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Chapter 10

Education and Technology at Stanford in the Twenty-first Century

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1. Historical Perspective

To put into historical perspective the great educational innovations of the past, there are at least five major technological innovations comparable to the current computer revolution: written records, libraries, printing, mass schooling, and testing.

1.1. Written Records

The first major educational innovation was the use of written records in ancient times for teaching. We do not know exactly when such use began, but we do have, as early as Plato's Dialogues, written in the fifth century B.C., sophisticated objections to their use.

Today no one would doubt the value of written material in education, but there were strong and cogent objections to this earliest innovation in education. The objections were these: a written record is impersonal; it is very uniform; it does not adapt to the individual student; it does not establish rapport with the student. Socrates and the Sophists, the tutors of students in ancient Athens, objected to introducing written records and destroying the essential personal relation between student and tutor. (For a detailed statement of this position, see Plato's *Phaedrus*, 273–76.)

It has become a familiar story in our own time that a technological innovation has side effects that are not always uniformly beneficial. It is important to recognize that this is not a new aspect of innovation but has been with us from the beginning.

1.2. Libraries

The second innovation was the founding of libraries in the ancient world. the most important example being the famous Alexandrian Library established around 300 B.C. (For a detailed presentation of the society and culture of Ptolemaic Alexandria, see Fraser 1972.) Because of certain democratic traditions and the preeminence of the creative work in philosophy and poetry, it is easy to think of Athens as the intellectual center of the Hellenic world. In fact, that center was Alexandria. From about 250 B.C. to 400 A.D. not only was Alexandria the most important center of mathematics and astronomy in the ancient world, it was also a major center of literature, especially because of the collection in the Alexandrian Library. The first critical literary scholarship in the Western world—the editing of texts, the analysis of style, and the compiling of bibliographies—took place there. This revolution in education consisted not simply of having in one place a large number of papyrus manuscripts but in the organization of large bodies of learning. Scholars from all over the Western world came to Alexandria to study and to talk to others. Substantial libraries existed also in other major cities of the ancient Mediterranean cultures and in China, India, and Korea.

1.3. Printing

The third innovation of great historical importance in education was the move from written records to printed books. In the West the printing of the Gutenberg Bible in 1452 marks the beginning date of this innovation. It is important to recognize, however, that block printing was used extensively in Korea and China three or four hundred years earlier (Carter 1955). The earliest printed book comes from China and is dated 868, but there is much evidence of block printing at least for the preceding hundred years. Nearly half a millennium later, it is difficult to have a vivid sense of how important the innovation of printing turned out to be. No more than five major libraries existed in the ancient world of the Mediterranean. In 100 B.C., the Alexandrian Library had few competitors; it was impossible for many copies of manuscripts to be reproduced when all copying had to be done tediously by hand. The introduction of printing in the fifteenth century produced a radical innovation—indeed, a revolution—in the distribution of intellectual and educational materials. By the middle of the sixteenth century, not only European institutions but wealthy families as well had large libraries.

Once again, however, there were definite technological side effects that were not uniformly beneficial. Those who know the beauty of the medieval manuscripts that preceded the introduction of printing can appreciate that mass printing was regarded by some as a degradation of the art of reproduction.

It is also important to have a sense of how slow the effect of a technological innovation can sometimes be. Not until the end of the eighteenth century were books used extensively for teaching in schools. In arithmetic, for example, most teachers continued to use oral methods throughout the nineteenth century; appropriate elementary textbooks in mathematics were not available until the beginning of the present century. Fortunately, the time scale of dissemination in the modern world is of an entirely different order from what it was in the past. Perhaps my favorite example is the estimate that it took more than five years for the news of Julius Caesar's assassination to reach the farthest corners of the Roman Empire. Today such an event would be known throughout the world in a matter of minutes.

It was not unusual for methods of recitation to be used in the elementary school until the nineteenth century; the same was true at some universities. According to at least one account the last professor at Cambridge University in England who insisted on following the recitative tradition, which dates back to the Middle Ages, was C. D. Broad. As late as the 1940's, he dictated, and then repeated, each sentence so that students would have adequate time to write it down exactly as dictated.

1.4. Mass Schooling

The fourth innovation, and again one that we now accept as a complete and natural part of our society, is mass schooling. We have a tendency in talking about our society to put schools and families into the same category of major institutions, but there is a great psychological difference between the status of the family and the status of schools. The family is an integral part of our culture. The evidence that families in one form or another have been our most important cultural unit goes back thousands of years. Schools are, by contrast, a recent innovation in our culture. In 1870, for example, only 2% of young people graduated from high school in the United States. One hundred years before that, only a very small percentage finished even third or fourth grade.

In most of the world, less than 1% of the population completed secondary school as recently as 50 years ago. In many developing countries today the best that can be hoped is that the majority of young people will receive four years of elementary-school education. Until population growth slows down, it will take all available resources to achieve that much.

The position of the United States as a world leader in education is sometimes not adequately recognized, though U.S. leadership in creating a society with mass education is one of the most important aspects of American influence in the world. The worldwide revolution in mass schooling is one of the most striking phenomena of the twentieth century.

1.5. Testing

The fifth educational innovation is testing, which is in many ways older than mass schooling. The great tradition of testing was first established in China; testing there began in the fifth century A.D. and became firmly entrenched by the twelfth century A.D. Tests were used continuously from the twelfth century through the nineteenth century in the selection of mandarins, the civil servants who ran the imperial government of China. The civil service positions held by mandarins were regarded as the elite social positions in the society. A variety of documents attests to the importance of these tests in Chinese society (for a recent overview, see Chaffee 1985). In examining the literature of the fifteenth or sixteenth century, for example, one is impressed by the concern expressed over performance on tests.

Literary tales often focused on the question whether sons would successfully complete the tests and what this would mean for the family. (In those days women had no place in the formal management of the society and no place as applicants for civil service positions.) The procedures of selection were as rigorous as those found in a contemporary medical school or a graduate school of business in the United States or Canada. In many periods, fewer than 2% of those who began the tests, which were arranged in a complicated hierarchy, successfully completed the sequence and were put on the list of eligible mandarins.

Although the history of testing goes back hundreds of years, in many ways it is proper to regard it as a twentieth-century innovation. Scientific and technical study of tests began only in this century, with a serious effort to understand and to define what constitutes a good test for a given aptitude, a given achievement, or a given skill.

The five innovations I have discussed—written records, libraries, printing, mass schooling, and tests—are the very fabric of our educational system today. It is almost impossible to contemplate education without each of these innovations playing an important part. Of these five technologies, the effect of none was adequately forecast at the time of introduction. Of course, a few individuals foresaw some of the consequences and had something to say about them, but the details were not accurately foreseen. No doubt the same will prove true of technologies now developing.

2. What Computers and Telecommunication Offer

What I have to say about the use of computers and telecommunication in education in the 21st century will also probably fall in the category of inaccurate prognostication. (For a summary of early efforts at Stanford when interactive computers had been around for less than a decade, see the two books, Suppes, Jerman and Brian 1968 and Suppes and Morningstar 1972.) The technology and its applications are changing too quickly for one to make accurate predictions for the next century. All the same, there are several salient points about the future I want to emphasize.

2.1. Speech

In a variety of publications on computer applications ranging from automobiles to factories, the usefulness of speech has been emphasized. Yet I think it is fair to say that the most extended and most sophisticated use of computer-generated speech will be in education. The computers that are used for instruction twenty years from now will, almost without question. no longer be silent but fully talking and listening and doing so with a great deal of instructional sophistication. The silent computers that dominate the present scene will definitely be a thing of the past by the end of the 21st century.

2.2. Diversity

The second point of saliency will be the great diversity of courses that will be available. Because of budgetary constraints there has been a tendency over the past few years to reduce the variety of course offerings in colleges and universities, and also to some extent at the secondary-school level as well. This tendency I see being reversed and being reversed in a dramatic way by computers and telecommunications. Courses of a highly specialized and technical nature or, if not technical, of an esoteric nature. can be offered to a very small number of students. Moreover, they can be offered in a manner that will be economical, just as it is now economical to publish a book that has a worldwide circulation of perhaps a thousand. I see technology-based instruction as being a major force for increasing the diversity and richness of what is offered in education at all levels.

2.3. Individualization

What are the arguments for the individualized instruction computers can offer? First, and above all, computers offer immediate attention to individual responses. Second, computers can correct these responses and convey information about their character, especially when the student's answers are incorrect. Third, computers can adapt the pace of instruction in delicate and subtle ways to the individual student's pace of learning. Relatively simple computer systems can give us these three features, together with the virtue of the student's actively participating as opposed to passively listening.

2.4. Cognitive Models

Our ambitions for good computer instruction will not stop with the phenomenological features of a good tutor; we want more. We want good instructional programs also to have a good cognitive model of the student and his learning problems. (For a current survey of models in psychology, see Suppes, Pavel, and Falmagne 1994.) A good tutor intuitively has a sense of what is going on in the head of the student, but ordinarily a good tutor does not have an explicit cognitive theory of how the student is solving problems and why he is getting stuck in his problem-solving efforts. Some aspects of the process seem extraordinarily mysterious, but we should be able to make significant progress on such cognitive models even if some questions are still unanswered a century from now.

2.5. Accessibility of Information

The transformation of learning that will take place because of the increased accessibility of information will be greater than that which occurred with the creation of the Alexandrian Library more than two thousand years ago. Scholars of the ancient world properly stood in awe of the resources at Alexandria. The kinds of resources that were brought together there in one place will be available through computers and telecommunications in every nook and cranny of every country. The greatest potential effect of this availability of information by electronic means is the decentralization of our schools, universities, and other parts of our society, a topic that I shall examine at greater length later in this essay.

2.6. Augmented Technical Skills

We are all familiar with the kinds of problems that can be tackled with current computers that were simply out of reach even thirty or forty years ago. These problems range from massive computations about the weather to linear models applied to every sort of problem from medicine to economics. Students in undergraduate classes now routinely perform numerical calculations that were unheard of thirty or forty years ago and that were impossible fifty or sixty years ago. Such numerical power will continue to increase, and the number-crunching computers of today are rapidly being joined by symbol-crunching computers of comparable power. We expect symbolic analysis at our fingertips, whether it be applied to the structure of DNA, to a complicated mathematical equation that has to be transformed, or to a mathematical proof that needs completion of its combinatorial parts. We have become, both in instruction and research, as dependent on symbol crunchers as on number crunchers. The effect of these two in combination with access by telecommunication to highly specialized resources will be to augment our technical skills, and the sophisticated instruction we expect in technical skills, far beyond anything we have seen up to the present.

There is some reason to think that scientific development in many disciplines will become increasingly complex. A thesis that science will keep unifying and keep simplifying is, in my judgment, much more a romantic hope than a conclusion supported by the actual development of science over the past fifty years. If my skeptical view of unity is at all close to the truth, the problems of instruction will become ever more difficult. We will need every possible resource to augment our technical skills. Computers and telecommunications will be by far and away the most important means for doing so.

3. Institutional Change

The continuing developments in computers and telecommunication sketched but in no sense described in detail in the last section will have a profound effect on higher education in the 21st century. (For a detailed review of the first such experiments at Stanford, see Suppes 1981.) That effect will, in my judgment, be as profound as the most important revolution in education in the 20th century, namely, the introduction of mass schooling in most parts of the world. Although this century has seen also far and away the most massive increase in higher education in the history of the world, in many respects the way in which colleges and universities conduct their business is not too dissimilar from the way it was conducted as long ago as the 18th century or at least the 19th century. Students going to college in 1890 did not have in fundamental ways a different psychological experience from those going to school in the 1990's. It will be very surprising if this is still true in the 2090's.

I have organized my remarks about predicted changes at Stanford, but what I have to say will undoubtedly apply as well to comparable institutions. Whether the predictions are made for Stanford or for other institutions they are bound to be badly inaccurate as the 21st century progresses. The details as I sketch them are surely wrong. The general ideas should be grossly right. I have organized my remarks into three sections before, at, and after Stanford. What I mean by these headings will become clear in what follows.

3.1. Before Stanford

An appreciable number of entering Stanford undergraduates have essentially a year's college credit of work completed in the form of Advanced Placement exams. It is easy enough for a bright Stanford student to complete in high school the Advanced Placement exams in English, mathematics, history, one or two of the sciences, and some foreign language, in order to have full credit for a first year of college. Such students, if they so desired, could easily graduate in three years. I am not saying that they want to or even that it is the desirable thing to do. It is just that the opportunity is already there by completion of Advanced Placement courses in high school to have finished the first year before arrival. But this is only the tip of the iceberg. It is quite clear that the top 10 or 15% of the students entering Stanford could easily have completed a second year if technology had been used appropriately to offer courses to them.

Let me speak from some personal examples. For the past several years I and my colleagues have been running through the Continuing Studies Program at Stanford, the Educational Program for Gifted Youth (EPGY). We have been offering by computer and telecommunication university-level courses for very bright students in secondary schools, especially schools close to Stanford, but increasingly to students not in schools immediately adjacent to Stanford. The very best of these students are capable of finishing the Advanced Placement courses, not as graduating seniors, but in or tenth grades. (For a detailed report on the test results for the past several years, see Ravaglia, Suppes, Stillinger, and Alper, 1995.) By the time the top students are juniors in high school they will have completed the equivalent of a full year of college work and can now complete in their junior and senior years at least one more year. How should that be done?

In general terms, Stanford should admit such students early and encourage their continued rapid progress. A concrete proposal, but only one of many possible, is for Stanford to admit students who have completed the kind of Advanced Placement program I mentioned by the end of the tenth grade. But, unlike the old Hutchins program at the University of Chicago, this program does not mean that they should come to Stanford at the time when they would ordinarily be juniors in high school. They stay in place in their high schools, but in agreement with the high schools, by computer and telecommunication, Stanford offers them courses beyond advanced placement in mathematics, science, English, and foreign languages. It might even be that Stanford would not grant university credit for the learning of elementary foreign languages, something that should be really a responsibility of the high schools. However, in case the students want to learn such languages as Chinese, Japanese, or Russian, it might well be their high school does not offer them. Stanford, as part of its preparation of these students, would give them intensive work in these languages in their last two years of high school.

More important, beyond the Advanced Placement courses in mathematics and physics, the next level of Stanford undergraduate courses in mathematics and physics could be offered to the students in their last two years of high school with Stanford credit. Remember, I am talking about the top 10 or 15% of students admitted at Stanford. These students could certainly carry such a work load in these last two years. The minimum would permit them to finish the equivalent of a Stanford year and also complete some of the other standard high school requirements. More important than these standard academic high school requirements would be the fact that they were remaining in the social setting of their high school, living and learning with their social peers and remaining through their early adolescent years at home. I am skeptical that even in the 21st century we shall want to have a deluge of fifteen and sixteen year olds on the campuses of residential universities such as Stanford. What we want to do is educate them when young, but not be responsible for prematurely transferring them from home to college residence.

High school graduation should ordinarily be easy enough to orchestrate by arranging with the appropriate credentialing authorities for dual credit to be received for standard university courses taken during high school years. In some states the authority to grant such credit is decentralized to local school boards, in others it remains the responsibility of the state educational agency. In any case, such arrangements should not be difficult, particularly in view of the fact that in most cases the high schools will be supported in their usual way with a Stanford student counting as part of the average daily attendance for that high school, the basis for funding from state or local authorities.

To give you a sense that these possibilities are real and not ones that I am simply imagining, I will quote to you a few statistics from our recent EPGY results at Stanford. The youngest student in our program to complete the course for the second Advanced Placement exam in mathematics, that is, the BC Advanced Placement exam in calculus, was at the time a seventh grader. The youngest student to complete the course for the mechanics exam with a calculus prerequisite was an eighth grader, and the same student completed the course and took the electricity and magnetism exam with a calculus prerequisite as a ninth grader. But what we are offering, although still special, does not involve just single students. In 1993 in the whole of the United States there were only eight students in the ninth grade or earlier who took the mechanics Advanced Placement exam with a calculus prerequisite (1993 AP National Summary Report Tables). Of those eight students, five were students in EPGY at Stanford. Their grades were: three 5's, the top grade, one 4 and one 3. These striking results do not mean that we simply had an unusual distribution of gifted students available to us, it means that most very able students were simply not given the opportunity to take such courses at an early age, even though they were quite competent to do so.

Finally, to finish out this discussion of before Stanford, there would be nothing that would do more to promote a larger number of these students than a general decision at Stanford to run the kind of program I have described. It would encourage in many ways bright students to go ahead and complete the Advanced Placement courses at an early age, so they could move on to early admission at Stanford while still remaining at home.

3.2. At Stanford

Stanford students, under the setup envisaged, would arrive in a large number of cases with at least a year's work done and in some cases at least two years. For those students who did not get a fast start—and after all some of the best and brightest are late bloomers—there would be other makeup procedures Stanford could offer. Perhaps one of the best examples would be in the area of foreign languages. Consider a student who starts late but discovers he or she really wants to specialize in the economics or politics of the Pacific Rim. For this purpose he or she wants to learn both Chinese and Japanese and as yet he or she has not really started either one of these languages. That student could already begin in the summer prior to arriving on campus by taking, while still at home, an intensive course in Chinese or Japanese. This work could continue during the first year, and then a similar intensive course could be offered in the summer after the student's freshman year. These courses might not receive college credit, as we gradually eliminate such credit for elementary language learning, but the skills could be acquired and the language would be under command. This is just one example of the way in which technology could be used to facilitate a late-blooming student's needs.

While on campus a student's room would, as the 21st century progresses, increasingly be converted into a sophisticated learning center. I do not mean to suggest that students will spend most of their time in their rooms listening, looking, and responding to electronic instruction; I just mean that rich resources will be available to them, and if they do not want to attend lectures, they can look at and listen to those lectures remotely. In some cases in fact, the lectures may only be offered this way. What is more important, really, is the way in which instruction will change. The 50-minute lecture, at least in the sciences, will probably disappear and be replaced by something much more interactive and much more individualized.

In this connection I must mention one experiment I did a good many years ago with Stanford students (Crothers and Suppes 1967, p. 168). This was a study of students learning an initial segment of Russian under different regimes of instruction. The model we had for distributed learning worked rather well, but what was really surprising about the experiment were the large differences in the individual learning rates of relatively homogeneous Stanford students. The difference between the rate of learning of the slowest and the fastest of this relatively homogeneous group was astounding. (With a mean on the final test of 129 correct responses out of 300, the range was 78 to 189 for the twenty students who were the subjects in the experiment.) No doubt the same is true of the learning of mathematics and physics. This suggests that lectures are a poor way of adapting to the individual differences of students. The technology will be used effectively in the next century to make such accommodation.

It might sound as if I were recommending the elimination of all group learning activities, such as lectures, quiz sections, and seminars. Nothing could be further from the truth. It is just that lectures have the wrong natural lockstep. The brightest student in physics can look out the window most of the time during lectures, while the slowest one is struggling to follow an introductory course in quantum mechanics. Working together in the laboratory on projects, doing complicated problem sets together, and engaging in similar activities should certainly continue and be extended.

But what, above all, should be extended in a very definite way beyond what is now the case is the teaching of seminars by faculty at all levels. It is in the seminar room, with interaction, conversation, dialogue, and mutual challenges, that much of the education at Stanford in the 21st century should take place. This kind of education is expensive and extraordinarily labor intensive. It is just for this reason that we should use technology to do all of the preparation whenever possible. In subjects with an enormous systematic development, such as mathematics or physics, or in subjects in which students can be led into dialogue and discussion relatively easily, such as philosophy, students should be brought to the frontiers by whatever means possible and as rapidly as possible.

For example, in terms of this rapid approach to the frontiers, students who enter Stanford with two years already completed should be ready by what would be their third year on campus to begin intensive graduate work and to be ready for intensive seminars in physics by what would be their fourth year on campus. Maybe these seminars, in the case of physics, would consist of participating in some experimental work, but whatever the various approaches, what should be foremost in the instructional effort is to get the student to the seminar level as rapidly as possible. It is this kind of instruction that will return us to the glories of the Sophists in ancient Athens but at a different level and with very much of a different subject matter in mind. It is not the subject matter but the human interaction that was valuable and remains valuable now. It may well be that a good part of the role of the Sophists will be replaced by extraordinarily smart computer programs that talk, listen, and engage the student in challenging dialogue. But I am not sure that anything as bright and wonderful as this will be available even at the end of the next century. Without it we can still make wondrous progress.

3.3. After Stanford

Stanford has an active alumni association and the participation of many alumni in various activities, but what should be the level of their participation in the next century? We already have legislation on the books in many states requiring professionals from accountants to pharmacists to take regular continuing education courses of a certified nature in order to retain their own professional certification. In the increasingly technical world in which we live this tendency will undoubtedly continue. Lawyers, doctors, and all kinds of other professionals will be regularly taking continuing education courses, and Stanford would be remiss not to offer a wide range of such instruction to its alumni and other professional persons. It could be an activity that in terms of numbers of persons and even numbers of instructional hours, far exceeds the current teaching on campus. Technology will make it possible to run these courses from Stanford but not to require local attendance. A doctor in Alaska will be able to keep up-to-date on his specialty and receive credit for doing so without ever leaving his home or office. The same is true for all kinds of other professionals. But it is not just the professionals. Stanford will be encouraged to offer and undoubtedly will offer by technological means a great variety of courses to the adult population. There will, of course, be some occasions when it will be desirable to bring these learning professionals on to campus, but it will not be often and can only really be for purposes of a psychological boost and the satisfaction of their natural desire occasionally to return. What is important is that Stanford can play a kind of central role in the lives of its alumni that does not exist at present but that will be critical to their role in the increasingly technological society of the 21st century.

3.4. Psychology of the Virtual Classroom

Why be on campus at all? The new technology will permit us to conduct even a seminar with students actually located in all parts of the world. No doubt such seminars will be given and will be very effective. Take some relatively esoteric but still important topic. An example I like is Kant's *Third Critique, The Critique of Judgment*, especially the second half on teleology. I can see a seminar being offered on this text in the middle of the 21st century with the members assembled from six different countries and consisting of not more than twelve persons. I picked a topic in philosophy, but it could just as easily be a specialized topic in physics or in economics. Just how the credits will be assigned and who will pay what, I shall not venture to say.

No doubt the psychology of the virtual classroom will become increasingly intimate but will still be no match for the physical presence, so the place for Stanford as a physical institution will remain. As Stanford undergraduates have told the faculty for many years, it is not really what goes on in the classroom that is important, it is the life shared together living on campus. The joys and sorrows of those undergraduate years spent together will continue to have appeal and will continue to play a significant role.

It may be a different story at the graduate level, just because of the great desirability of specialization. Seminars will be held with the members assembled from everywhere, and that may be forecast as the great contrast between undergraduate and graduate education in the next century. But I think that also can be too sharp a contrast. There is too much, in science above all, that is like apprenticeship. You do not learn how to do experiments by just watching and listening. Hands-on work is essential, and for that continuing physical presence may be needed. But there is still a forecast that runs against even this prudent reservation. It is that the nature of experimentation will change as the role of technology rapidly increases. It may even be that in the most advanced experimentation in any one scientific domain there will be only a few places in the world with the equipment necessary to perform it, and those who want to participate will often do so remotely but still actively and essentially. If this prediction turns out to be true, graduate education will indeed be the model of the virtual university.

So the psychological needs of the undergraduates and the graduates may well diverge. The desirable socializing camaraderie of the undergraduate may well evolve into something quite different for the graduate student. The psychology of camaraderie for graduate students will be transformed, as it already is already being transformed for working scientists and scholars, into rapid, continual, and informal network communication. I, like many others, am already finding at the close of this century that most of my informal intellectual communications take place with my professional peers scattered around the world rather than with my local colleagues. It is already that way for large numbers of graduate students. There is a real likelihood that this will be the dominant trend. What will this trend mean? Will graduate students be admitted as virtual graduate students? Can a student remain in Beijing and be an integral part of graduate training, take courses, and receive a degree? Up to now such students have traveled to the universities of their choice. But there is no reason why that system cannot be reversed to have the technology bring the university to the students. Stanford, I am sure, will be able to find a way to change itself and prosper from such radical new developments in its organization as an institution of learning.

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