A Personal View of Education

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Education has been an important part of my life as a child, as a student, as a parent, and as a faculty member at MIT. For me, the experience of learning new things and of imparting knowledge to others carries with it a special sense of excitement and gratification. Although I have never had any formal training as an educator, my career seems to suggest that I have an intuitive sense for it, and certainly I have had a lot of experience at it. I have also learned a lot about education from my wife, who, besides having a career in education, has in my view excellent instincts as a teacher and a parent.

My professional life revolves around teaching and research, which at MIT are symbiotic activities. I was once asked which one I would give up if I had to choose between them. I hope never to have to make that choice because the two are complementary and each is exciting and fun. However, if forced, I think I would choose teaching over research. I particularly enjoy the thrill of a successful classroom performance and of working closely with students. I am also awed by the enormous leverage and responsibility that teaching provides in terms of propagating one's knowledge, standards, and ideals. Many of my former students are now teachers, as are many of their students. Teaching, like parenting, influences an endless succession of generations.

In this essay I would like to express some of my personal views about teaching and learning. There are, of course, many equally effective styles of teaching and

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learning, and I present my thoughts on the subject in the modest hope that they will cause others to think about what works best for them.

TYPES OF LEARNING

There are obviously many facets to learning and to our roles as educators. An important part of learning involves a straightforward absorption of basic facts and skills. In learning arithmetic, we memorize multiplication tables and practice procedures for long division. In language learning, we work on expanding vocabulary and conjugating verbs. In history, we learn dates, events, places, and their interrelationships. At another level, however, there is a need to develop the judgment, insight, and intuition to use these skills and facts appropriately and creatively.

I vividly recall my own experience when I was first learning geometry in high school. I was intrigued by the fact that one could start with a few simple axioms and definitions, use them to prove some simple theorems, then prove more complex theorems from those first simple ones, and so on. As I was learning the basic skills of geometry, I developed the impression that geometry and other branches of mathematics are carried out by simply "turning the crank," that is, by routinely applying previous theorems to generate new ones, in the way that a machine might do it. It was not until some time later that I came to realize that a major part of creativity in mathematics is in knowing what theorem to prove, in having the deep insight required to conjecture that something previously unknown is in fact true and to guess at why it is true.

How one learns or teaches creativity and insight is not at all clear to me. A prerequisite is clearly a fluency with the basic skills associated with a subject. Much of education, at least as it is done today in the United States, focuses on working problems that are well formulated and easily associated with a particular part of a textbook or lesson. In a typical arithmetic or mathe-

matics class, for example, students may be asked to prove a particular theorem, given the previous theorems in the textbook. The students know in advance that solving the problem requires only the material they have covered up to that point. In working with graduate students who are learning to do creative research, one of the teacher's most difficult challenges is to break this pattern. In research or industry, the problems to be solved are much less structured and typically do not fit into nice compartments. Structuring problems in such a way that we know which tools to use is often the hard part. As I often comment to my research students, "Once you get an issue to the point where it looks like a problem on a problem set, the hard part is done."

I would suggest that we need to start in the earlier grades, exposing students to unstructured problem solving by means of problems for which there is no clean solution available. Of course, this needs to be done in a balanced way. In the United States, the pendulum has swung in several directions over the years. In the 1960s, there was a trend toward open classrooms and what was referred to as "exploratory learning." This approach was often overdone to the exclusion of training in basic skills, and the result was often students who could not spell or compute. The pendulum then swung strongly back toward the basics. In the 1980s, there was — as there still is — considerable emphasis on trying to achieve a balance between exploratory learning and the development of the basic skills.

COMPUTERS IN EDUCATION

The distinction between basic skills and creativity brings me to the issue of the role of computers in education, particularly at the grade school and high school levels. As an analogy, I recall recently watching a tennis class. On some of the courts a student was on one side of the net with a machine on the other side. The machine shot tennis balls across the net with different speeds and directions so that the student could practice the skills required for returning a variety of shots. The machine was consistent and tireless. Other students were working closely with a coach to develop instincts, anticipation, and strategies and to get feedback on form, technique, etc. In my view, the computer is particularly effective in a role similar to that of the tennis ball machine. It is excellent for endless and often entertaining practice with drills to learn and improve basic skills. For this it is often much better than a "live" teacher, since it is infinitely patient, non-judgmental, and very forgiving. However, I believe that the individual teacher or "coach" and personal interaction are needed to guide the student in developing judgment and creativity. Put another way, the computer is an excellent tool for teaching, as are textbooks, slide projectors, chalkboards, and workbooks. But it cannot teach creativity and insight, other than that which is naturally gained through drills and experimentation. When used effectively, however, it relieves the teacher of a variety of routine tasks. In geometry, for example, it can help the student learn definitions, do practice problems at varying levels of difficulty, explore relation-

ships, and gain precision with the skills and experience with the concepts. In history, it can help in learning facts and their associations and can potentially offer elegant ways, such as hypertext, to access a large store of information.

Computers enrich the educational environment in a variety of other ways, particularly at the university level. The availability of campus-wide networking and electronic mail greatly enhances communication at all levels. The ability to simulate mathematical expressions and engineering systems offers an opportunity for "theoretical experimentation" in many courses to develop insight and to help in visualization. It can do all these things in an entertaining way that can make the experience fun and exciting for the student.

I feel strongly that having fun is very important. I am reminded of a conversation in which I asked a research colleague why he was working on a problem that to me seemed somewhat irrelevant. His answer, literally, was that "the whole idea is to have fun." That phrase has stayed with me, and I repeat it often to my students. If, as teachers, we can impart to our students a positive feeling about themselves and a sense of fun and gratification in learning, then many other desirable aspects of their education will follow naturally.

Of course, I find that students need to be reminded constantly that along with the fun comes a lot of hard work. As Thomas Edison said, invention is 1 percent inspiration and 99 percent perspiration. As another way to put it, I realized many years ago when doing a major project on my home that you can paint 90 percent of a room in 10 percent of the time. The walls are easy. It is careful attention to the trim and other fine details that makes the difference. This is consistent with my earlier comment that along with the development of exploratory and creative skills, we cannot lose sight of the importance of precision with basic skills.

I have occasionally seen it suggested that computers may eventually take over the educational process, and these suggestions usually cite various dramatic experiments and results. It seems to me that these experimental results are often due to what has become known as the Hawthorne effect. Many educational experiments that are highly successful in pilot programs are considerably less successful when installed on a larger scale. This results from the fact that it is often not the details of the experiment that make it a success, but simply the enthusiasm and excitement that are transmitted to the students from the teachers, associated with the fact that they are trying a new approach. In this sense, it is often worthwhile to introduce and experiment with new techniques and educational tools (such as computers) strictly for the novelty they offer to students and teachers. In addition, of course, these techniques and tools may well have long-term value, as I believe computers do when used for the right purposes.

TEACHERS AS MENTORS AND FRIENDS

I am a great believer in the importance of the teacher's role as mentor. As teachers, we are, in effect, intellectual parents. There are many styles of mentoring

that are appropriate and effective, just as there are many styles of parenting. What is most important is that the style be comfortable and natural for both student and teacher.

Some of my colleagues prefer a relatively formal student/teacher relationship. My personal style is to encourage students to interact with me informally, starting with their use of my first name. Particularly with my graduate research students, I often strive to develop a relationship in which we become friends and colleagues. I must say that in my role as a parent at home also, I often say to my two children that I hope that they see me not only as their parent but also as their friend.

In thinking about the dual roles of teacher and friend, I am reminded of a situation many years ago involving one of my former doctoral students, now a successful scientist. We were both learning the sport of wind-surfing. On one particular morning, we met to review his thesis progress, and in fairly authoritative terms as his teacher, I emphasized the importance of his working harder and making quicker progress. As it turned out, that afternoon conditions were particularly good for windsurfing, and I was in somewhat of a dilemma as to whether, as his teacher, to encourage him to spend the afternoon working or, as his windsurfing friend and "student," to encourage him to take advantage of the good weather. You can guess how it turned out. Even now he and I still fondly recall that day and dilemma. In general, I feel strongly that it is appropriate and meaningful for students to feel that I am both their teacher and their friend. Of course, in situations in which there is conflict between the roles of teacher and friend, the responsibilities of the teacher should always come first.

ROLE REVERSALS

It is also often the case with students that there are times of role reversal in which they are the teacher and I am the student. I believe that this role reversal is as important to me as it is to them. This happens frequently at MIT during Independent Activities Period, when essentially the only requirement for a course being offered is that there be someone interested in teaching it and someone interested in taking it. During IAP many intriguing courses are taught by students with special skills and interests and taken by faculty and other students. Two of the most enjoyable courses that I have taken during IAP were "close-up magic" (card tricks), and "lock-picking." Both were taught by former classroom students of mine. They were quite frankly thrilled with the role reversal, and so was I.

Beyond this simple role reversal, all of us are and should always be students as well as teachers. In fact, in the Electrical Engineering and Computer Science Department, faculty are encouraged to take occasional courses as students. We attend all the lectures, do all the required assignments, and take the exams alongside the regular students. I have done this several times. The most recent was an undergraduate core subject taken mainly by freshmen and sophomores. For most of the semester I sat next to one particular freshman who clearly grasped the material much more quickly than I did and to whom I often turned for help. One day after class he asked me why I was taking the course. When I told him it was because I would be teaching it the next semester, he looked totally astonished and then burst out in laughter. I can say from personal experience that periodically returning to the classroom as a student is both exhilarating and humbling. Among other things, it gives us an excellent view of ourselves from the students' perspective, thus providing an opportunity to heighten our sensitivities as teachers. The opportunity for faculty to take occasional courses has been further enhanced and formalized recently in my department through the establishment of the Adler Scholar Program in memory of Professor Richard Adler.

With regard to classroom interaction, again there are many styles that are appropriate and effective. I personally try to be highly interactive in my lectures, even with large classes. Interestingly, when I am a "student" in a class in which the teacher is highly interactive and looks for participation from the class, I tend to be nervous and to feel intimidated when asked to respond on material that I am just learning. However, I also find myself paying especially close attention to the lecturer, so that if I am called on, I have at least a reasonable chance of having a meaningful response.

FOSTERING SELF-ESTEEM

As I have tried to stress, I view my role as a teacher to involve not only imparting skills in a specific area but also developing students in a broader sense. Of particular importance is the development of creativity, insight, and a positive, confident self-image. Confidence and self-esteem are essential since creative processes inevitably involve disappointment and failure, set off, one hopes, by occasional successes. In guiding doctoral students through a major research project, I consider it important to push them to their creative limits and to instill in them the self-confidence to carry out creative research on their own. As we all know, in order to fly, it is important to believe that you can.

Self-confidence and self-esteem are, of course, personal qualities that are best instilled by both parents and teachers at an early age. This point was made to me very emphatically by my wife, Phyllis, when our daughter was about to enter school. She was tested for early admission and passed easily. As a proud parent, I was pleased that she was ahead of her age in intellectual ability, and I was in favor of her entering school early. Phyllis clearly saw it as preferable that our daughter wait. As she pointed out, in making such a decision, it was important for us to consider the physical as well as the intellectual aspects of development. The younger children in a class are often unable to do things that the older children can, simply because they are a few months behind in motor skill or behavioral development. Nevertheless, the younger children often mistakenly see this as reflecting a lack of innate ability, and it affects their self-confidence. For this reason, it is

generally better to be one of the older children in a class than one of the younger ones. Having watched my two children and others progress through school, I have no doubt that Phyllis is absolutely right on this point.

VISUALIZATION AND CREATIVITY

There are a few additional points that I am eager to convey to my students at some stage in their education. The first is the importance of visualization or, equivalently, planning ahead. I remember as extremely significant a moment in my freshman year in college when a close friend asked me to describe how I would most like my career to turn out. He encouraged me to express my wildest, most optimistic dream. With the disclaimer that I could not imagine this ever happening, I said that I would most like to know a subject well enough to write a book on it, to be a professor at a top university, and to lead a small, successful research group. While there are many elements of good fortune that contributed to the fulfillment of this dream, a significant element was the fact that I was encouraged by my friend to articulate and therefore visualize it. I now try to take each of my research students, and any other students with whom I have a close association, through the same process of visualization with regard to their careers.

Another point is the importance of having a set of serious interests that can offer refreshing diversions from work. My own outside interests revolve around sports. A sometimes frustrating but also exciting aspect of creativity is that it seems to happen at a subconscious level and rises to the surface only when ready. In my experience, it is often the case that, after laying the proper intellectual groundwork, I can encourage creative inspiration best by doing something completely different that puts my mind in a relaxed, somewhat meditative state. It is literally true that the creative breakthrough on my doctoral thesis occurred for me two thirds of the way up a ski lift in Vermont.

I often say to my students that no news is bad news and that all news is good news. The phrase as I have worded it is just confusing enough that it encourages them to stop and think for a while. What I mean specifically is the following: One of the exciting things about a creative endeavor such as research is never knowing exactly where you are going to end up or how you are going to get there. Along the way there are many surprises, some of which may on the surface seem disappointing. For example, perhaps a student learns that his or her great "discovery" has been discovered before, or is wrong. My view is that nothing is ever completely new and that all news is good news — that is, there is often as much or more to be learned from the disappointments as from the successes. In fact, a very important role for teachers is to show students how to recover and learn from mistakes, failures, and disappointments.

THE MOUSE AND THE ELEPHANT

I would like to conclude with one more mental image that I am eager to convey to my students. In 1980, I gave a series of lectures at Tsinghua University in Beijing. My host asked me at some point how I pick research problems to work on. I tried to explain the importance to me of choosing problems based on my instincts and on the fun and excitement associated with an uncertain outcome. Because of the language difficulties, I eventually turned to a metaphor that I have since used quite frequently. As I explained it to my host, choosing a problem to work on is like standing at the edge of a field of tall grass, from which there are several tails sticking out. The idea is to tug lightly on each to get some feel for what might be at the other end. For example, is it a mouse or an elephant? Eventually, instinct and judgment will suggest which tail to follow, and it should then be pursued vigorously for the fun and excitement of discovering what it is attached to.

Although I have been teaching for many years, this is the first time that I have had the opportunity to express my personal views about education in a somewhat formal way. When I started to put this essay together, I was not quite sure whether my train of thought would lead to a mouse or an elephant. I hope that I have at least conveyed the sense of personal pleasure that I derive from teaching and the importance that I place on the relationship between student and teacher. I was particularly fortunate to have had a number of excellent teachers who had significant impact on me personally. Among them were Amar Bose, who showed me by example the importance of exceptional standards; Ben Gold, who showed me by example the importance of friendship and informality; and Thomas Stockham, who showed me by example the importance of inspiring teaching. I hope that in a similar way I can convey these values to my students. I particularly look forward to many years of being a friend and teacher to my students and to being their student as well.

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