaction for a teacher, since it confirms that they have been doing their jobs. There students have been up half the night-maybe all night-finishing problem sets and preparing for their midterm exams.

Four courses in science and engineering each term is a heavy workload for anyone; very few students fail to learn, first and foremost, the discipline of intensive and constant work.

Lesson Two: You learn what you don't know you are learning.

The second lesson is demonstrated, among other places, in 18.313, a course I teach in advanced probability theory. It is a difficult course, one that compresses the material typically taught in a year into one term, and it includes weekly problem sets that are hard, even by the standards of professional mathematicians. (How hard is that? Well, every few years a student taking the course discovers a new solution to a probability problem that merits publication as a research paper in a refereed journal.)

Students join forces on the problem sets, and some students benefit more than others from these weekly collective efforts. The most brilliant students will invariably work out all the problems and let other students copy, and I pretend to be annoyed when I learn that this has happened. But I know that by making the effort to understand the solution of a truly difficult problem discovered by one of their peers, students learn more than they would by working out some less demanding exercise.

Lesson Three: By and large, "knowing how" matters more than "knowing what."

Half a century ago, the philosopher Gilbert Ryle discussed the difference between "knowing how" courses are those in mathematics, the exact sciences, engineering, playing a musical instrument, even sports. "Knowing what" courses are those in the social sciences, the creative arts, the humanities, and those aspects of a discipline that are described as having social value.

At the beginning of each term, students meet with their advisors to decide on the courses each will study, and much of the discussion is likely to resolve around whether a student should lighten a heavy load by substituting one or two "knowing what" courses in place of some stiff "knowing how" courses.

To be sure, the content of "knowing what" courses if often the most memorable. A serious study of the history of United States Constitution or *King Lear* may well leave a stronger imprint on a student's character than a course in thermodynamics. Nevertheless, at MIT, "knowing how" is held in higher esteem than "knowing what" by faculty and students alike. Why?

It is my theory that "knowing how" is revered because it can be tested. One can test whether a student can apply quantum mechanics, communicate in French, or clone a gene. It is much more difficult to asses an interpretation of a poem, the negotiation of a complex technical compromise, or grasp of the social dynamics of a small, diverse working group. Where you can test, you can set a high standard of proficiency on which everyone is agreed; where you cannot test precisely, proficiency becomes something of a judgment call.

At certain liberal arts colleges, sports appear to be more important than classroom subjects, and with good reason. A sport may be the only training in "knowing how"-in demonstrating certifiable proficiency-that a student undertakes at those colleges. At MIT, sports are a hobby (however passionately pursued) rather than a central focus because we offer a wide range of absorbing "knowing how" activities.

Lesson Four: In science and engineering, you can fool very little of the time.

Most of the sweeping generalizations one hears about MIT undergraduates are too outrageous to be taken seriously. The claim that MIT students are naive, however, has struck me as being true, at least in a statistical sense.

Last year, for example, one of our mathematics majors, who had accepted a lucrative offer of employment from a Wall Street firm, telephoned to complain that the politics in his office was "like a soap opera." More than a few MIT graduates are shocked by their first contact with the professional world after graduation. There is a wide gap between the realities of business, medicine, law, or applied engineering, for example, and the universe of scientific objectivity and theoretical constructs that is MIT.

An education in engineering and science is an education in intellectual honesty. Students cannot avoid learning to acknowledge whether or not they have really learned. Once they have taken their first quiz, all MIT undergraduates know dearly they will pay if they fool themselves into believing they know more than is the case.

On campus, they have been accustomed to people being blunt to a fault about their own limitations-or skills-and those of others. Unfortunately, this intellectual honesty is sometimes interpreted as naïveté.

Lesson Five: You don't have to be a genius to do creative work.

The idea of genius elaborated during the Romantic Age (late 18th and 19th centuries) has done harm to education. It is demoralizing to give a young person role models of Beethoven, Einstein, and Feynman, presented as saintly figures who moved from insight to insight without a misstep. Scientific biographies often fail to give a realistic description of personality, and thereby create a false idea of scientific work.

Young people will correct any fantasies they have about genius, however, after they come to MIT. As they start doing research with their professors, as many MIT undergraduates do, they learn another healthy lesson, namely, a professor may well behave like a fumbling idiot.

The drive for excellence and achievement that one finds everywhere at MIT has the democratic effect of placing teachers and students on the same level, where competence is appreciated irrespective of its provenance, Students learn that some of the best ideas arise in groups of scientists and engineers working together, and the source of these ideas can seldom be pinned on specific individuals. The MIT model of scientific work is closer to the communion of artists that was found in the large shops of the Renaissance than to the image of the lonely Romantic genius.

Lesson Six: You must measure up to a very high level of performance.

I can imagine a prospective student or parent asking, "Why should I (or my child) take calculus at MIT rather than at Oshkosh College? Isn't the material practically identical, no matter where it is taught, while the cost varies a great deal?"

One answer to this question would be following: One learns a lot more when taking calculus from someone who is doing research in mathematical analysis than from someone who has never published a word on the subject. But this is not the answer; some teachers who have never done any research are much better at conveying the ideas of calculus than the most brilliant mathematicians.

What matters most is the ambiance in which the course is taught; a gifted student will thrive in the company of other gifted students. An MIT undergraduate will be challenged by the level of proficiency that is expected of everyone at MIT, students and faculty. The expectation of high standards is unconsciously absorbed and adopted by the students, and they carry it with them for life.

Lesson seven: The world and your career are unpredictable, so you are better off learning subjects of permanent value.

Some students arrive at MIT with a career plan, many don't, but it actually doesn't matter very much either way. Some of the foremost computer scientists of our day received their doctorates in mathematical logic, a branch of mathematics that was once considered farthest removed from applications but that turned out instead to be the key to the development of present-day software. A number of the leading figures in experimental molecular biology received their doctorates in physics. Dramatic career shifts that only a few years ago were the exception are becoming common.

Our students will have a harder time finding rewarding jobs than I had when I graduated in the fifties. The skills the market demands, both in research and industry, are subject to capricious shifts. New professions will be created, and old professions will become obsolete with the span of a few years. Today's college students have good cause to be apprehensive about future.

The curriculum that most undergraduates at MIT choose to follow focuses less on current occupational skills than on those fundamental areas of science and engineering that at least likely to be affected by technological changes.

Lesson Eight: You are never going to catch up, and neither is anyone else.

MIT students often complain of being overworked, and they are right. When I look at the schedules of courses my advisees propose at the beginning of each term, I wonder how they can contemplate that much work. My workload was nothing like that when I was an undergraduate.

The platitudes about the disappearance of leisure are, unfortunately, true, and faculty members at MIT are as heavily burdened as students. There is some satisfaction, however, for a faculty member in encountering a recent graduate who marvels at the light work load they carry in medical school or law school relative to the grueling schedule they had to maintain during their four years at MIT.

Lesson Nine: The future belongs to the computer-literate-squared.

Much has been said about computer literacy, and I suspect you would prefer not to hear more on the subject. Instead, I would like to propose the concept computer-literacy-squared, in other words computer literacy to second degree.

A large fraction of MIT undergraduates major in computer science or at least acquire extensive computer skills that are applicable in other fields. In their second year, they catch on to the fact that their required courses in computer science do not provide the whole story. Not because of deficiencies in the syllabus; quite the opposite. The undergraduate curriculum in computer science at MIT is probably the most progressive and advanced such curriculum anywhere. Rather, the students learn that side by side with required courses there is another, hidden curriculum consisting of new ideas just coming into use, new techniques and that spread like wildfire, opening up unsuspected applications that will eventually be adopted into the official curriculum.

Keeping up with this hidden curriculum is what will enable a computer scientist to stay ahead in the field. Those who do not become computer scientists to the second degree risk turning into programmers who will only implement the ideas of others.

Lesson Ten: Mathematics is still the queen of the sciences.

Having tried in lessons one through nine to take an unbiased look at the big MIT picture, I'd like to conclude with a plug for my own field, mathematics.

When an undergraduate asks me whether he or she should major in mathematics rather than in another field that I will simply call X, my answer is the following: "If you major in mathematics, you can switch to X anytime you want to, but not the other way around."

Alumni who return to visit invariably complain of not having taken enough math courses while they were undergraduates. It is a fact, confirmed by the history of science since Galileo and Newton, that the more theoretical and removed from immediate applications a scientific topic appears to be, the more likely it is to eventually find the most striking practical applications. Consider number theory, which only 20 years ago was believed to be the most useless chapter of mathematics and is today the core of computer security. The efficient factorization of integers into prime numbers, a topic of seemingly breathtaking obscurity, is now cultivated with equal passion by software designers and code breakers.

I am often asked why there are so few applied mathematicians in the department at MIT. The reason is that all of MIT is one huge applied mathematics department; you can find applied mathematicians in practically every department at MIT *except* mathematics.