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ABSTRACT

Computers in non-school settings, educational computer games, and education without schools are the primary topics covered in this three-section paper. The first section describes the use of personal computers in two different, non-school environments: the home and computer clubs. A "diary study" by Yaakov Kareev is summarized, in which the interactions of two young boys with a home computer were observed over a 7-month period. The second study discussed investigated how computers could be used for learning through the establishment of two clubs for 10-year olds. The second major section describes different kinds of learning activities that could be easily implemented on present-day microcomputers. Incorporating ideas from existing games, adventures, and simulations, the specific games and activities that are suggested include simulated worlds, educational adventure games, geographical and chemical adventures, adventures in programming land, an evolution mystery, and multi-function computer activities. The final section discusses implications of the introduction of personal computer technology for education and examines the trend toward a decentralization of education and a possible shift from formal institutions such as schools to home and peer play situations. (LMM)

Computers in Non-School Settings: Implications for Education

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The development and spread of inexpensive microcomputers is posing major challenges for the current educational system, challenges based to a large extent on grassroots developments. While the potential for intensive use of computers has existed for a long time, the high price of computers and the continuing expense of maintaining communication with a remote central facility proved prohibitive in many cases, and almost always required some benefactor to support the project.

Recent advances of microelectronics have drastically reduced the price of computing power and thus reduced the dependence on outside funding. Many parents have taken the initiative themselves to buy personal computers for their homes. There are currently more than 1.25 million personal computers, with estimates of 600,000 to be sold in 1980 (Flanigan, 1980). In addition, there are an increasing number of educational programs, marketed directly to owners of these computers. This development is occurring outside the scope of educational institutions, but the impact of a substantial number of students working with computers in the home will soon have to be accommodated by schools.

The predictions about the impending impact of computers on education are also based on the simple observation that it is easy to design highly motivating computer activities with clearly identifiable educational components. The flexibility of computers can assure a wide choice of activities to satisfy many tastes and ability levels. The activities themselves and their contents can be designed to achieve a wide range of educational objectives.

What we see, then, is the spread of a technology which offers a range of highly motivating activities for a decreasing cost. In this paper I will start by describing some observations we have made of the use of computers in non-school setting, in homes and in informal club settings. I will then describe a range of ways that entertaining computer activities can also serve important educational purposes. Finally, I shall sketch out the challenge that microcomputers raise for our current educational system.

Computers in Non-School Settings

Computers in Homes

In an attempt to gain some insight into the issue of how computers are and can be used for education in homes, Yaakov Kareev, while spending a sabbatical year in our laboratory, conducted a "diary study" of the use of a personal computer in his home. The study involved his two boys (aged 7;6 and 6 at the beginning of the study) and the results reported span a period of seven months. With a computer at home, computing suddenly becomes a free rather than scarce resource. That fact often changes the style of interaction with the computer, as illustrated by one episode involving the two boys.

They had been using a sketching program to create drawings on the computer screen, which they then saved for later viewing and modification. One day, they had a drawing displayed on the screen, an assortment of dots scattered about. They huddled in front of the computer and carefully moved the cursor (a dot that can be moved to indicate the current position for drawing) from one dot to another. The boys then ran from the living room into their playroom, where they played for a while. Then they ran back to the computer, carefully moving the cursor over next to yet another dot, and again ran to their playroom. This sequence was repeated several times. Finally, when asked what in the world they were doing, they patiently explained that they were playing "Startrek". With the computer as "control room panel", they were "warping" from one star to another, then "beaming down" to the planet to explore (in their playroom).

This "Startrek control panel" example is a good illustration of how computers can be integrated into a larger environment by childen. It is a use that we, the authors, would not be likely to invent, as we have been conditioned to think of access to a computer as a scarce resource. With the computer available on a continuous basis, the boys treated it much in the same way they would treat any other object used for play.

There was a progression of usage in this home, that we believe characterizes a reasonable prediction about usage in other homes as well. Initially there was a large degree of enthusiasm about a variety of computer games available on the computer. Playing was typically intense, but the boys would spend relatively short periods of times with any single game as they were eager to sample others. That pattern changed after a number of days, with longer periods of play devoted to a single game and with much emphasis placed on setting personal records in games where scores were provided. Game playing remained popular throughout the period, but different games were popular at different times. Sometimes the boys would return to games they had not played in months. These cyclical patterns of game playing are very similar to what one observes with non-computer games, and serve as another indication that children treat the computer as another toy.

The computer neither completely displaced all other play nor did interest disappear as the novelty wore thin. Instead, the boys continued to use it across the seven months of this study, while their patterns of usage shifted. After the initial game usage phase, they also became interested in graphics and music programs. A high point of this usage pattern came several months into the project, when they helped produce a picture and a song appropriate for the Hannukkah holiday. At about this time, each child received his own "floppy disk" to store his pictures on, and a little later they were also allowed for the first time to start the computer and change disks on their own. With that permitted, they became much less dependent on adults in their use of the computer, and could use it even without adults around.

At this point, they were introduced to a text editor program, which they could use to enter and modify text easily. They enjoyed using this screen editor (the UCSD Pascal Editor) for laboriously entering stories they made up, but mostly for entering "crazy stories" -- text entered by hitting keys randomly on the keyboard. Editing commands to delete, change, and insert text were very popular with the children.

While there was a strong temptation to try and teach the children some programming, we made a conscious decision not to force the issue. They were told that the different activities they were engaged in involved the use of computer programs, and were presented with programs via the use of the 'LIST' command in BASIC. They were then shown how programs could be modified -- initially to change the values of some parameters they did not like in some of the game programs. For example, in a game called Space War, they asked for an increase in the amount of energy allocated by the original program, so they could play longer. In a game involving the operation of a lemonade stand they asked for a different mix of rainy, sunny, and hot and dry days than that originally available. Only after becoming experts at operating the computer and familiar with low level notions of programming did the children start writing simple programs, for example, ones that filled the screen by printing out strings of characters over and over again.

The computer had an important side benefit: it served as an important aid for language learning. In the beginning, the need to read computer messages and program names, and to type in answers to play games served as a strong motivation for coming to grips with English (a second language for the boys). Later, the text editor and story programs helped them refine their language skills.

Finally, after almost seven months of playing computer games, creating computer graphics and music, editing text, and modifying and writing programs, they discovered one more use for the computer. They were trying to figure out how much money they had earned from baby sitting so that they could plan for an upcoming toy shopping expedition. They were surprised when told that they could use the computer to calculate that amount. They entered the numbers and operations within the BASIC 'PRINT' statement ("PRINT 6.25 + 2.37 - 1.31"), and were pleased to see the computer print out the answer. When told the computer was similar to a calculator, one of the boys said "No, it's much better than a calculator, since here you may correct your errors".

What we see, then, is that with the computer at home the children engaged in a large number of educationally relevant activities. Not only did they learn how to operate a new system, but they also improved their performance in numerous games, and improved their language skills. Probably most important of all, they became aware of the wide range of uses of computers. Finally, it should be noted that the computer did not become an all encompassing preoccupation with the boys. Interactions with it stabilized at an average of about one hour a day. That time seemed to come mostly at the expense of television viewing time.

Computers in Clubs

Informal adult led clubs and other voluntary groups are settings where the use of computers is becoming increasingly widespread. One aspect of both clubs and homes that differentiate them from schools is the more flexible interactions allowed. Another difference is that computer activities in clubs and homes must compete with a wide range of alternative activities. Unless the computer activities are sufficiently entertaining children will not engage in them. Entertainment value has long been recognized as an important ingredient for learning environments. However, in school settings it often plays only a secondary role (often accepted only as a necessary evil). In contrast, in less formal environments, entertainment provides the initial motivation necessary for the success of any educational undertaking.

In an attempt to find out how computers could be used for learning and problem solving, we set up two computer clubs for ten year olds, who voluntarily attended over the course of four months. During each club meeting children were free to engage in any of the computer activities available. A more detailed account of the club activities appears in Levin and Kareev (1980).

There was a large amount of cooperative interaction among the children in the clubs. Even though most of the computer activities available in the clubs had been originally designed with one user in mind, they were most often used by groups of children. This was true even though the computers were an abundant resource during club sessions (in fact it was not uncommon to see a deserted computer in one end of the room, with several children gathered around another). By working together children were able to divide up the work among themselves thereby dealing with the complexities of new situations in an efficient way. For example, in a game called Harpoon, which required the players to enter two pieces of information, one group smoothly divided up the task so that one child took responsibility for determining one aspect while two others determined the other.

We observed a recurring progression in the way children engaged in computer activities during the clubs. First, when a new computer activity was introduced, a large group of children (four or five) would gather around as an adult demonstrated it. Then one child would claim a turn and sit at the keyboard. This child would often serve as a typist, entering the suggestions of other children and the adult. Next, children would begin to interact with the computer without adult participation, except when they sought help. As the children acquired expertise and the novelty of the activity wore off, the group would grow smaller, often with just pairs of children working together. An expert child might then begin to work alone, increasing the difficulty level of the task when possible. This progression from low-level performance to expertise recurred almost every time we introduced a new computer activity to the club. Once a child became an expert at a particular activity, other children would turn to him or her for help rather than call an adult. Since there was a relatively large number of activities, expertise was widely distributed among children.

Computer games were the most popular kind of activity in the club. However, most of the games required the practice of skills likely to be useful outside the microworlds of the games. For example, in the Harpoon game, the children tried to "throw a harpoon at a shark" on the screen. To do so, they had to specify its X and Y coordinates. The harpoon flew to the spot specified, either hitting the shark or splashing into the water. This highly entertaining game provides practice at estimating the number corresponding to a position on a number line, a basic skill for mathematics. The ability to embed basic skills and knowledge in entertaining computer activities allows education to move into less formally structured environments. It also raises the possibility that education in formal environments may be made more motivating without sacrificing its other goals.

We have described the use of personal computers in two different non-school environments: in a home, and in a computer club. The environments shared common features. First, the computers provided much initial support. Many of the activities were computer games in which the setting and rules were determined by the computer programs, with the participants being explicitly informed about the range of activities available to them. More creative activities such as story making or sketching were also selected with special attention to the availability of clear and easy-to-follow instructions concerning the range of possible actions.

Secondly, children were free to choose any of the available activities. At any point in time they could invoke any program and switch between them. Within any activity they were free to determine any aspects dependent on the user.

These two settings differed in one important way from school settings. In schools, educational content of a lesson is of primary concern, and the entertaininment aspect is secondary. That is, it is nice when a lesson is entertaining, but it isn't necessary. This is <u>not</u> true in less structured settings. The entertainment property becomes <u>necessary</u> for children to choose to engage in the activity, however educational. This new requirement for educational activities forces us to explicitly consider ways to embed instructional activity in entertaining programs. Next we will explore some ways that this can be done.

Educational Computer Games

In this section we describe different kinds of activities which are available or can be easily implemented on present-day microcomputers. Many people are unaware of the wide range of activities possible on the computer, and of the educational goals which may be achieved by using them. Variety in computer activities is necessary not only to achieve different goals, but also to accommodate individual preferences for such activities. In a recent survey of the popularity of computer games Malone (1980) found that even the most popular one was regarded as such by only 17% of the children. Furthermore, even when they have clear preferences for certain activities, people using computers prefer to engage in a variety of them.

Simulated worlds

An important educational use for computers is to allow students to explore a domain of knowledge through interaction with a computer simulation of that domain. For example, there are air flight simulation programs for personal computers that present on the computer screen both the view out the airplane cockpit window and the instruments on the control panel. Within this simulated "world" a person can take off, fly around, land, even crash. Similarly, there are simulated worlds for learning about ecology, physics, psychology, chemistry. Student can safely conduct dangerous physics experiments; students can move around through complex organic molecules, viewing them from different angles; students can examine the policy implications of different government actions by experiencing their effects on simulated populations.

The exploration of simulated worlds can be valuable for learning, but often learners need additional organizing structure to maintain and focus motivation. A game format can provide this structure, and many computer simulations serve as the basis for computer games.

Many parents and teachers decry the current popularity of computer games on the grounds that children spend so much time refining skills and acquiring detailed knowledge that can only be used in some fantasy world. However, it may be possible to capitalize on the immense popularity and power of these game situations for educational purposes, by building the games around accurate simulations of knowledge domains that the children will find useful outside the scope of the particular games.

Educational adventure games

Children who play existing adventure games learn in great detail the geography of the fantasy world (what cave rooms are connected to which), the various dangers and ways to combat them, the location and value of treasures and other objects found in the fantasy world. These game worlds are very flexible, though. In Dungeons and Dragons, for example, one of the players serves as the "Dungeonmaster", and is assigned with the task of creating and maintaining the particular world within which a game is played. Educational adventure games can be built and played within simulated worlds that reflect knowledge we want the players to acquire.

Geographical adventures. One of the advantages of historical novels or adventure narratives is the knowledge that the reader acquires as a side effect of reading the book for entertainment. We learn about India or Afganistan by reading Kipling. Similarly, the computer adventure games could be set in some part of the world, so that the geographical knowledge acquired while playing would carry over beyond the game. Children learn about caves, dragons, and arbitrary treasures in the current adventure games. A Spy Adventure game could be set in Europe, with children learning about countries and cities, historical figures, and political events instead. Some children could act as GameMasters, by setting up the dangers and resources in the game world, and would have to do their "research" on the geography and history of Europe to create a realistic game.

Another possible set of games would involve an Election Adventure, in which the players take the roles of candidates and their campaign staffs, and try to win an election. The game can be customized to the country, state, or district of the children, directing their attention to the geography and important political issues of their own area. Each player would have to select positions on issues and plan the campaign such that the candidate gets to speak before the appropriate groups to gain their votes. Given limited time before the election, the campaign staffs would have to pay close attention to the geography of the area, so that they can plan a campaign tour that minimizes travel time. In this mini-world children would acquire both geographical and social science knowledge, as well as important planning and problem solving skills.

So far, we have given some examples of how computer games can be used to teach geographical, historical, and social science knowledge and skills, as a by-product of their use for entertainment. What about more abstract knowledge and skills, such as those required in chemistry, biology, or even computer programming? Could we imagine an "adventure" game involving the periodic table of elements or the evolutionary tree? Well, let us try.

Chemical Adventure. Many people are intrigued but puzzled by the periodic table of elements. They have seen the imposing chart hanging from the blackboard of a chemistry classroom, but it remains a strange little known world. Recall that the table is arranged in such a way that similarities in properties are reflected by the proximity of the elements in it. The dimensions underlying the organization of the table are so well specified that once the table was proposed it was possible to describe the properties of "missing" (i.e., then unknown) elements.

Suppose that in a game world, we personify elements as people having characteristics analogous to their namesake elements. So we would have the muscle men Chromium, Manganese, and Iron, the attractive Chlorine, Fluorine, and Iodine, the casanovas Lithium, Sodium, and Potassium, the super rich Platinum, Gold, Silver, and Copper. A goal in this game might be to rescue Silver, who is being held hostage by the seductive Chlorine (the compound silver chloride, used on photographic paper). To carry out this mission, the player has to obtain a magic lantern that will distract the beautiful but dangerous Chlorine (bleached blond hair, long flowing green gown). Then the player could use a magic powder (free electrons) to sprinkle over Silver to reduce his attraction to Chlorine, so that he can be set free. (It could make a great film.)

Along the way the player would have to avoid the dangerous Arsenic and Plutonium, distracting Arsenic with Gallium, or using Lead as a shield from Plutonium's rays. The players could try to gather together a number of members of the Carbon family and the Hydrogen family (a light headed bunch) to form The Sugar Company, held together by bonds of friendship. This group might function for a while, only to break up when things got hot. The players ask for advice or a sign of approval from the aloof nobles Neon, Argon, or Xenon. They could use the "family resemblances" embedded in the periodic table to predict the behavior of a newly met elemental character, or to guide them in their search for a character needed to solve a problem posed within their Chemical Adventure.

This sketch of a Chemical Adventure points to the ways that a computer game program could draw upon the same aspects that make current adventures entertaining, yet teach an abstract knowledge domain. This game is a "quest" adventure -- a coordinated electorial campaign or war game or detective story could just as well be designed within this world as alternate ways to teach the properties of chemical elements and the periodic law.

Adventures in Programming Land. Another domain that is often considered complex and obscure is that of computer programming. Part of this obscurity is due to the approach taken in introductory programming courses. The student is introduced to the lowest level commands of a computer language and given the most trivial problems to exercise his/her skills. Can we instead create a simulated world within which this low level knowledge can be acquired in the service of more interesting high level goals?

Let us try to construct an "adventure" world containing characters, objects, actions, and problem that are isomorphic to those encountered in programming. Since I am now typing this text into the UCSD Pascal Editor, I will try to sketch out an Adventure in Pascal Land. Let us take a little girl, named Ada, who falls through the input porthole of her Apple computer. She encounters a magical land, full of different kinds of people. There are the various "characters", who work together in "string" groups. There are the adult numbers, the "reals", and their children, the simplier "integers". There are the talking signposts, the pointers, and the bossy crosswalk signs, the booleans ("Walk! Don't Walk!"). Ada has to learn from these people and give them instructions to organize a search for the magic password that will allow her to exit the output port of Pascal Land.

The search will focus on the huge Dungeon of Pascal Land, containing thousands of cells arranged in a vast three dimensional array. Ada cannot fit through the gate leading into the Dungeon, so she sends her friend DeCart, along with some Integer children to help him keep track of where he has already looked. She learns the dimensions of the array, and so can give explicit instructions of how far to go down each hallway, looking into each cell for the magic key, before turning to explore another hallway. If she makes a mistake, the search team will go too far and fall into the endless pits beyond each hallway.

Ada has to give her commands in the language of the land, called Pascal. If she gives the wrong commands, then either the inhabitants fail to comprehend her (because of syntax errors), or worse, misunderstand her and go off to do something different from what she wanted (logical errors). She has to work to overcome these failures to communicate in order to get everybody working together.

Evolutionary Mystery. Let us try out a different genre as a way to structure educational activities in a simulated world. Detective stories are a popular form of entertainment. Suppose we embed a "who-done-it" in a world where the suspects are the different members of the animal world. The player is the detective, and gathers clues about the criminal. The information might be provided at the scene of the crime, or gathered through interviews with the suspect animals. Clues may involve the size of the animal, its color, type of skin, footprint, food consumed, kind of terrain where the crime took place, time of the day when it occurred, etc. The player will have to narrow down the list of suspects given all that information, or even gather these kind of data him/herself. The suspects may be initially chosen to represent widely different animals, but as the player gains experience they can be picked from among increasingly similar groups. The player would quickly learn common and distinguishing characteristics of different animals. With appropriate directions players could also learn the hierarchical nature of the biological classification system and the different categories in it.

Multi-function Computer Activities. It is possible to design computer activities that are entertaining, yet at the same time teach the players skills and knowledge in many different knowledge domains. As an example, we created a computer program called HiSeas, in which players sail a ship across the ocean, trying to reach a destination port. At the top level, this game exercises spatial reasoning, as the players have to keep track of direction and distance to avoid getting lost. Along the way players encounter dangers (shark attacks, rogue waves, typhoons) and have to exercise problem solving skills to overcome them. Within the shark attack episode, for example, a player has to apply numerical estimation skills, determining where to throw a harpoon to hit the shark. Finally, the whole sequence of the player's "adventure" is stored by the computer. Players later can rerun their stories, and some practice their writing skills by modifying their story.

Starting with this HiSeas game, it was easy to create different educational/entertainment worlds as variants to it. We simplified the language and the simulated world (with the help of Peg Griffin) but retained the same task to develop a version for fourth graders called LoSeas. We completely changed the world (with the help of Warren Simmons) so that the task was to get from 80th St to 112th St in New York (avoiding street gangs, 5 alarm fires, and packs of wild dogs), in a version called MeanSteets. We also sketched out a variant of the game set in space, which introduces interesting new three-dimensional spatial reasoning problems. Obviously there are other worlds within which practice of the same skills could be embedded.

There are large individual differences in preferences for games and other computer related activities (see Malone, 1980; Papert et al., 1979; Watt, 1979). Our tour through the different worlds derived from the original HiSeas game has been designed to show how it is possible to develop a family of games cast in sufficiently different environments to appeal to a wide audience. While an inner city child may find it irrelevant to navigate a boat across the ocean, s/he may be intrigued when challenged to travel to uptown Manhattan (and probably perform the task quite well). At the same time all these games provide practice with a common set of basic skills.

So far we have discussed the question of how the appeal of educationally relevant computer-based learning activities may be increased by presenting the same kind of activity within different worlds. To reach even wider audiences, and to provide variety to all, one might think of activities other than those represented by the action or adventure genres of games. Only some of the people enjoy war novels or science fiction books; many others enjoy other literary genres. We suspect that similar differences may exist in preferences for computer games, and efforts to design completely different games may pay handsome dividends.

Education without Schools

Previous impacts of new technology on education have had centralizing effects. Radio, television, earlier uses of computers have all been forces for standardization and centralization. With the development of personal computers, there has been a reversal in this influence.

At a recent conference in San Diego, a classroom teacher reported on the uses of a computer in his elementary school class. He mentioned the use of drill and practice, games, and programming. Then he mentioned how the class had used the computer to print up mailing labels for a newsletter to parents, which previously an outside firm had been paid to do. Finally, he described how he started keeping his student's records on the class computer. At this point, he gave a wry smile, and said "... and this may be seditious, but we discovered that we didn't need the district's central computer any more." This teacher uncovered almost accidentally the decentralizing effect of personal computers on education.

We return to the grassroots where we started at the beginning of this paper. Personal computers return the initiative for action to the people directly involved in learning: students, teachers, peers and parents. To students, personal computers offer a chance to take an active role in learning. To teachers, personal computers provide an avenue for trying new ideas for teaching in an educational world that is increasingly hostile to new ideas. For parents, personal computers provide education as a side effect of other functions, such as entertainment, information access, and word processing. In the short run, the impact of personal computers may return some measure of power to the front line troops.

What of the long run, however? Another aspect of the general decentralization is the shift of education from formal institutions such as schools to informal environments such as home and peer play situations. There are some signs of movement in this direction, but how far can it go? Let us examine this more closely, first through a bit of historical perspective, then through some futuristic fantasy, and finally through an analysis of of the functions that schools serve.

Schools form a central part of our Western culture. Yet through most of man's history, people were NOT educated in schools. Even today, much of mankind is unschooled. And an examination of the knowledge and skills of even the most schooled among us shows that much of what we know has been acquired outside the formal setting of schooling. How do people become competent adults without schooling?

In many cultures, education takes place in two different settings, one in which general knowledge is acquired and one in which expert knowledge is learned. Children in many village, farm, and nomad societies learn general knowledge and skills through an informal play interaction with peers, loosely supervised by adults and closely supervised by local experts, the older children. In this way, children acquire knowledge and skills every member of their group needs to function as an adult.

Yet even in village, farm, or nomad groups, there are specialized skills that only a few members of the group need to take the effort to learn. The arts of blacksmithing, childbirthing, or rain making are valued by the group, but not necessary for every member to know. These skills are acquired in a more structured apprenticeship setting, with a learner working with an expert as a helper, gradually acquiring expertise while at the same time making a contribution to the work of the expert.

Why was such a widely used system replaced in our society by schools? Over the years, as civilization became more complex, the knowledge and skills required increased, both for specialized disciplines and those needed in general. Apprenticeships became more and more expensive; play interaction ineffective to convey the more complex knowledge and skills. Very few parents could afford to hire Aristotle to tutor their children. Schools were established, as more efficient ways to educate competent members of a more complex society.

Now as our technological society becomes even more complex, we might imagine that there would be a need for even more schooling. However, let us present a scenerio of how people might become educated in a high technology society without schools. Let us imagine a time where personal computers are as widely spread in homes as televisions are today. (This might occur not for educational purposes, but for business, recreational, information access, or other reasons. Consider the case of electronic calculators, which have come into common use in the US outside of schools, but are not yet commonly used in classrooms.)

With personal computers a commonplace in homes, parents will buy programs that claim to be educational. (Already parents who own personal computers are buying "educational software" to be used by their children.) Such programs have to be entertaining as well, else they will never be used, as parents will find it difficult to enforce the use of boring programs. So children will engage in activities that are both entertaining and educational, playing with their peers. The computer programs will provide the support and direction, while leaving a considerable range of action in the hands of the learners.

Initially, personal computers were used purely in isolation. However, recently, ways of tying personal computers together (using the telephone system, for example) have been developed. In this way, a simple personal computer can access a data base on some other computer (the AP news wire, the Dow Jones Stock report, etc.). These networks of personal computers open up a whole range of possibilities, including some with interesting implications for education.

One possibility, already demonstrated on the Plato CAI system, is interactive educational games, with spatially separated participants. When using a Plato game program, you might well find yourself playing with a person in California, another in Illinois, and a third in Georgia. Peer interaction may take on a whole new meaning, as players who are separated by thousands of miles interact. But more importantly, learners can tap into a vast network of expertise when they run into problems. Such networks will allow access to experts in many different areas who also have personal computers tied into such a system, perhaps through an electronic mail system. The networks will also contain computer data bases on various topics, that can be drawn upon for expertise. Such "mixed-intelligence networks" (Levin, 1980) can provide for broader educational support than an isolated personal computer/learner unit.

So, for acquiring the basic knowledge and skills needed to function as an adult, children could participate in "play" involving their personal computers in their homes or at neighborhood centers, interacting with friends locally and "electronic penpals" remotely. Support and direction for learning can be embedded in the programs that are provided for the use of the children. Like basic education in non-school settings, much of the guidance can be provided by peers, especially those that have acquired expertise in the particular domain in which a child is having problems.

But how can a person acquire expertise in a rich and complex area of knowledge, like medicine, business, science, or art? Aren't schools required to provide sufficient structure for acquiring these skills? First, let us note that at the most advanced levels of each of the domains, students learn outside of classrooms, in various kinds of apprenticeship settings. The last years of medical school and internship, on-the-job training, the thesis work of advanced graduate school, and advanced studio training are all apprenticeship settings. Training in an apprenticeship is generally seen as superior to regular schooling, but too expensive to extend to lower levels of training.

The question to consider, then, is whether the impact of personal computers will be to extend this apprenticship mode to encompass a wider range of advanced education. There are two separate factors that might bring this about. The first is the development of "expert" computer aided instruction systems. Tutorial systems like those developed by Brown and Burton (1975) and Collins (1976) are the forerunners of more sophisticated programs that not only have expert knowledge in a specific knowledge domain, but are also skilled at providing the appropriate support for learners. So we can expect to see an expansion of "computer conducted apprenticeships".

Secondly, as computers become more widespread in our society, the possibility for "teleapprenticeships" arises. One of the reasons that apprenticeship is expensive is the disruption that apprentices cause to the everyday function of highly paid experts. An apprentice cannot easily participate in high pressure meetings or phone calls without disrupting the ongoing interaction. However, as more and more of business, research, and other professional communication shifts to electronic mail, it becomes easier for an apprentice to "look over the shoulder" of an expert who is using non-real time telecommunication. It also becomes easier for the expert to farm out low level projects to the apprentice, and to receive the results for use.

So, in one possible future for education, much of advanced training will be once again conducted in various kinds of apprenticeship settings. Students will acquire a skill both through interactions with expert tutoring programs and through the exercise of these skills as a tele-apprentice to an expert using interactive telecommunications in the normal course of work.

There are two aspects to the long term challenge to schools, then. The first is that much of the general education every competent member of society needs may shift to less formal "peer play" settings, in the home and in the local community. The second is that much of advanced specialized education may shift back to apprentice type settings, back to the environments within which the skills will be applied.

There have been previous calls for the "deschooling" of society (Illich, 1970), based on ideological grounds. In some senses, the claim here is more revolutionary, since it is based on a description of ongoing developments, rather than a normative argument for some ideal state. At the very least, this possible development needs to be discussed seriously, both by those taking the challenge as a threat and those taking it up as an opportunity. Any development this major would have unexpected side effects, surprising us both with unanticipated benefits and with unforeseen problems. Only by carefully considering the impact can we hope to take intelligent actions to shape our futures.

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