To provide some historical perspective on the anticipated role that computers will play in our society, I would like briefly to review what I consider to be the three great educational technologies that have preceded the introduction of computers.

The first was the founding of libraries in the ancient world, the most important example being the famous Alexandrian Library that was established about 300 B.C. Because of the seductive charms of Plato and the Greek dramatists, it is easy to forget that the real intellectual centre of the Hellenistic world, from a broader standpoint, was Alexandria and not Athens. From about 250 B.C. to A.D. 400, not only was Alexandria the most important centre of mathematics and astronomy in the ancient world, but it was also a major centre of literature, especially because of the collection in the Alexandrian Library. The first real beginnings of critical scholarship in the Western world in literature, the editing of texts, the analysis of style, the drawing up of bibliographies were achieved in the Alexandrian Library.

I see as the first technological revolution in education the organization of large bodies of learning in a given place. Libraries of a substantial nature were to be found in major cities of the ancient world, not to mention the collections of learning in China and other civilizations. The recognition that learning needed to be collected in a single place, and in a written form that would provide continuity and a basis for continued intellectual activity of a higher order, was the first major revolution. The technological part of this revolution was the organization of libraries like that at Alexandria.

The second major technological revolution was the intro-
duction of printing. The historic date in the West, as we all learned early in school, was 1452, for the printing of the Gutenberg Bible. Block printing on a substantial scale began several centuries earlier in China and Korea. In the western world, the introduction of printing meant that men of affluence could have substantial libraries of their own in the sixteenth century, and the records show a great outpouring of printing of learned works in that century. It is sometimes mistakenly thought that a widespread printing of books began at the same time for student use in schools. This was not the case. The method of recitation that dominated the Middle Ages continued not only in the sixteenth and seventeenth centuries, but well into the eighteenth century. In fact, the use of recitation to teach some subjects, such as elementary arithmetic, continued far into the nineteenth century. The widespread use of books in schools did not occur until the latter part of the eighteenth century, at the earliest.

This brings me to the third technological revolution, the introduction of mass education through schools. When we think about schools, we tend to think about them in a very limited way. We think of them as having been here forever and as staying forever, and we think that they are going to sustain about the same form that we have experienced ourselves. But even for North America, this reverie is false as to the facts. The first national statistics on education of a systematic sort were begun in the United States by the U.S. Office of Education in 1870, and for that year, it was estimated that just 57 per cent of the young people between five and seventeen years of age were in school. Of the seventeen-year-old group, only 2 per cent were graduates from high school. Public schools that involve the bulk of the population are strictly a phenomenon of the twentieth century. For most of the world, they are not even a phenomenon of the twentieth century, but are of much more recent creation. In tropical Africa, until the last decade, a negligible percentage of the students went on to secondary school, and in some countries only 10 or 15 per cent completed elementary school. Similar data obtain for developing countries in other parts of the world.
Given that the phenomenon of schools is so recent and yet plays such an important part in our society, it is not difficult to turn to computers to provide the opportunity for a fourth major technological revolution in education. I want to explore some of the alternatives to schools that are offered by computers. The purpose of my preliminary remarks is to emphasize how transient the phenomenon of mass education has been and, consequently, how relatively easy it would be to change it. Schools are not institutions that are deeply embedded in the culture of western civilization, or in the civilization of any other part of the world. Their shape and form have been constantly subject to change. There is no reason that schools must exist as they have for the past thirty or forty years. It might be thought that universities offer a more continuous and constant history, but this is true only for the select institutions. Higher education for the bulk of the population is of course an even more recent phenomenon than mass education at the elementary and secondary levels. We have just begun to explore the alternatives to the traditional university organization. I shall consider several possibilities in this paper.

*Computers as instructional devices*

Before considering some of the alternative organizational structures computers make possible, it will perhaps be useful to examine briefly the way in which computers can be used as instructional devices. Current applications of computers in our society range from the automatic control of factories to data-bank searches for credit ratings. A high percentage of regular employees in Canada and the United States is paid by computerized payroll systems. Increasingly, in a variety of biological and physical experimentation in the sciences, computers are used for on-line monitoring and control of experiments. The use of computers for administrative purposes, such as that of payroll, is familiar now to most people. The way in which computers can be used for instruction, however, is not yet widely known and it may be useful to review, even if briefly, the operating procedures.
In the first place, because of the computer's great speed, it can handle simultaneously a large number of students. Each student can be working at a different point in a particular curriculum, or be in a completely different curriculum. In the simplest mode of operation, the student sits at a terminal device that is something like an electric typewriter or a teletype. Messages are typed out by the computer, and the student in turn can enter his responses on the keyboard. To augment this simple typewriter terminal, perhaps the most important next feature is to add an audio capacity to deliver messages under computer control. The next step in complexity is to add graphic and pictorial displays as, for example, to a television terminal under computer control. In our own work at Stanford, because of the relatively low cost, we mainly use teletype terminals. In the world of the future, more complex terminal configurations of the kind I have described will be widely available.

Some of you may be saying, 'So what? So a computer can operate quickly and therefore handle a number of students; a good lecturer can talk to a lot of students also. What's so unusual about what a computer can do?' I think the central argument for instruction by computer may be found in an examination of the deep possibilities of individualized instruction. The first and most important aspect of individualization is based on the well-known psychological generalization that there are definite and clearly significant individual differences in students. The fact is that children enter school with remarkably different abilities and retain them throughout their careers; further, they work at different rates and at different levels of accuracy and understanding. But, unfortunately, for obvious economic reasons, schools and colleges are not able to offer an individual curriculum programme to each student according to his needs. The computer, simultaneously handling many students, can let each progress at his own pace and at his own level of achievement.

A different and equally important aspect of individualization is the immediate correction of individual student responses when an error is made. It is an instructive experience to compare first-graders in class with first-graders at computer terminals, to
observe the effects of giving the student immediate correction and reinforcement for his responses. I expect that the same stimulus would be observed in the teaching of elementary skills at the university level. Our computer-based Russian course at Stanford demands the attention of the student during the entire fifty-minute period, because his part of the programme is solely concerned with his own responses and his own work. No such individual attention can possibly be given in the classroom. In a class of ten or fifteen, the student knows that when he gives a response, almost certainly the teacher will call upon another student, not himself, for the next response. He can immediately relax and let his mental machinery idle for the next few minutes. With a computer terminal, the situation is more like that of having an individual tutor.

Let me turn now to various possible levels of interaction between the student and the computer programme. Following a current usage, I shall refer to each of the instructional programmes as a particular system of instruction. At the simplest level, *individualized drill-and-practice systems* are meant to supplement the regular curriculum taught by the teacher. The introduction of concepts and new ideas is handled in conventional fashion by the teacher. The role of the computer is to provide regular review and practice in basic concepts and skills. In the case of elementary mathematics, for example, each student receives daily a certain number of exercises that are automatically presented, evaluated and scored by the computer programme without any effort by the classroom teacher. Moreover, these exercises can be presented on an individualized basis, with the brighter students receiving exercises that are harder than average, and the slower ones receiving problems that are easier than average.

One important aspect of this kind of individualization should be emphasized. It is not necessary to decide at the beginning of the school year in which track a student should be placed; for example, he need not be classified as a slow student for the entire year. Individualized drill-and-practice work is suitable to all the elementary subjects that occupy a good part of the curriculum. Elementary mathematics, elementary science, and the
initial work in a foreign language are typical parts of the curriculum that benefit from standardized and regularly presented drill-and-practice exercises. A large computer with 200 terminals can handle as many as 6,000 students on a daily basis in this instructional mode. In all likelihood, it will soon be feasible to increase these numbers to 1,000 terminals and 30,000 students.

At the second and deeper level of interaction between student and computer programme, tutorial systems take over the main responsibility both for presenting a concept and for developing the skills necessary for its use. The intention is to approximate the interaction a patient tutor would have with an individual student. An important aspect of the reading and elementary mathematics tutorial programmes, with which we have been concerned at Stanford in the past ten years, is that every effort is made to avoid an initial experience of failure on the part of the slower children. On the other hand, the programme has enough flexibility to avoid boring the brighter children with endlessly repetitive exercises. As soon as the student manifests a clear understanding of a concept, on the basis of handling a number of exercises, he is moved on to a new concept and new exercises.

At the third and deepest level of interaction, dialogue systems are aimed at permitting the student to conduct a genuine dialogue with the computer. The dialogue systems at present exist primarily at the conceptual rather than the operational level, and I do want to emphasize that in the case of dialogue systems a number of difficult technical problems must first be solved. One problem is that of recognizing spoken speech. Especially in the case of young children, we should like the child simply to be able to ask the computer programme a question. To permit this interaction, we must be able to recognize the spoken speech of the child and also to recognize the meaning of the question he is asking. The problem of recognizing meaning is at least as difficult as that of recognizing the spoken speech. It will be some time before we shall be able to do either of these things with any efficiency and economy.

I would predict that within the next decade many children
will use individualized drill-and-practice systems in elementary school; by the time they reach high school, tutorial systems will be available on a broad basis. Their children may in turn use dialogue systems throughout their school experience.

If these predictions are even approximately correct, they have far-reaching implications for education and society. Let me now turn to some of these implications.

Alternative educational structures

Let me give one or two examples of changes we can effect in the structure of educational institutions by using appropriately the new technology of computers and television. Because of my own special interest in computers, I shall concentrate on computer possibilities; but it should be understood that television would also be a component for the proposed changes in structure.

My first example concerns the organization of high schools. An American phenomenon much discussed in the history of education in the twentieth century has been the introduction of the consolidated high school that brings together students from small schools to a centrally located large school that offers a variety of educational opportunities and resources to the students. The American consolidated high school is one of the glories of the history of education. Today, however, many of us feel that the large high school has become one of the most difficult institutions to deal with from a social standpoint. The mass aggregation of adolescents in one spot creates an environment that is on the one hand impersonal, and on the other potentially frictional and explosive, partly because of the large numbers of students and supervising adults in close quarters.

The use of our new technology will make possible an alternative structure that will return us to the small schools of the past. The ideal high school of the future may consist of no more than a hundred students and, in many cases, be located close to students' homes; or it may be a specialized school, catering for students' particular interests. The variety of curriculum and other educational resources, such as libraries, that has been so important a feature of the consolidated high school, will be made
available by computer and television technology. I should say in this connection that the changes that can be brought about through the use of computers are more drastic and more radical than those that can be effected only through television. The difference is the possibility of a high level of interaction between the computer programme and the student, the sort of thing that is not possible with a standard television lecture or laboratory demonstration.

In connection with the development of small schools, I believe that the introduction of computers as instructional devices is just as inevitable as the introduction of books in the past, even though there could be resistance from educational liberals. It is easy to imagine a refrain that could have been heard in the eighteenth century, to the effect that it is terrible to create an impersonal distance between the teacher and the student by handing the student a book and not letting him listen to the lilting voice of the teacher's recitation. The same kinds of arguments about impersonalization are familiar and have the same superficiality. As I have tried to emphasize in the preceding discussion, the computer can provide more individualization and more individual attention for the student, not less, than the teacher in those parts of instruction—like the teaching of basic skills—that require a high level of active response from the student.

I want to emphasize, however, that I do not see the computer as an instructional device in competition with the teacher. The role of the computer is like the role of books: to amplify the skills and time of the teacher. The economics of education will not, in any immediate future, change so as to reduce the student-teacher ratio at any level of education in any part of the world. Skilled teachers, however, will be able to use computers to individualize instruction in the standard parts of the curriculum and to reserve their own efforts for troubleshooting and individual attention of an intensive sort.

Because many of you will not be familiar with the rich possibilities that may be embedded in computer programmes for instruction, it is important to emphasize the many ways a
computer programme can do things that a tutor cannot. For example, a computer programme can prepare individualized student lessons from a large data base in a fashion that would be realistically impossible for a tutor, and certainly impossible for a teacher handling ten, twenty, or thirty students.

My second major example concerns alternatives to elementary schools. Through most of the history of civilization, young children have been taught primarily at home, often perhaps in an extended family group. We now have the technical possibility of returning the student to the home or to small neighbourhood groups. Although these alternatives have not yet been thoroughly explored, it is important that discussion of their availability begin as early as possible. As far as I know, the new romantics in education have not discussed the radical possibility of dissolving elementary schools entirely and returning the child to the home—or to neighbourhood groups of three or four homes—for his education.

In describing this possibility, let me emphasize that I am not maintaining that it is necessarily a wise move. I do, however, think it important that this technical possibility is now available. At the very least, it should be explored experimentally. By proper use of computer technology, the basic skills of reading, mathematics, and language arts can easily be brought to the student in the home or in a cluster of homes. Parts of the elementary science curriculum also can be handled by computer. Other parts of the elementary science curriculum, of the social studies programme, and much of the work in art and music could be handled by television. I envisage a situation in which a master teacher would divide his time among several units. The mothers of the children would assume responsibilities for supervision and some would work as teachers' aides. This would be completely natural, because of the proximity of the school to their homes. In many urban settings, for example, it would be natural to place classrooms in apartment complexes. In other districts, a small one-room building could be added, or it might even be feasible to pay a small rent to one of the families for the use of space in a home. The main thing to avoid is heavy capital
expenditure for physical plants; we have had too much of it in the past.

The third alternative structure deals with higher education. Here the possibilities are perhaps the easiest to implement and may be realized sooner than the others. In the areas surrounding Stanford, several community colleges are already offering courses for credit by television. As we face the costs throughout the world of providing higher education for increasing numbers, the use of computers and television to reduce costs and to decentralize the educational effort seems almost inevitable. One can see terminals available in apartment complexes for students at the community college level. At a later stage, one can envisage terminals in plants where employees work full-time, but also actively pursue their education. I should mention that in California, for example, a reasonable percentage of students in the state higher educational system are employed full-time, simultaneously with their enrolment as students. The development of such a delivery system for higher education will also naturally answer demands for continuing education for adults. At a more distant date, one can expect the terminal resources described earlier to be available in the home for the teaching of a wide range of subjects, from foreign languages to advanced technical courses in science and mathematics.

It may seem expensive to introduce such a delivery system for higher education. However, elementary computations show that if we replace the capital costs of campuses with expenditures for setting up the delivery system, the costs become competitive with the current costs of higher education. I shall not go into detailed calculations, but it is possible to back up this statement with a quantitative analysis.

Outstanding problems

My natural state of mind is sceptical and empirical. I am not inclined to make over-optimistic predictions about alternative structures in education in the immediate future. I do, however, think that the predictions I have sketched will be part of the future in a time scale that is not yet easy to forecast. I would like
to conclude by discussing some of the major problems that stand in the way of a more rapid development of such alternative structures.

Economic problems. Computers are expensive, and it is difficult to organize a delivery system, as described, at an acceptable cost. There are a couple of points worth emphasizing. As a large number of students are placed on a given computer system, the cost of the central computer is less important than the cost of individual terminals and telephone communications. This is true, certainly, for a system that has on the order of 1,000 terminals and handles between 20,000 and 30,000 students a day. Part of the problem is the large initial capital investment. Another part of the economic problem is the operating cost. Perhaps the most important economic problem, however, is to be tough-minded about ways in which technology can actually substitute for labour-intensive efforts by teachers. These problems have just begun to be explored. A great tradition in education is that every new technology simply becomes an add-on cost to the present bill for instruction. In the future, it will likely be impossible to sustain this system. The economics of education will demand that technology be used as a substitute for rather than as a supplement to teachers. This is not a problem for teachers, in my judgment. It means that the skills required of teachers will increase, the professional requirements for teachers will increase, their status and compensation will correspondingly increase, but the absolute number of teachers relative to a given population of students will decrease.

Institutional problems. Problems of institutional change are poorly understood. There is evidence that universities, for example, are among the most conservative institutions in our society. In any case, the rapid development of alternative structures for education will be neither simple nor easy. On the other hand, the willingness of community colleges, which do not have a long tradition, to consider new methods of instruction and new approaches is encouraging. There are problems of prejudice and
entrenchment, but there are also intellectual problems of understanding the kinds of organization we want for the future. The technology affords many possibilities, but we have not thought through which of these possibilities we consider the most advantageous, the most interesting, or the most exciting.

The central idea I have been stressing is that through computers we have the means to develop alternative structures that will effectively decentralize the present educational system. The issue of decentralization of services, of places of work, of almost all aspects of our life is gradually coming to the fore as a central social and political problem of the last part of the twentieth century. The issues involved in decentralizing education will be among the most significant of these problems of decentralization. The problems that face us are not really technological: they are conceptual, institutional, and social. I have certainly not made any concrete suggestions for tackling these problems; at most, I wished to bring them to your attention.

Intellectual problems. Finally, there are intellectual and scientific problems that surround a proposed deepening of the use of technology. We are on the edges of some major problems that need to be solved. As yet, we have a fairly simple-minded set of explicit ideas as to making computer programmes conduct sophisticated dialogues with students and be perceptive of students’ needs. The difficulty is not technological, but scientific. We do not have an explicit understanding of the way in which one intelligent human being conducts a meaningful conversation with another. It is a limitation that is as old as Plato. Many of us can talk well, and sometimes even listen, but we have a poor understanding of how we do it. We have no analytical grasp of the structure of a dialogue. We do not know what the ingredients of intellectual discourse are between tutor and student, and until we have this deeper understanding we shall not be able to reach as far as we want with the kinds of technology discussed.

Aristotle said that man is a rational animal. I would prefer to say that man is a talking animal. A curious, interesting, and deeply human fact about man’s technology is this: a deeper and
subtler intellectual command of, say, computer technology is completely coupled with a central area of research on human beings themselves. The understanding of how we use language, the understanding of the structure of our language, and the understanding of why we say what we do when we do, are all involved. As we acquire such understanding of ourselves, we can apply it to education in deep and powerful ways with the aid of technology.