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ABSTRACT

This paper describes the history, philosophy, and outcomes of work at the Educational Technology Center at the University of California, Irvine, with particular emphasis on the activities of the Physics Computer Development Project. Ten years of evolution for the physics projects and its basis of grant support are examined, and a series of principles is outlined as a guide for anyone working in the development of computer-aided learning materials. The outcomes of the project which are described include the preparation of computer dialogs, the use of the computer for problem solving, the Irvine Center course management system, the design of full courses, and the Irvine authoring system. Background information on the evaluation procedure used for the Irvine project is also provided, as well as recommendations for the future of computer-based learning at the Irvine Center and in other educational settings. (MER)

EDUCATIONAL TECHNOLOGY CENTER AT THE UNIVERSITY OF CALIFORNIA, IRVINE

by

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This paper describes the history, philosophy, outcomes and other aspects of the work centered in the Educational Technology Center at the University of California, Irvine. A major component of this activity has been performed by the Physics Computer Development Project.

History

It is difficult to know where to start describing our project. But I will take a personal point of view. My own interest in computers developed about 1959 when, as a faculty member at the University of Alaska, I attended IBM courses about a new IBM compute a 1620. This early, now seemingly primitive, machine was one of the first inexpensive machines to have a higher level language available, FORTRAN. It was not heavily used at the University of Alaska. I participated in the early use of it, working with a graduate student, Harold Leinbach, in developing a program which involves an electron coming through the atmosphere. A group of people stood around, and excitement was generated as to how far an electron would penetrate the atmosphere.

Soon after that I began to teach a physics class in which I saw natural ways to use the computer and to make use of the excitement I had observed. This development continued for several years in Alaska until I left in 1962.

After Alaska I tried to determine to what extent such work was being done elsewhere. I finally received a letter from someone within IBM, later to become a friend, to the effect that they didn't know much about using computers in education but that someone in Alaska was doing it. At this point I decided that perhaps I was on to something new!

After spending a year as a National Science Foundation Faculty Fellow at Harvard, mostly working in the history of physics, I went to teach at Reed College for the next four years. At Reed College first a 1620 and then an 1130 allowed me to continue working with computers. I was fortunate to be teaching a large natural science class for nonmajors, and the computer became a natural adjunct to that class.

The Reed environment was limited to small computers. I made attempts to secure larger interactive systems in Portland, but that seemed to be in the future. Hence, when the opportunity was presented to me (through Kenneth Ford, then chairman of the Physics Department) to join the faculty at the University of California, Irvine, I was happy to make the move.

Irvine had committed itself already in its earliest stages to the importance of the computer as a learning device. It obtained, and still obtains, superior support for that purpose from the University of California systemwide.

The Irvine situation was not entirely smooth. I arrived in the middle of a computer crisis. A large joint project between IBM and the University was developing a timesharing system for educational purposes. The system was to be running when I first arrived on the campus, but early tests showed problems. This and various other factors, including resistance from re[illegible] users, led to a hectic first year. At the end of that year th[illegible]M equipment left, and we had two new computers, a Sigma 7 and a PDP-10. I played a considerable role in choosing the Sigma 7.

About this time I received the first of a number of grants from the National Science Foundation. Table 1 shows the grants received at Irvine. Existence of a good timesharing system, the Sigma 7, plus support from the National Science Foundation allowed me to do many of the kinds of things I had been planning.

TABLE 1

Grant Support from the National Science Foundation

Dates	Title	Amount
7-1-69 to 12-31-71	Development of Computer Based Materials for Teaching Undergraduate Physics	$350,426
1-17-71 to 9-30-72	College Science Improvement Program Cooperative Projects for Two-Year Colleges	56,200
1-1-72 to 6-30-74	Computer Based Interactive Graphics in Teaching Undergraduate Physics	182,000
6-1-74 to 5-31-75	Computer Graphics in Learning	213,100
6-1-75 to 5-31-76	Computer Graphics in Learning	217,400
6-1-76 to 11-30-77	Computer Graphics in Learning	230,433
5-1-77 to 4-30-78	Conference on Educational Applications Intelligent Videodisc Systems	17,550
5-21-78 to 11-31-81	A Testing and Tutoring Environment for Large Science Course (CAUSE)	249,200
	Total	$1,516,309

As can be seen, our support from the National Science Foundation has been consistently good. The fact that we have been supported almost continually for a ten-year period has allowed us to make steady progress. Furthermore, it has led to increased use of computers within classes. This year, for example, we have beginning physics and beginning math classes (discussed further in a later section) in which all the tests are given on-line directly at the computer and with considerable additional material used in those classes too. These two classes do not cover the complete range of educational usage at Irvine; but much of what happens in other classes is similar to that to be found in other institutions.

In addition to support from the National Science Foundation we have received several types of support from the University of California First, my department has been cooperative in allowing our work with computer-based learning materials to be my research activity at the University. This was agreed on before I reached the university, and I have no complaints with the way that agreement has been honored, even though the people who made the initial agreement have long since left. Second, through the Innovative Projects funds of the University, funds systemwide in the University of California that support curriculum development, we have had a series of grants. While these grants have been smaller than the National Science Foundation grants, they have been very helpful particularly in providing us capabilities for maintenance of programs.

TABLE 2

Dates	Title	Amount
1969/1970	Development of Physics Room at at Irvine	$ 12,000
1972/1973	Development of Motivational and Remedial Units for Use in Beginning Physics Class	10,000
1973/1974	Development of Additional Materials for Physics 1	3,450
1974/1975	Developing Computer Dialogs	6,000
1974/1975	Uses of Irvine Physics Dialogs on Other UC Campuses	30,250
1974/1975	Computer Programs for Instruction of of Medical Studies (with Hall and Ballard)	9,400
1975/1976	Further Development of Instructional Material - Physics 3	3,792
1978/1979	Computer-Based Learning for Beginning Physics	10,448
	Total	$ 85,340

Another major contribution from the University of California has been computer time. The University receives funds directly from the Legislature for instructional uses of computing. Irvine has used each year some of these funds for developmental purposes as well as the more standard use of them for class work. Our project has benefitted from these funds.

During the more than ten years that the project has been active at Irvine a number of people have played critical roles. Richard Ballard joined the project in 1970 as a codirector. Joseph Marasco joined the project in 1975 as another codirector. Both have now left the project; Joseph Marasco still works with us in the design and development of materials even though he has a full-time job elsewhere. Our senior programmer for many years was Estelle Warner. More recently the people directly involved are Donald Darling, codirector of our CAUSE grant, from the Math Department at Irvine and Stephen Franklin, project director of the CAUSE grant, from the Computing Facility.

Much of the work of the project has depended on a very devoted and hard working group of student programmers, almost entirely undergraduates, who have worked with the project for many years. Furthermore, visitors, often for extended periods of time, have made major contributions in helping us write programs and in their overall design.

Philosophy

As with any long and extended project, one would expect some changes in the philosophical positions of the project. But I like to view these as evolutionary changes, consistent with our earliest philosophy but offering some refinements.

The best source of information about the early philosophy came in speeches given by the project director, Alfred Bork, at the Second Annual Conference on Computers in the Undergraduate Curriculum at Dartmouth in 1971 and at a SIGUCC meeting two years later. The Dartmouth speech was one of the three keynote speeches at the meeting. I outlined a series of principles which I felt should guide anyone in the development of computer-aided learning materials in the form of six "theses."

Thesis I: Different students learn in different ways.

Most teachers would agree, but practically all courses seem to ignore student differences. Most courses are rigidly structured, with only one path to success and only one set of learning materials. An environment truly responsive to students must have a variety of materials and techniques for learning.

Thesis II: We are only beginning the task of learning how to use the computer in education.

I worry greatly about teachers who feel that they already know all the answers. We have a long way to go, and theoretical analysis will not tell us how to employ computers effectively. Hence we want to maintain flexibility, and we should be prepared for long years of trial and error while using computers in learning.

Thesis III: Useful ways to involve computers in teaching may depend on subject matter involved.

What is highly effective in physics may turn out to be useless for literature. This is obvious with computational uses, which are tailored for a specific need. It is perhaps less obvious with other types of usage. While we may find techniques which transcend subject matter boundaries, we will continue to need specific techniques for individual areas.

Thesis IV: It is wise to retain all usage modes for computers in every learning situation.

Computational, tutorial, simulational, managerial, and other modes as yet unnamed may all prove to be of great importance in in education. Further, in view of Thesis III, a mode worthless in one discipline may be valuable in another area.

Thesis V: We should continue to develop ways of learning independent of computers.

Some areas and some students may profit from other techniques.

Many powerful learning tools exist. The film can be used interactively with computers as a very effective learning medium. Furthermore, in some areas, nothing competes in teaching effectiveness with a student's experience in working problems. Thus, I am not in sympathy with the "whole course" approach to computers in education, where the computer becomes the sole medium. Today we don't know enough to use computers exclusively, and we may never want to.

Thesis VI: The test of all learning is with students--does the material, computer or otherwise, lead to some type of learning for some students?

All educational materials need to be widely used and continually modified on the basis of students' experiences.

The subtitle of the speech also reflected the project philosophy. It was "Let a Thousand Flowers Bloom." The emphasis was that at that time we were very much in a learning mode, trying to understand how to use computers effectively in learning environments. Therefore the important thrust was to try many approaches, many different modes of computer usage, rather than to focus early on a single approach. At the present time I believe we (meaning everyone) are still in this experimentation period, but approaching the end of that period.

Another early "philosophical" paper from the project (first given at the SIGUCC meeting at the fourth CCUC) described "ten widely believed myths." The following is abstracted from that document.

Myth 1: You must choose between direct and adjunct use of the computer.

Either students can do their own programming, using the computer as an intellectual tool--sometimes called the adjunct use--or students can interact with teaching programs prepared by others--the direct or mainline use.

Myth 2: You must have massive equipment to use the computer in education.

Some of the more interesting teaching applications have come from schools with minimal computer equipment. Small stand-alone minis certainly do rule out some of the kinds of things that can be done. Thus, dialogs are not possible on small minis; but many other types of usage are possible.

Myth 3: One language is much easier to learn than another.

When students write programs for problems in physics or mathematics courses, the questions of which language to use and how students learn that language become important. Arguments are often based on supposed easy learning of one language or another; thus proponents of BASIC often claim that it is very easy to learn. My own experience indicates that the way the language is taught is much more important than the language itself in determining speed of initial learning.

Myth 4: Computers will be widely used in education in present organizational structures or institutions.

The ability to provide learning materials at any time and at any pace, and provide self-testing features, the ability to respond individually to students, to have access to large amounts of data, all imply that the way schools operate are likely to change drastically when computers are widely used in learning. One interesting view of how this revolution might happen is presented in Education and Ecstasy by George Leonard.

Myth 5: At this time your best buy for a terminal is the Model 33 Teletype.

I feel strongly that educational users should never buy Model 33 Teletypes today!

Myth 6: Computers are too expensive to use in teaching.

Regardless of what one thinks about the costs today, the future situation is clear: Of all the costs involved in the educational process, computer costs are almost the only ones going down. Teachers, books, buildings, and films are going up in cost, while computer costs, because of a rising curve of technological development, are still diminishing dramatically; so the computer will become more and more competitive as a teaching device over the next few years.

Myth 7: If we acquire a CAI language, that solves our problems.

The availability of a dialog language, no matter how good the language may be, is only a small part of the process of getting reliable and educationally useful teaching materials on the computer. The whole problem of an authoring system--the way one persuades teachers to write materials, the full facilities provided, the incentives for doing this, the use of secretaries, programmers, and other kinds of auxiliary people, the testing procedures, the gathering of feedback, and the preparation of suitable computer-related text material--is enormously more important than the question of the language itself.

Myth 8: PLATO and MITRE are solving all the problems.

Both are very interesting projects. To regard them as exhausting all the possibilities, however, is quite wrong. Many interesting teaching materials that exist today could not be run on either of these systems.

Myth 9: Valid educational material can be developed without involving experienced teachers in the area.

Teaching is still teaching whether done by computer or by any other device. My experience shows that really effective educational materials are still coming, in spite of talk to the contrary, almost entirely from those who are very much involved in the teaching process. The intellectual structure of every discipline is different, and the tough question of fundamental goals cannot be resolved in any simple, quick way. While computer scientists and educational psychologists can help develop learning material, I do not believe they can do it alone.

Myth 10: The computer used educationally uses only minor amounts of computer resources.

I can find little to quarrel with even today! Perhaps in Myth 2 I underestimated the future potential of small computers.

The strong emphasis on graphics in the early days of the project has continued. Our earliest grant emphasized graphic capabilities. My feeling has always been that visual information plays an extremely important role in the learning process, and that every learning approach, whether involving computers or not, could normally expect to use graphical information.

This belief in graphics has been reinforced and deepened by the experiences of the project. But graphics has come to take a larger meaning than it had at first. Initially I had in mind only the question of adding pictorial information. While this still plays a critical role, we now more and more consider text itself to be a graphic component. We consider the composition of each screen seen by students to play a major role in the effectiveness of the material. I will have more to say later about the implications for the importance of visual design in the developmental process.

The fact that the project has never had any doctrinaire attitude toward the way the computer could be used in education, but has always argued that many different ways might be usable, has had important ramifications. As we have moved along, we have often been guided by the necessities of classes. One of the dominant aspects of our work in later years, for example, has been the use of interactive, on-line testing. These tests, to be described later, are combined learning and testing materials offering much help to students who are in trouble. But we came into this approach only gradually as we started to teach large classes with our computer-based material and encountered problems. The development of such approaches was completely consistent with our previous philosophical position.

Another shift during the course of the project in philosophical outlook was from developing individual pieces of material toward worrying more about how these materials fitted into a total course. Initially it was the compelling examples that were of most interest to us. Often compelling examples turned out to mean compelling to us, to our evaluators, and to our many visitors rather than to the students. Some of the compelling examples were real bombs with students! This pushed us more into looking at the total class environment and to asking what was really needed for that.

Another shift in philosophical position came about through external developments. When the project began an interactive system almost certainly had to be a timesharing system. So naturally it was that type of hardware that was assumed. The rise, particularly in the last several years, of inexpensive, powerful stand-alone systems has completely altered the picture. Stand-alones offer, we argue, tremendous advantages in marketing and delivery of computer-based learning materials. Hence, our recent work is focusing in that direction. While this does not affect any of the underlying pedagogical philosophy, it does very much affect our attitude toward transportability and related factors.

One philosophical direction in which the project has differed from many other projects is that with regard to the use of special "CAI" languages. The decision was made in the early days of the project that as all the ways of using the computer educationally were not known we would not tie ourselves down to any CAI language. Rather, we would try to work within available general purpose languages, exploiting the full capabilities of the computer. Our feeling was that as we gained more experience we would want to do things that we could not conceive of initially, so to begin by designing a language would be a mistake. We have found this to be a very effective position and have maintained it. At the present time we are moving away from much of our present software into a new PASCAL-based system. The notion of working within very powerful, general purpose, higher level languages still seems to us to be the best way of proceeding; we do not believe that any of the existing CAI languages will survive.

Outcomes of the Project

I will discuss the outcomes of our work under five different headings--the preparation of computer dialogs, the use of the computer for problem solving, our course management system, the design of full courses, and the Irvine authoring system.

1. Student-Computer Dialogs

The major continual activity of our project has been the preparation of interactive student-computer dialogs, learning conversations between the people who prepare the material and the student. These programs typically take somewhere between one-half and one and one-half hours of student time for completion. They are often run in a number of sessions and can at the authors' discretion allow restart at the point reached in the previous session. Some programs, particularly those which provide student facilities, are more open ended as to the amount of time that might be involved. Although most of our dialogs have been written by members of the project, visitors often participate in this process, so many others have names attached to them.

For convenience I will discuss the dialogs in terms of a variety of categories. They cover a wide spectrum of pedagogical uses, not any single strategy. These categories, as with all human classification systems, furnish no absolute distinctions and often categories are blurred. Further, several aspects often occur within a single program.

An important early concentration was in interactive proof dialogs. The notion was to let the students develop important proofs in the course in as interactive a fashion as possible. This is to be contrasted with the student seeing the proof as done by the instructor on the blackboard or as displayed in a textbook, a passive process. It was felt that students could better develop capabilities of doing such proofs themselves if they played an active role in the process. Many of our early dialogs were in this tradition, and some later examples can be found too. The earliest dialog, CONSERVE, written by Noah Sherman at the University of Michingan and the author, is an example. A more modern example is the MOMENTUM dialog, again a joint product of the author and Robert Eisberg of the University of California, Santa Barbara.

A second class of dialogs is concerned with helping students in developing concepts. Again, the strategy is to avoid the authoritarian approach of many classes where concepts are introduced by fiat. We attempt to convince students that some reason or necessity exists for a particular concept before the name of that concept is introduced. Thus, in the dialog 3D (Arthur Luehrmann and Alfred Bork) the notions of divergence, curl and gradient are arrived at as generalizations on the concept of derivative before the student has the names for these quantities. The FIELD program introduces slowly, with some use of simulation, the notion of electric field, again in an interactive fashion.

A similar collection of dialogs is concerned with helping students with formal reasoning capabilities. It is assumed that these students are not full formal reasoners yet, but are reasoning in what Piaget would refer to as concrete modes. This work has been particularly guided by our collaboration with Arnold Arons in the Physics Department at the University of Washington. Six programs have been written jointly with Arons and the author; Joseph Marasco was also involved in one of these programs, HEAT. Three of the programs concern magnetic fields, and two are astronomical--the sky as seen from the earth and the phases of the moon.

Laboratory simulations are also useful. We can provide an experimental situation for students similar to experiments that might be carried out in laboratories. But many more experiments can be carried out in a short period of time, and students can be immediately queried as to the meaning of the results. Perhaps the most extensive dialog of this kind is HOCKEY, again primarily due to Robert Eisberg. The experiments involve colliding pucks, first in one dimension and then in two dimensions with three types of collisions considered. The aim is to get students to arrive at the notions of mass, momentum, and conservation of momentum.

Controllable worlds are a type of simulation too but with emphasis on a broader capability than those provided in the laboratory environment. The student is given the ability to manipulate the world, often in ways not usually available. The first controllable world, MOTION, provided a flexible $\vec{F} = m\vec{a}$ world with the student picking force laws, initial conditions, equation constants, and what to plot. A second approach was in the FIELD dialog with the ability to plot electrostatic field lines and equipotential lines.

But some of our attempts to produce extensions of this idea were not successful. We tried to produce a range of such simulations that provided much greater flexibility in interacting with students. But in spite of considerable project resources, these programs did not succeed. Only one reached running form, and this had a limited subject area.

The possibilities with on-line testing were first explored by Stephen Franklin within the precalculus mathematics course. There it was found that the tests gave a very natural way to conduct any personalized system of instruction course, relieving the instructors of the routine burdens of testing and record keeping but still providing quick feedback to students as to what problems were correct and which incorrect.

After our initial experiences with tests we began to become more impressed with the possibilities, particularly in combining within tests some of the same types of learning capabilities that we had been providing in the other types of programs discussed. The intriguing possibility was to be able to offer direct and immediate assistance to students, finding out just what the student errors were and responding immediately with pertinent help. The twenty-seven on-line mechanics tests were developed with this in mind. They cover the first quarter of a beginning science-engineering majors physics course (several different tracks, as discussed later) and represent the most extensive coherent development we have undertaken.

These examples do not cover all the possibilities, but they give a good overall impression of the types of materials we have produced. A full list of dialogs is available from the project.

2. Student Problem Solving

Our project has always felt that one of the most important aspects of the use of the computer within courses was in providing the ability for the students to use this powerful intellectual tool to solve their own problems. The computer thus "expands" the human intellect. This use of the computer often allows new approaches to courses, approaches impossible before the computer existed.

One major question is what computer languages students should use for this problem solving activity. The project has developed a continually revised position paper with regard to this issue. It was felt from the beginning that the issue of languages should be rationally decided! That is, we should be able to set criteria as to what was desirable, and then to compare existing languages against these criteria. The result was that the two choices that are "best" for contemporary science-engineering students are APL and PASCAL. The arguments for each are very different. Our paper argues that the least desirable language for this purpose is BASIC. In most cases this issue is decided either simply on what is available or on grounds of sheer emotionalism.

In addition to picking the right language another important overall issue is that of efficient methods of learning the language. If a computer language is to be learned as a part of another course, such as a physics course, it must be very efficient in terms of student time. Traditionally university courses have not been that concerned with efficient use of student time. Often it is the professor's time that is being economized! But student time is an important issue.

We have found two generally effective ways of teaching languages; both can be used with some languages but not others. The first approach is to start with whole programs, to explain these programs, and then to have the students make modifications of them. The second approach, which we have used extensively in APL, is the ten finger approach. Here the students sits down, gets into APL, and is given (in separate printed material) a series of lines to type in. By observing the results of these lines a controlled discovery process is generated.

3. Course Management

It is universally recognized that a major problem in any large course is the bookkeeping problem, the recording of grades, the compilation of final scores, and related activity. Many partial computer systems have been designed to help with pieces or all of this problem. Hence, as we moved more toward large courses as will be discussed in the next section, we became more concerned with course management.

We decided to design a general course management system with little restriction on the type of course. Thus, we wanted the same facility to work for both a traditional course and for a course taught through the personalized system of instruction or Keller plan. The course structure, including all the information about what things were within the course, were to be part of the database.

Naturally an important component of any course management system is the recording of information. This can come directly from the on-line quizzes or through secretaries or instructors on off-line activities related to the course.

Another important activity of a course management system, particularly in a personalized system of instruction environment, is the control of the quizzes--the question of who can take what quizzes and when. This will again be a function of course structure and can be determined by the author for any particular course. Some modules may depend on other modules and some may not. Also the question of what is to happen after a quiz is not passed is important. It may be desirable, for example, to impose a time delay after a student has not passed a quiz once before allowing the student to take the quiz over again. It may also be desirable to impose a limit on the number of tries a quiz can be taken before the student must see the instructor.

A final aspect of course management is the feedback aspect, providing various types of information to the instructor and to the student. Of particular importance we feel is providing flexible feedback to the instructor, so the instructor can spot problems that are developing in the class and can contact individual students based on this information.

Our management system at Irvine allows all these variants and also provides feedback to aid the instructor in spotting potential course or student problems.

4. Full Courses

Development of complete courses begins to put together some of the components already discussed, since many of them play a role. This development also brings in many factors, however, that have not been discussed. We have tried to use the computer to produce special types of courses difficult to obtain in other ways.

The major emphasis is on providing greater choice for students. The notion was that students should have a variety of choices which were offered in few traditional courses. For example, the use of the PSI environment, although it is not unique to us, allowed students choice in pacing through the material. A choice in learning materials is also desirable.

Another choice, much rarer, which we provide in our newly structured course is that of providing different content within the same course. The on-line quizzes covered several different contents; no one student took all the 27 quizzes that were developed. The strategy could be extended to give several courses within the same administrative format and with the same staff.

In the development of a course much material is needed besides the dialogs themselves. Module descriptions were developed for each of the student tracks. For one of the alternate approaches a full set of notes, begun at Reed College, was further developed while at Irvine. A set of exercises for increasing intuition, used with the controllable world dialogs, was developed also. In general our philosophy to learning material is to provide a great variety of learning materials associated with each of the units.

The two principal courses developed were the precalculus mathematics course, developed primarily outside the project but using the extensive software developed in the project, and the first quarter of the introductory physics course.

Methods of Implementation

One of the major interests of the project has been the development of an effective authoring system. By an authoring system I refer to the entire process of producing computer-related teaching materials. An authoring system should be friendly to the various people who work with it, particularly the instructors involved in the project. It should reduce costs as far as possible. It should lead to highly effective material.

Older authoring systems developed almost without thought. They could be fairly described as cottage industry systems, where the approach was for one person to do all the work. The cottage industry approach, while it may work for early experimental stages, is inappropriate for any large-scale production activities. Furthermore, the whole "lore" that grew up with it, including a collection of special languages, will, we believe, have to be abandoned eventually.

The problem suggested a systems approach. An analysis of the process involved and a structuring of a system to meet the needs is the rational approach.

One aspect of such an investigation was that we could conveniently employ other kinds of models. The most suitable models seemed to be those already used for large-scale production of educational materials. Within academic situations the work at The Open University was particularly interesting, even though it did not refer directly to computers. Furthermore, the structure of the textbook industry also gives very useful clues about how to proceed.

One important criterion of the authoring system from the earliest stages was that it should not restrict in any way the types of materials produced. We felt unhappy with systems, such as ones that were proposed elsewhere, where the authors were put in procrustean beds to make some of the later stages of the process easier. We felt that the focus should always be on the pedagogical design, and the greatest freedom should be allowed at that stage.

We gradually evolved toward seeing the authoring system as involving seven steps. In each of these seven processes different types of people will play the dominant role. Some steps seemed to us to be well understood in much of our current activities. Others we believe we understand, but are typically not in a position to carry out fully. In one case the process is one where much is to be learned.

The first and focal part of the activity is instructional design for the development of the pedagogical specification of the materials that are to run on the computer. Since faculty members are presumably the experts in how to promote learning in their own subject areas, they must play a major role in this process. Educational psychologists and other instructional design individuals may also be involved. We have found this activity to work best in groups of two or three, working intensely. Pleasant environments away from interruptions in the usual university environments and away from telephones are a necessity. The work is not easy, because unlike ordinary teaching activities the teachers must design in effect a whole range of conversations at a single time and must look carefully at what kinds of student problems should be considered. The instructors need detailed acquaintance with students to be perceptive in the handling of these problems. They work by creating informal flowcharts, specifying all the decisions to be made, the text, and the drawings. I emphasize that this is the most important stage of the authoring process.

The second stage in authoring, the editorial process, is the least understood part of our structure. Many book publishers are accustomed to a greater and greater editorial role. They may feel uncertain about the present situation because they do not see a clear editorial role. In our recent activities we have found that the people who are familiar with the instructional design of materials can take other people's material and offer editorial comments. With the vocabulary the process is like any other editorial comment for book-like environments. But when it comes to the question of what decisions are to be made based on student input the issues become fuzzier. More experience is needed.

The growing importance of visual design in our project has already been discussed when the project philosophy was considered. Early computer material almost entirely ignored this, letting things appear on the screen or page simply where the computer language chose to put them. We have moved consistently toward a conscious control of the design process.

The ideal person to be involved in screen design is a competent graphic designer, the type of person who might do layout for a magazine ad. For this designer to function effectively, it is necessary to develop specialized kinds of software. Our screen design software allows such an individual to sit at a computer screen, to compose a variety of elements, to move them around the screen, to change their size and shape in various ways, and then to tell the program to write the necessary code. Both graphic and alphanumeric aspects are covered; a variety of textual treatments are allowed. Newer developments working with stand-alone systems with selective erase capabilities are bringing in such new possibilities as the ability to control scrolling and formatting within individual areas of the screen while not affecting the rest of the screen.

The next component in the authoring system is that of logic design. This is the part that is most closely related to traditional computer programming activities. It is clear, therefore, that this work will be done by programmers, either professional programmers or those particularly trained for this purpose. We now work with under-graduate students.

The question of the language environment for logic design must be considered. In the cottage industry stage very specialized languages were designed with the pious (but unsatisfied) hope that they would be easy to use by ordinary teachers. Such languages as COURSEWRITER, PILOT, PLANET, and TUTOR fit into this category. We felt, however, that any such language would limit the type of material that was produced, and we preferred to stay within powerful, general purpose, computer languages, developing whatever special capabilities that were needed within that environment. Thus, if we needed new resources, they could be constructed because we were working within a general purpose language. Our older work used a variety of such languages, a mixture of assembly language macros for the interactive parts, FORTRAN for calculational parts, APL for the interactive design materials just described, and COBOL for database management. Our newer work is proceeding within PASCAL as a single language in which to develop all aspects.

After the program is initially prepared the next stage is for the individuals involved to sit down together and run the program a few times, criticizing it and suggesting changes. Things look very different when one sees them on the screen than they did when they were on paper, and many new elements come in through a series of reworkings of the program at this stage.

Next, class use is essential. No matter how good the designers were the question of how the material works with actual students is critical. More will be said about this in the evaluation section. An important point is that the computer can save information and this can be a powerful aid in improving the dialog.

The next obvious stage is modification of the program based on the information obtained. Again, the strategies in the above stages must be flexible enough to allow easy modification, often by programmers and graphic designers other than those initially involved with the material. These last several phases may go through a number of cycles with modifications leading to new class use leading to new modifications.

Evaluation of the Irvine Project

Two types of evaluation will be considered. First there are internal evaluation activities conducted by the project itself. Second are external evaluations conducted either with project funds or through independent agencies or individuals.

Internal Evaluation

Perhaps the major test of the Irvine materials has been their repeated use in large classes. Unlike some projects which develop materials that get used only in trial classes, we have aimed from the beginning at dialogs which can be used in large class environments in regular courses. We have always believed that this is the "true test" of the material. Use with a few students where project members can play a major role in working with the students (either intentionally or unintentionally) does not show whether the materials can be used in general environments outside the developing institution. Our mechanics material has now been used for four separate quarters in two different types of beginning physics courses. About 800 students have been involved.

One of our major interests in working with large classes is to see whether the course restructuring ideas, the possibility of allowing students to choose content, is possible in typical large courses. In each of the classes we have offered a variety of choices with the choices differing somewhat from time to time. We have demonstrated that the instructor can decide for a particular course what the options should be and that students can be sufficiently informed to make choices.

We have also shown that we can be responsive to students in a number of ways within the course and that the overall system provides, therefore, a reasonable learning environment.

External Evaluation

Several types of external studies of the project can be mentioned. Perhaps the most elaborate of these was conducted by Michael Scriven with funds from our grants from the National Science Foundation. Two major aspects of this study were examination of the course itself while running and an examination of some of the controllable world dialogs. Participating in the study were Jill Larkin and Mark St. John from the Sesame program at Berkeley. The formative study tended to agree with our internal evaluations of where the courses were strong and weak. Perhaps the material which received the highest rating was the help sequences in the on-line quizzes. Students in fact felt deprived in quizzes that did not have help sequences. On the other hand, the material that still presents the greatest need for improvement is the material designed to increase physical intuition. Time has not permitted us to rewrite this material as yet; we received useful and specific advice from the evaluators in this regard.

Another type of external evaluation could be described as peer review. A number of different aspects are interesting. We often "exhibit" at national meetings with gratifying results. The project has had a steady group of visitors from all over the world, and these visitors have often written glowing descriptions of the project in various publications.

A somewhat more formal activity of this type occurred in connection with Change magazine's project to identify innovative teaching in the United States. This project was not particularly concerned with computers but rather with excellent courses. It was a discipline-oriented project. In each case Change went to the discpline leaders of education and asked for a selection of projects. Change then made a preliminary investigation of these projects and selected typically four projects for major articles in each discipline. Our project was one of the four chosen in physics (Change, January 1978).

It is interesting to look at the list as a whole incidentally, because a fair number of computer-related developments occurred in various areas considered by Change.

The Future of Computer-Based Learning

It is important in a growing and dynamic area as computer-based learning to give some thought to the future. We should be able to suggest where developments should take place next to assure that this learning tool will develop as rapidly and as powerfully as possible. This is particularly critical in an area where large companies will soon be involved in marketing activities.

The following topics indicate areas in which I believe research is important at the present time or areas of future development. We cannot do all of these within our own project. However, many of them do indicate directions that we would like to pursue.

1. Research in Learning

In spite of all the work that has been done we still have much to learn about the learning process and about how the computer can be most effectively used in that process. Hence, continued research in computer-aided learning is essential. We have only scratched the surface of the question of how the computer is most effective in learning. Even the issue of more effective production of material needs additional work.

I do not believe, however, the assertion of some that all developmental efforts should stop until this research takes place.

That would only lead to poorer materials, because others, not always with views we might like, will continue to work.

2. Stand-alone Systems

I have argued in several articles that the future of computer-based learning will be very much dominated by intelligent stand-alone systems, systems which will only on rare occasions converse with another computer elsewhere. These systems will continue to decrease in cost and increase in sophistication for a long period.

Of particular importance will be the increasing number of home computers. I have seen estimates that 250,000 personal computers have already been sold, and projections of a saturation market of 60,000,000. Whether this is accurate or not, it is clear that this market will continue to grow as more and more large vendors enter it. Several important announcements in this direction are forthcoming.

The personal computers of today are not entirely suitable for educational purposes. But they are improving rapidly. Most home systems employ graphics. It is particularly interesting to note that it is now the case that one can buy complete graphic systems (stand-alone computers) for less than one can buy graphic terminals! The reasons for this are not entirely clear, but I believe they are at least partially due to the fact that the complete graphic systems are later designs. Older graphic terminals tended to be ordinary CRT terminals with a separate new component built into them to handle the graphics. More recent stand-alone devices are integrated designs, so these new systems can realize cost savings because of this approach.

3. Intelligent Videodisc

Another important factor with regard to hardware in the immediate future will be the development and use of what I have termed elsewhere the "intelligent videodisc" system. The idea is to combine in an intimate hybrid blend the capabilities of the stand-alone computer just mentioned and the capabilities of the new optical videodisc systems. The videodisc systems are not only now available for the industrial-educational market, but they are also available for the home market. Home systems are currently selling for under $700.

The importance of systems for education which combine the computer and the videodisc is that they allow us to bring into the computer-based learning environment a full multimedia capability. Thus, at any point within a learning sequence a slide, a video sequence, or audio messages can be presented. All of these media and the computer code can be stored on the same inexpensive, long lasting disc. So the intelligent videodisc can extend our present computer-aided learning resources to these new dimensions.

The market is essentially a mass market. The cost of making discs is expensive in small quantities but becomes cheap when the quantities are large. The discs are easy to handle and so form a marketable product. Several developmental projects in this direction are already proceeding, but much additional work is needed. The economic issue of computer alone versus computer plus videodisc must also be carefully investigated.

4. Continual Improvement in Quality

Much of the period of the last twenty years has gone into understanding how to use the computer as a learning device. In addition to the research already mentioned part of this is simply the gaining of experience, the trying of many different possibilities.

I believe that we still have a distance to go in this experience gathering. Although the materials now available are much better and much more effective than they were a few years back, they still represent only a glimmering of the future potential. Almost all of the current modules will look relatively primitive only a few years further along. I am not simply referring to any current materials but even to our best efforts to this time. Very little that is currently available will find its way into commercial release.

5. Increased Use

The amount of use of computer-based learning material in education at any level in the world is almost trivial at the present time. Even in universities that claim to be doing much of it, only a few courses are typically involved. The major delivery system in education worldwide is still the combination of lecture-textbook, starting at an early age and continuing through graduate school.

In the next few years we will see a sharp rise of computer-based learning activity, as more effective materials and less expensive machines are available to the user. Increased use will be seen at all levels of education, and it will also be seen in traditional and newly developed nontraditional educational modes.

6. Further Developments in Authoring Systems

The process of development of computer-based learning materials as we carry it out at Irvine has been described. Further studies of this process and further attempts at variants are essential for further progress. We need to refine our techniques so that effective material can be produced at reasonable cost. Specific problems exist as already pointed out. For example, the question of how to use editorial services within the process needs further experience.

7. Large-scale Production and Distribution

Currently our production and distribution modes for computer-based learning material are almost nonexistent. A few organizations such as CONDUIT are distributing a very limited range of materials. All the marketing mechnisms and production and distribution mechanisms that exist for established educational media such as the textbook do not exist for computer material. Thus if a mathematics professor is looking for computer-based learning material, either part of a course or an entire course, there is simply no way to turn at the present except in very limited areas.

As usage increases and as the commercial vendors see a larger and larger market in the home and in schools, we can confidently expect that more material will be available, and that national marketing activities will begin. Interesting questions arise as to which kinds of companies will be involved in this process. Clearly a number of existing companies have a considerable stake in the market. One is the textbook publisher. Another is the computer hardware manufacturer.

But new companies may be involved. Several such companies have already come into existence, and more may appear as the older companies find that, as is typical, it is hard to adapt to new conditions.

8. Changes in Traditional Institutions

As some traditional institutions begin to use the computer more, questions will arise as to how these institutions will change, and questions will also arise as to what will happen as other institutions, because of their conservative policies, resist change.

The computer allows new educational possibilities different from those in current use. It allows self-pacing not only within individual courses but within the entire curriculum. There is no reason why courses should start on quarter, semester or term boundaries or why students should spend a fixed amount of time in either individual courses or in the entire educational program of the institution. With new and powerful learning resources available around the clock and with these resources being individualized so each student can move at his or her own pace, we can expect changes.

Along with these scheduling changes will probably also come changes in the grading system. Many studies have indicated that current normative grading has almost no correlation with any aspect of the student's life after school. While the possibility of grading by competencies completed is new (and so little evidence is available concerning its connection with the real world), at least it provides new opportunities to make success in school relevant to success in society.

We can expect that some institutions will resist changes and will regard the computer as the work of the devil. The interesting question will be whether these organizations will continue to remain competitive, as students become more and more aware of the effectiveness of computer-based learning and as society becomes more and more concerned with the costs of traditional education.

9. Changes in the Role of Teachers

Teachers are very much concerned with the question of how the computer will affect their status. One obvious answer is that the large-scale production of computer-based learning material, already mentioned, will require very large numbers of teachers. Hence, many teachers may shift from the deliverer of courses to the designer and developer of materials.

A second change in the role of the teacher will be to handle the learning problems which the computer and other learning media available cannot handle. There will always be need for this, for the teacher using expertise to determine why the student is not learning in spite of a rich variety of available modes and approaches. I already begin to see such a change developing in my own experiences with classes that depend heavily on the computer. This will mean that the teacher will spend less time in large group environments and more time with individual students.

10. New Institutions

Perhaps the most exciting development in the period ahead will be the rise of new types of educational institutions, some resembling such new existing institutions as the Open University in UK. Many of these new institutions will be able to capitalize greatly on the computer as a learning device, particularly as the computer becomes more and more available in public libraries, other public places such as science museums, shopping centers, airline terminals, and homes. Others may come out of such areas as extension services of existing institutions, while other institutions may be entirely new.

11. New Educational Systems

The rise of new types of institutions, the demise of some of the more traditional institutions, plus the changes in other formal institutions imply massive changes in the educational system, a new system. This is perhaps the most difficult of the changes to foresee, since it depends on so many other factors already introduced. This development will be the capstone of the entire movement.