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ABSTRACT

This paper describes the present practical use of computers in two large beginning physics courses at the University of California, Irvine; discusses the versatility and desirability of computers in the field of education; and projects the possible future directions of computer-based learning. The advantages and disadvantages of educational networking (including regional computer centers for education) and the stand-alone, one-on-one computer are discussed. One stand-alone system now being developed for a home-based videodisc system which attaches to a television set is described. It is suggested that computers will occupy a more important role in the educational process in the future than they do at present. (KKC)

LEARNING WITH COMPUTERS - TODAY AND TOMORROW

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Several physics classes at the University of California, Irvine, furnish examples of how computer use can be integrated into courses. Current developments in technology suggest several interesting new possibilities.

1. INTRODUCTION

Although the computer has been employed for teaching and learning for about fifteen years, it still occupies a minor or nonexistent role in most classes outside of computer science itself. But this situation is now changing as more teachers and administrators have understood the value of computers in learning. A great variety of uses are possible and useful. In the first part of this paper I take a practical approach, examining two large beginning physics quarters at the University of California, Irvine as taught last fall. In each, computer use was only one aspect of the courses. Briefer comments discuss other courses at Irvine.

The future of computer-based learning will be heavily influenced by current technological progress. Both more extensive educational networking (including regional computer centers for education) and the stand-alone, one-on-one computer are suggested by present work with microcomputers. While we cannot rule out either of these possibilities, we can see some advantages in one direction or the other. It seems very likely that computers will, in one way or another, occupy a more important role in the educational process than at present.

2. IRVINE COURSES AND COMPUTERS

The University of California includes nine undergraduate campuses, including three campuses only ten years old. Irvine, one of the new campuses, runs three competing computers--a Xerox Sigma 7, a DEC PDP-10, and PDP-11/45; all offer timesharing, and batch is available also on the first two. The user is free to pick the computer suitable to his needs. The educational endeavors described in this paper all involve the Sigma 7. Unlike most University computer centers, educational use dominates over research and administration, accounting for well over half the total use; computer science and physical science are the heaviest users. Instructional use is supported from funds from the state of California. The relative affluence of Irvine in instructional computing derives from the imagination of the first Dean of Graduate Studies, Ralph Gerard.

Many of the educational materials described here were produced by the Physics Computer Development Project, supported during the past six years by the National Science Foundation and the University of California. The Project has generated about forty highly interactive student-computer dialogs, and has developed an authoring system for developing such materials. It also added graphic capability to APL; these graphic facilities are now part of the standard Xerox APL. Graphics also plays an extremely important role in all the recently developed dialogs. The Project is still very active in developing materials. Some use is made of these materials on other University of California campuses, through an intercampus phone system, and in neighboring schools. Other departments at Irvine are using the underlying software to develop dialogs.

The two detailed examples in this section both involve physics courses in which the computer is used in a variety of modes. In both cases many other teaching media are also employed.

2.1. Physics 1

Physics 1 is a one-quarter course that precedes standard beginning courses. Most of the students in it take the five-quarter, science-engineering sequence starting the next quarter. The two principal broad objectives of Physics 1 are to provide adequate tools for the study of physics and to increase interest in physics. The course is a PSI course, in the self-paced tradition, with students working at their own rates. The quarter's activity is divided into nine units.

Three units deal explicitly with computers, from the standpoint of problem solving. The first, roughly the first week of the course, is devoted to learning both BASIC and APL. The test for this unit asks the student to write, enter, and operate a small program in each language. The learning method is interactive, not dependent on lectures, textbooks, or CAI material. Students sign on to the terminal, enter the particular language, and type in a series of statements provided. They watch the results and occasionally try to answer questions on the sheet given to them. The procedure might be compared to learning about a strange animal by giving it selected stimuli and observing the response to those stimuli. About three hours of student time are required to learn the basic notions of each language.

The second unit is also concerned with the computer, devoted both to flowcharting and other practical aspects of programming, and also to employing the graphic capabilities of APL. As with other aspects of computing, we stress the ability of computers to draw pictures, and get the student to think right from the beginning about where it is useful to have numbers and where it is useful to have a diagram.

The third computing unit occurs much later in the course, in connection with learning mechanics. The material, Introductory Computer-Based Mechanics, was written initially in a workshop sponsored by the Commission on College Physics, by Alfred Bork, Arthur Luehrmann, and John Robson. The material is a self-contained unit, sold to students in a packet of notes for the course. They learn to set up and solve for the motion of any one-dimensional mechanical system, given any force law and any initial conditions. One tremendous advantage of the computer at this level is that it gives another way for students to get directly at differential equations in studying moving systems. It is only through the use of laws of motion as differential equations that their full power can be realized, and thus the computer allows the students a powerful and rewarding approach almost impossible in the traditional course.

In addition, a number of computer dialogs are usable in connection with these and other units. One of the units deals with complex numbers, and a diagnostic remedial dialog is available, a series of problems of increasing difficulty. When students have trouble with a problem, they are put into a remedial sequence that teaches the necessary concepts. Thus, a student need not spend time with material already familiar, but can go on to the areas where assistance is needed. Alternate methods of learning about complex numbers are also provided. In connection with the unit on mechanics already mentioned, we also make use of a dialog concerning motion. This dialog will be described in more detail in connection with the Physics 3 course. The unit on data analysis has associated with it a dialog on significant figures, drilling students and offering assistance where needed.

Optional units are also available for the students who finish work before the end of the quarter, a common occurrence in a self-paced course. Several of these involve the computer. A common optional unit employs Introductory Computer-Based Mechanics II, a sequel to the previous monograph prepared by the CONDUIT Physics Committee (Alfred Bork, Wayne Lang, John Merrill, and Herbert Peckham). Learning another computer language, learning how to prepare dialogs, and completing a specified dialog were also optional units this past year.

2.2. Physics 3

The Physics 3A course at Irvine is the first quarter of a three-quarter beginning sequence with about 300 students, mostly premedical. The subject matter is mechanics. As with Physics 1 the computer is used in both a problem-solving and dialog mode, with many of the same materials employed in Physics 1; but the emphasis shifts somewhat toward dialogs. Several weeks of the quarter depend heavily on the computer.

Students learn either APL or BASIC, with the choice left to them; the "Ten Finger" material used in Physics 1 is again the basis for learning the language. Introductory Computer-Based Mechanics is also employed, with the students writing programs to analyze the motion of mechanical systems. Thus, the student can approach mechanics immediately in a differential equation form.

The principal dialog used in Physics 3 is MOTION. It allows students to investigate one-particle mechanical systems in great detail, changing force laws, constants in these laws, and initial conditions. They can examine graphically the interesting variables associated with the system, such as position, velocity, momentum, energy, and angular momentum, plotting any two or three variables. MOTION lets students make requests in a language natural to them, and tries to assist the student having problems. In Physics 3 it is used both in a "play" mode, with students exploring freely, and in a structured way to respond to homework problems. Students are asked in a homework assignment to explore oscillators, determining how the mass and spring constant affects the motion, and they are asked to seek closed orbits for a body moving under the action of two fixed inverse-square force centers. MOTION is the type of program that can be returned to time and time again, and can be used by a range of students from secondary school to graduate school; it is heavily used by students outside of physics classes. In the month of October, 1974, 15,000 terminal minutes were spent by students using MOTION.

The four hundred students in Physics 1 and 3 in the fall quarter of 1974 used about 3,500 terminal hours. As we encouarge students to work in groups of two or three, so that they can discuss what is happening, this represents about 7,000 student terminal hours, about 1½ hours per student per week. Our access is not as much as we would like; if the instructors were allowed to use computer resources at will, use would rise.

Physics 3, taught by Rich...d Ballard, also employs other media. Thus, the problem-solving sessions were videotaped and made available to students, and multimedia sessions were common. Computer use rates high in student comments about the course.

2.3. Other Courses at Irvine

Many of the other physics classes at Irvine use the computer. Details differ from year to year, depending on who teaches the course, but background student use is always high. Both dialog and computational aspects occur. Thus, we have several dialogs on vector calculus, for use in electricity and magnetism sections of beginning courses. Another program allows students to plot electric fields from arbitrarily moving point charges, and this is sometimes also assigned as a calculational task in an intermediate course. New programs in quantum mechanics and relativity, already in partial use, provide a wide range of learning experiences in these areas. Several types of dialogs are directed explicitly toward improving the problem-solving capabilities of students, and others toward increasing intuition about the behavior of physical systems.

The most extensive use outside of physics of the software developed by the Physics Computer Development Project has been in a precalculus, self-paced math class. The computer administers the unit exams, picking randomly out of a large collection, and thus allowing multiple tries; it is also responsible for record keeping. Current development of dialogs is also going on in other areas of math and in biology, chemistry, fine arts, medicine, and sociology.

3. FUTURE

Although, as we have seen, the computer is having a noticeable impact on some courses, we are still beginning to learn how to exploit its full learning potential. We can, by examining the current situation, hope to make reasonable projections into the future.

3.1. Computers and Other Media

Those of us who maintain that the computer will revolutionize education at all levels meet occasionally with disbelief. One source of this disbelief is the history of other technological aids to learning. Often a new aid, such as video or programmed instruction, has been hailed by its proponents as a revolutionary factor that will transform our schools; but the expected great changes do not occur. This cycle has been repeated a number of times. So we must ask how the computer as an educational media differs from the others that preceded it, why its potentialities are greater than those of film, audiovisual, video, and other media.

One aspect where the computer is potentially superior to other teaching media is individualization. A film, or a video program, is a fixed sequence; often in practice it is not even possible for a student to see the film again or to repeat a sequence of a film that is not understood, and the pace cannot be altered. Similarly, a lecture or a slide-tape show can react to students in only a limited manner. A highly branching programmed text can allow different learning sequences for each student, but still is restricted. But a good computer program can make use of many types of information about the student, and can respond in great detail to student performance; each student can have a unique learning experience. Even the pace can be adjusted. No media other than a teacher for each student offers the flexibility of the computer.

This is not to say that the flexibility is always attained; existing computer dialogs are only beginning to become highly responsive to the individual student. Individualization is, I believe, an extremely important educational goal, reflecting the vast differences in student ability and performance, and the computer offers us the best hope for attaining it.

Another important educational aspect of the computer arises from the powerful idea of simulation. Because the computer can simulate real or imaginary worlds, given its calculational capabilities, it can create unique new experiences for the student. Experience is a critical component of learning. But direct experience is often limited, and, even in the laboratory, difficult to control. A computer simulation with a good student interface can in a short time greatly increase the experience available to students, and these experiences can be unique to each student. Thus, the direct experiences possible with moving objects involve only a few forces and initial conditions, and they are all restricted to x-y space. But a dialog such as MOTION can allow free play with all these aspects; in a few minutes the student can see many different types of motion, and can conduct controlled experiments with certain types. One interesting aspect of programs such as this is that they prove to be usable at a wide variety of levels. Films, too, particularly with slow motion and with microscopes, can give experiences beyond those in everyday life, but in a different area than that offered by the computer. But the film shows everyone the same phenomenon, while the computer provides the cases the student specifically requests. It should be noted that the computer needs graphic capability to provide the rich range of experiences possible; we need to see the moving objects, not a collection of numbers describing its position.

A third compelling reason why computers will eventually be the dominant mode for learning is the long-range financial picture. Most components of education are increasing in cost, but computer-based teaching is declining in cost. The difference is that computer technology is still in a period of very rapid evolution, while other media and techniques are evolving much more slowly. We are only now learning to exploit the power of large-scale integration and new memory techniques, and new technological advances are almost commonplace in this area. The cost of computing, for equivalent power, will continue to decrease dramatically. Advances in software development are not so spectacular, but even here we are improving. Currently it is difficult to estimate if computers are cost-effective in education, both because of the difficulties of calculating educational costs and because of the unique advantages of the computer already discussed. But in the future the computer will compete very well with other ways of teaching.

So far I have contrasted the computer with other media. But I also believe that computer techniques, to be discussed later, will make other media more versatile, more adaptable to the individual user. These techniques can, during the next ten years, provide a convenient way, for example, to view video sequences, allowing the user to repeat sequences or call on expanded sequences as needed. Each media does have advantages for certain types of learning, and we can expect maximum effect in teaching systems that combine all of them, using each in ways appropriate to it.

3.2. The Future of Computers in Education – Literature

What are the most interesting future directions? If we are convinced, as I am, that computers will play an increasingly important role in learning, both because of their effectiveness and because of their increasing economic competitiveness, then we need to think carefully about the future. Too often we follow the lead of technology, going where technology takes us, rather than asking what are the trends of technology and then molding them to produce the most desirable and effective future. Although a few individuals have attempted long-range plans, not enough such thinking has been done with regard to computers in education.

One interesting view, at the public school level primarily, is that in George Leonard's book, *Education and Ecstasy*. Two chapters of this book reflect the school of the future. The environment is very freely structured, with the students each progressing at their own rate in a super-P.S.I. or self-paced fashion, but with the computer responsible for all the management and much of the delivery. Visual displays--three-dimensional, large, in color--are critical as is the extensive information base about each student contained in the computer.

We can find very few other pictures that try to look twenty-five years ahead as in the Leonard book. An older and much less friendly view is in Zamiatin's *We*, a Russian novel of 1924. The "teacher," in what appears to be a standard classroom situation, is a poorly-functioning robot, teaching in a rote fashion. This teaching supports the unpleasant restrictive society pictured in the book; this and similar possibilities serve to remind us of the dangers inherent in effective teaching devices.

3.3. Network vs. Stand-alone Computers

We can see at least two conceivable immediate futures, with regard to the nature of computer hardware, to some extent mutually exclusive. At this time it seems difficult to predict which will occur, although I have my prejudices. We need to pursue both directions, because each is most favorable toward one aspect of the development of computer-based teaching materials.

The first development might be termed the continual expansion of networks, the making available of facilities beyond those in the immediate geographical location of the person involved. Networks could serve a region, or could be national in scope. One very promising direction, not pursued at present to any great extent, is that organized along discipline lines. I conceive a sizable machine used purely for teaching in a single discipline, or a group of related disciplines, with all the users sharing the resources on that machine. The great advantage would be that existing and new material could immediately be made available to a much wider audience than the campus or school at which it was developed. An even greater advantage is that we could obtain tremendous leverage in the *development* of more material in the area represented. Given many schools actively using the material on a regional discipline-oriented basis, some of these schools and some of the teachers in those schools will also become developers of material. The number of people who *can* develop material (and use what they develop) is thus greatly increased in the particular discipline; we might even see a quantum jump in the production of effective materials in that discipline. As many people would be involved, several might develop materials for a topic, so we would have open competition of materials; such competition would lead to more effective materials. Large-scale comparative testing would also be possible.

I would hope that any such development would take place on a machine that had all the power and capability possible on a modern computer. Only a few timesharing systems are presently sufficiently versatile. Limitations made for the sake of "efficiency," in a computer sense, would, I believe, not be desirable; it is *not* desirable to restrict the size of user programs or to restrict the amount of "personal" core allowed for a program, except insofar as these restrictions are required within any well-operating timesharing system. Users should have complete access to private files of their own, both within problem solving and dialog modes. All common languages should be available, so that the best language for a particular application can be used, and thus the students' background could be capitalized on, no matter what language had previously been studied. This is particularly important in an educational institution which inherits a good number of its students from other colleges, and so must adapt to varying backgrounds.

As is clear from other comments in this paper, I would want the vast majority of the terminals available on each campus to this discipline-oriented machine to be graphic terminals, although the actual ratio might differ from discipline to discipline.

A group of related disciplines might be the first users. Whether the machine would eventually become specialized to a single discipline would, I believe, be something that would be determined by usage rather than by planning. Careful records would be kept, and it might be possible to specialize machines in disciplines after some real experience was obtained in multicampus environments with very large numbers of students in routine standard courses. I do not believe that the current experience in any system is large enough to make such decisions.

Perhaps groups of discipline-oriented machines could form an important component of an educational technology center such as the ones described in the Carnegie Commission Report, The Fourth Revolution - Instructional Technology in Higher Education. While I can see no very visible move to create the centers of the Carnegie report, that still seems a sensible approach, particularly with regard to the mechanism for developing sizable amounts of material.

This is, however, only one possible model of the future, a model particularly appealing in connection with the development of teaching material using the computer. However, from a hardware point of view an even more attractive approach will soon be practical. This might be described as the stand-alone system, a device which contains not only the usual input-output and display capabilities, but almost all the processing capability necessary for applications on that machine. This direction is, I believe, the natural tendency of the evolution of microcomputer technology.

The advantages of such a machine are many. Perhaps the two most striking attributes of the stand-alone system are first the greater reliability--when one machine goes down only the person on that machine is affected, not the hundreds or thousands that might be simultaneously using a large timesharing system--and second the greatly increased graphic capability possible when not restricted to standard transmission rates such as 2400 baud. Even a system with modest computational capability, perhaps modularized to allow different amounts in different systems, can display much more dynamic and interactive graphics than even a very large and powerful timesharing system can for large numbers of students.

I should make it clear that I do not have in mind a system built around any existing minicomputers or microcomputers. I regard these devices as providing far too little computing power for the elaborate teaching dialogs I am envisioning in this discussion. But I believe that the microcomputer technology is at the point where we could develop in the next several years very powerful stand-alone systems. Such a system might attach occasionally to a large timesharing system, or to other computers, for special purposes. Thus, access to very large databases, or to record keeping programs, or to course management facilities, might require access to a bigger machine. But mostly the machine would be on its own.

A particularly intriguing possibility in connection with stand-alone machines, not widely known to those in the computer field, is the use of technology now being developed for the home-based videodisc systems. These systems, being developed by a number of major manufacturers around the world, are primarily aimed at the home market. The idea is that the home users buy a device which attaches to their TV sets. The "records" are possibly like an ordinary pressed vinyl (music) record. You take it home, and then "play" it through the television set. Times on the order of an hour of video on a record are feasible. Systems are now being demonstrated, and will soon be on the market. Among the companies involved are MCA, Phillips, IO/Metrics, RCA, Zenith, and Thompson CSF. Most systems use light to "read" the grooves.

While these systems are being developed primarily for home TV, reflection about the informational content in an hour's worth of TV (about 10^{10} bits) will immediately lead to interest on the part of the computer enthusiast. Furthermore, it is possible to randomly access material rapidly on these discs. Thus, we can envision a disc as containing a combination of video sequences, audio sequences, slides, (one groove around the disc), and computer code. A single disc might have on it a full language processor, such as APL or BASIC, and a complete video-based CAI course for learning the language; or a videodisc might contain elaborate sequences of teaching material, a dialog between the student and the computer, which would allow all the media to be used along with the other aspects of the interactive dialog.

Because of the large amount of quickly accessible storage available on the disc for read-only computer code, new system organizations might be possible, allowing the machine to survive with less core than necessary in a typical present-day minisystem. These discs also have the tremendous advantage of being a salable product, giving a way of paying royalties to authors, financing advertising, and the other features present in most educational media distribution, but which do not exist in current computer systems.

I doubt if the stand-alone videodisc system would be a suitable system for developing materials, nor for testing them with students initially, so it seems likely that this work would still often proceed on timesharing systems, with perhaps just the media portions coming from the stand-alone devices. Furthermore, it may be necessary to have some writeable storage other than high speed memory, so cassettes or floppy discs or similar devices may be an essential component.

Probably the display on the stand-alone device will allow color, and because of the need for video sequences from the disc, will at least be compatible with a television format. Full animation will be practical, far beyond the simple drawing possible in current low-cost timesharing graphics.

Such systems are not entirely pipedreams. Some features of the system described here, including the elegant graphic capabilities, are already available in existing laboratory machines.