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ABSTRACT

Computers have undoubtedly entered the educational arena, mainly in the areas of computer-assisted instruction (CAI) and artificial intelligence, but whether educators should embrace computers and exactly how they should use them are matters of great debate. The use of computers in support of educational administration is widely accepted. Computers and computing can be an object of study--the field of computer science. Another use is making computers a vehicle for learning, and this is usually referred to as computer-assisted instruction. The last use of computers has suffered from stagnation and disappointment despite the early high expectations. The field of CAI is in dire need of revitalization and several new directions for human uses of computers in teaching are gaming and simulation, artificial intelligence in CAI and "ad-lib" CAI. The emerging areas should give control of the learning situation back to the student. (WH)

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INTRODUCTION

Computers play such a central role in our everyday lives that the question might arise: "Have we, like Pygmalion, fallen in love with our own creation?" Is it conceivable that 20th Century man's ideal artifact is this neuter machine? Sculpted in pristine and shining metal, composed of countless arrays of minute electronic circuits, the computer today reaches out its terminals to the very heart of the human lifeline. Computing machines are ubiquitous in crucial areas such as transportation, communications, national defense, food and materials production, scientific research and education. Few who use the computer decry its advent; many actually depend on its presence; and some even glorify its existence.

The issues surrounding computer usage in education, however, are particularly controversial. Although still in a formative stage, computer-assisted instruction (CAI) has already incurred conflicting interpretations. From one point of view, CAI evokes the image of a 'perfect teacher' -- one with instant access to information, with infinite patience and exceeding accuracy, systematically ensuring maximum learning for all students. "No human teacher ever born, no method or media yet tried, can match the computer's capabilities", the computer-worshippers would argue. But, from a radically different point of view, the gifts of this young technology are scorned. The computer is seen as an agent of destruction, threatening our most cherished human qualities. Cries of "impersonalization", "programmed brainwashing", and "disguised racist oppression" project the Orwellian spectre of mass behavioral control in computerized education: students trained to be academic copies of a master-mind blueprint. "No computer can ever match the spontaneity, the versatility, and the emotional caring of a human teacher", the computer-haters argue. Still others distrust the entire 'schooled-up' educational system and have litte respect for the current quality of teaching -- whether by humans or by computers.

The controversy becomes more heated with the mention of artificial intelligence, particularly mechanical mentors. What fate will befall education when machines become capable of sensitive and intelligent interaction with human beings? Rosenthal's studies[1] of self-fulfilling prophecy might suggest that children of tomorrow will mold to a new orthodoxy - one of expected precision, pre-packaged behavioral objectives and programmed responses. Will students neglect humanistic values and perhaps even emulate the computer? Will they imagine, as Pygmalion dreamed of affection, that they are blessed by cybernetically individualized instruction? Then, will a computer terminal seem warm to the touch?

How the modern tale of Pygmalion and his computer ends no one can easily predict. In the paragraphs to follow no reasons for panic are cited, no panaceas prescribed. Rather, presented here in two parts, is an overview of current instructional applications of computers and a description of some promising new directions for human use of computers.

[1] c.f. Pygmalion In The Classroom: Self-Fulfilling Prophecies and Teacher Expectations, Rosenthal and Jacobson; Holt, Rhinehart & Winston, 1968.

PART I: INSTRUCTIONAL APPLICATIONS OF COMPUTERS

Overview

Computer technology purports to make an unprecedented impact on education; in fact, computers are already being used in schools. Most likely, Pygmalion in the classroom of the future will have access to an electronic partner every bit as dedicated to assisting his learning as he wishes. In educational circles today, however, "to use or not to use" computers in teaching is still a controversial issue.

The question -- indeed, the profound challenge before us -- is no longer whether or not to use the computer as an educational resource, but how to use this tool -- the most powerful and versatile tool mankind has ever known.

The scope of instructional applications of computers is dramatically far reaching. Answering the question of how to use computers in the teaching-learning process has importance for us all. It affects the organization and administration of education -- the nation's largest industry; it affects the current supply of 2 1/2 million teachers and the largest population of students (over 60 million) receiving formal schooling in all of history; it affects all children yet to enter school and all adults who will make learning a lifetime activity in a world of ample leisure time.

Computer technology first made its entrance through school doors in the early 1960's due to needs for increasing bureaucratic efficiency. Along with rapidly accelerating national enrollments came the call for educational data processing. School payrolls, student records, alumni files, and more recently, scheduling procedures, budgeting and planning -- all can be accomplished more expeditiously by automated information storage and retrieval systems. Today the data processing power of computers is well demonstrated and is clearly acknowledged in public school systems as the rule rather than an exception.

In fact, many large-scale operations in education are just not feasible without computer support.

In addition to performing administrative functions, the computer has been used as a subject <u>of</u> and a vehicle <u>for</u> learning. The study of computers per se -- their design, architecture and operating systems -- is a major part of the field of computer science. Use of the computer as a vehicle for learning is hailed under a variety of acronyms[2] generically called "computer-assisted instruction" (CAI). This field is in an embryonic stage of development.

<u>CAI: A Historical Sketch</u>

The origins of CAI were probably attempts by curious technicians to see if a machine could be programmed to interact with a human. (This is not to forget the plethora of conceptualizations by science-fiction writers.) The earliest programs were simply capable of printing pre-stored questions, accepting multiple-choice answers, and judging answers for correctness. One typical program (used by IBM for demonstration) taught a short-cut technique for multiplying two-digit numbers ending in 5; another asked factual questions about American history, such as "Who was the 15th president of the United States?"

Major pioneering in CAI occurred circa 1961 when the University of Illinois produced the PLATO system (Programmed Logic for Automatic Teaching Operations.) And, with magnanimous federal funding in 1966, Stanford University's Patrick Suppes spearheaded development of computerized tutorials in arithmetic and reading for elementary school children.

Today, there are many -- perhaps hundreds of -- CAI installations in this

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[2]Some of the popular acronyms are: CAI ("computer-assisted instruction" or "computer-aided instruction" or "computer-administered instruction"), CMI ("computer-mediated instruction" or "computer-managed instruction"), CAL ("computer-aided or -assisted learning), and CSI ("computer-supported instruction".) There are distinctions between all these terms which will not be discussed here.

country and abroad. Most reside in large universities, such as the University of Texas, Pennsylvania State University, Stanford University, University of Illinois, and Florida State University. Some are part of the armed services, such as the U.S. Naval Ordinance Training Laboratory. A few are integrated within public school systems, such as Philadelphia's Instructional Systems Center. Several industrial firms, such as IBM and RCA have made cautious forays into the area of CAI (for fun and profit).

After the initial upsurge in CAI activity-- primarily from 1965-68 -- progress has slowed. Developments over the last four years have not differed significantly from earlier work, and, contrary to predictions by many pioneers, use of CAI is not widespread. In fact, despite an investment of over $1 billion in federal support monies, less than 1/2% of secondary school students use computers in any way.[3] Today, CAI remains in an embryonic stage.

CAI Systems

The technology of CAI is generally sophisticated and expensive, although significant progress has been made toward making systems user-oriented and cost-effective. For example, the University of Illinois-- housing the largest computer-based education operation in the country-- projects that their new PLATO IV system will handle over 4,000 student-users at an average cost of about 35 cents per student contact hour-- a figure comparable to the purchase price of a textbook.[4]

Basically, a "CAI system" is described in terms of its "hardware" (the actual equipment), its "software" (the instructions which run the hardware), its "communications links" (the devices which allow persons to use the hardware

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[3] The subject of why school systems are reluctant to adopt CAI is the objective of a new study by the Human Resources Research Organization, Washington D.C.

[4] "Advances in Computer-Based Education: A Progress Report on the PLATO program", D.Alpert, and D.Bitzer, July 1969, University of Illinois.

and software), and its "curriculum" (teaching materials stored in the computer).

The hardware of modern day computers includes: input-output terminals for entering and receiving information; memory banks for storing data and programs; a central processing unit for performing arithmetic and logic; and an executive control for monitoring timing and sequence of all operations. Many descriptors are required to specify a given computer's capabilities, and many factors go into decisions for purchasing or renting one.[5]

The software of a computer syst[illegible] that which makes man-machine interface possible. People called "systems programmers" are responsible for the design and operation of translators -- sets of instructions which convert the Os and ls of machine language into convenient and useful commands of a programming language and vice-versa. Many different programming languages abound today: some are general-purpose, such as FORTRAN and APL; some are special-purpose, such as COBOL for business applications and LISP for list processing; and some were specially designed for CAI, such as COURSEWRITER and MENTOR.

The use of computers in teaching was first considered feasible with the advent of "time-sharing". The concept of one machine servicing many users 'simultaneously' is well-suited for students who typically request small, interactive jobs. The communications links of a time-shared computer are dataphones, or alternatively, ordinary telephones plus an acoustic coupler. Students connect to the computer via "terminals" -- teletypewriters, cathode-ray tubes with keyboard consoles, or plasma display tablets.[6]

The curriculum of a CAI system is the collection of teaching materials

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5 Major manufacturers are: Control Data Corporation, Digital Equipment Corporation, Honeywell, and International Business Machines.

6 For a reference on the fundamental aspects and interrelationships of the components of a computer system, see "Laymen's Guide to the Use of Computers", published by THE ASSOCIATION FOR EDUCATIONAL DATA SYSTEMS, 1971, 1201 Sixteenth Street, N.W., Washington, D.C. 20036.

stored in the computer. Typically, curriculum is developed by authors or a team of programmers, teachers and curriculum specialists who use a programming language to write instructional sequences. Approximately 100 hours of conceptualization, design, implementation, debugging, testing, evaluation and revision go into producing one hour's worth of teaching via computer. Lately, the use of "macros" has facilitated curriculum development by permitting teachers who do not know how to program to enter course material in a pre-structured format.

CAI systems have been utilized (mostly experimentally) at all levels of education -- ranging from elementary school to post-graduate study to on-the-job training. Subject areas have included mathematics, foreign languages, social sciences, natural sciences, reading and spelling, operations research, engineering, medicine, and music. Typical modes of instruction are drill and practice, tutorial, simulation, and problem-solving.[7]

Misuse of Computers in Teaching

This past decade has seen unprecedented use of computers in teaching, but not without concomitant misuses. As with previous technologies developed by man, computers have been misused, abused and unused -- often serving to aggravate rather than assuage problems currently besetting American education.

Most misuses of CAI can be characterized as "forced fits"; that is, use of computers in teaching is forced upon school systems, even where and when it doesn't fit. The consequences of forcing computer usage are frequently disastrous: computer terminals placed in classrooms and laboratories for 'experimental testing' either stand unused -- because an adequate training program is not available -- or unrepaired because no one assumes responsibility for servicing the machines -- or unsupervised as users fail to make

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[7] For a description of modes of CAI, see "Computer Innovations in Education", by Andrew Molnar, 1972, National Science Foundation.

productive use of system features (witness the repeated printouts of Snoopy!).

The physical surroundings relegated for computer equipment are sure clues to another form of forced fits. Typically, the setting is cold and impersonal -- often painted stark white with narv a trace of art. It seems as if the most aesthetically unappealing area is carefully selected for the computer room (more often than not, the basement). Even in legitimate classrooms in schools and industry, the number and spacing of computer terminals evoke Orwellian images. With as many as 30 terminals placed literally side-by-side in a single room, one conjures up the worst fears of automated training (I hesitate to call it learning). Clearly, there must be an extraordinarily high premium placed on efficiency in this stifling, factory-style education!

Yet another instance of forcing computer usage to fit is found in CAI curriculum. Much of the instructional materials available on computer systems today are 'canned' textbooks -- traditional texts wholly transcribed into a tutorial programmed instruction format, with the computer serving as little more than an automatic (and expensive!) page-turner. Again, the rationale is usually couched in terms of efficiency (that quality for which computers are so admired): "Your child will learn more in less time with greater retention..." How can responsible parents and educators resist such a compelling offer? This Madison Avenue appeal is, of course, tantamount to suggesting that children sit still for as long as possible, open their cerebrums wide, and receive regular and rapid spoonfuls of what someone else has deemed best for them to know. This kind of forced-feeding is the antithesis of the thinking of such prominent educators as Dewey, Piaget, Neill, Bruner, Holt, and Goodman; and it is understandable why this prescriptive, mechanical approach to pedagogy is under criticism from all corners today.

Problems associated with misuses of computers have also spread into psychological and sociological dimensions. When a novel and prestigous technology--such as Pygmalion's computer--is made available, unforeseen problems of human interaction can result. Two particularly exacerbating student behavior problems are identified as: (1) self-aggrandizement by 'computer pros', and (2) academic implosion by 'computer bugs'.

In the first case, some students who learn how to use the computer quickly and easily become obsessed with their power, sometimes to the extent of belittling and bullying neophyte learners (including their teachers). For these computer 'pros', using the computer seems to be a mark of distinction--an outlet for expressing their worth and power (perhaps for the first time since entering school). Even elementary school children will pronounce their knowledge and expertise: "Of course I know how to work the computer!" or "That's not the way to work it! Let me do it!" This self-aggrandizement can proceed to the point that timid prospective users never get their hands on the computer terminal and are forever turned off by anything to do with computers.

The second problem arises with students who are affectionately called 'computer bugs' or, alternatively, 'computer nuts'. These students become so intrigued by computers and programming computers that they disregard almost everything else. In a virtual academic implosion, they want to know all about computers - how they work, how to run programs, what has been stored in the computer's memory - right down to the most specialized and detailed operation. The severity of the problem is manifest in neglect for other subjects, low grades in school, underdeveloped socialization, and general lack of communicativity (except with 'the machine'). "They speak a different language" is a usual comment made by outside observers. The symptoms are, in fact, remarkably similar to those of the drug-dropout syndrome.

Perhaps the most deplorable misuse of computers in teaching today is their non-use. While it is true that not all uses of computers (or any technology) will be completely laudable, it is nakedly ironic that the great mind of man which produced so great a machine so miserably fails to think of creative uses for it, especially in education. Much of this high-powered technology sits unused in the central activity of our lives: learning. Partly due to the economic crisis facing education, partly due to pervading myths and fears about computer take-over, and partly due to the sanctimonious attitude of tradition-bound educators, the full power and potential of the computer have not been tapped.

One further consequence of computer misuse and non-use has been the birth of a computer mystique. Myths are born when the computer is represented as a mysterious, unfathomable invention -- one that only a select few can comprehend.[9] Unfortunately, computer myths are often created by experienced users and computer salesmen (perhaps unknowingly) and are perpetrated by elitists to protect their own interests. Many lay persons, when encountering a computer system for the first time, are literally hesitant to touch the terminal keyboard. "I will just push the wrong button", or "I'm sure I will break something", adults often excuse themselves. (By contrast most children are more than willing to experiment and end up trying all the buttons.) Or sometimes computer awe is expressed: "Oh, those computers these days are amazing! I could never understand how they work." And now, the greatest hoax of them all is emerging: computers are assumed to be 'smarter than people'. It is becoming dangerously commonplace to attribute qualities

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9 The myriad of "computer myths" are not identified here. For a partial list of misconceptions frequently promulgated by both critics and proponents of CAI, see "Advances in Computer-Based Education", D.Alpert and D.Bitzer. University of Illinois Report X-10 July, 1969, pp. 7-9.

of intelligence to a machine without considering how it has been programmed. "The computer would just beat me anyway (in a game)" or, when the computer's response time lags, a common blurt is: "It must be thinking."

Extensions of these problems point to a most foreboding have/have-not situation. Already we live in a society fractured by tensions between those who have material goods, power, freedom, happiness, etc., and those who have not. If the misuse, abuse and non-use of computers in education is not checked, then in less than a generation, another schism will be obvious: between those who have computer expertise and those who have not. An in-group using computers to gain (or retain) control over other groups of people has patently frightening implications. This problem is not new. It has its parallel in the most destructive pathology of our time: racism.

There are no pat solutions to these problems associated with the misuse of computers in teaching. Although they arise in a setting with a technological catalyst, they are fundamentally problems of human interaction.

Problems and Potentials

That CAI holds great potential for educating Pygmalions of the future is indubitable. From a student's point of view, CAI can mean the opportunity for individualized instruction: one can learn at his own pace, receive immediate personalized feedback, and freely choose the content, sequencing and degree of difficulty of instruction. For a teacher, CAI can relieve much of the tedium and redundancies of daily routine: the computer presents drill and instruction, automatically collects and stores performance data, and tests and diagnoses areas of learning difficulty. Ideally, this frees the teacher to engage in more human and humanizing roles - such as guidance, inspiration, and motivation. A school system also stands to gain from utilizing CAI: the general level of education for large numbers of students can be raised by systematically managing the instruction available on remedial, supplemental and enrichment bases.

Out-of-classroom uses of CAI are also conceivable and attractive. Computer terminals might be located at home or in a dormitory or at a local community center. And when the use of multi-media instructional systems is considered, the possibilities seem endlessly exciting!

While prospects for widespread CAI appear exciting and hopeful, a host of problems remain extremely challenging and sometimes foreboding. Costs of sophisticated educational technology are still prohibitively high; marketed hardware is generally not tailored for educational purposes; large time-sharing systems have gained a reputation for unreliability; software support often lacks compatibility; most so-called 'CAI integrated learning systems' are designed with a myopic view of students' creative pursuits; the quality of curriculum materials developed to date is dubious at best; and teacher training programs in computer usage are few and usually perceived as threatening. Furthermore, already-overburdened teachers do not have time for new, complicated technologies; school administrators often resist innovations for the wrong reasons; parents and community persons are unfortunately uninformed and not involved; and, while many students eagerly take interest in computers and programming, their interests are subverted by a lock-step certification system. As if these problems were not debilitating enough, CAI development suffers from the absence of cooperation between the responsible factions. Professional educators, businessmen, computer scientists, governmental agencies, and teachers -- all contentedly remain on their respective sides of the communications gap. Finally, the portent of behavioral control looms large when a central computer houses all information on all citizens; the spectre of a <u>1984</u>-education is too near and too possible when all students' progress can be predetermined.

The question seems to be: can Pygmalion avoid being intellectually imprisoned by the problems inherent in this technological aid -- 'his' computer?

PART II: NEW DIRECTIONS

When Harvard's Allan Ellis said that the computer is 'an anything machine', surely he was emphasizing not only its versatility but also that it is a tool to be used at man's discretion.

Using the computer as a tool rather than as a task-master serves to complement human teaching, rather than to compete for the attention of students. Some of the more promising new directions in instructional applications of computers seek such a humanizing role for the computer. These uses foster development of the whole, fully functioning person, not just singular skills, and highlight those qualities which are uniquely human and not those likened to mechanistic devices.

At a time when the field of CAI is in dire need of revitalization, several new directions for human uses of computers in teaching are emerging:

Gaming and Simulation

Artificial Intelligence in Computer-Assisted Instruction

"Ad-lib" Computer-Assisted Instruction

Gaming and Simulation

Game-playing is generally regarded as a natural, enjoyable activity for persons of all ages. Some games, such as chess, checkers, and go, are integrally woven into cultural fabrics. Views that "all the world's a stage" and that life is a game and that man is homo ludens (the playing animal) still hold widespread credibility.

That educational games stimulate positive, participatory learning is a common tenet. In his book Serious Games, Clark Abt aptly describes the value of games designed with specific educational goals and gives evidence that in properly supervised gaming, students appear to learn more quickly and more fully, retaining what they have learned better and longer. (See also Abt's article "Playing To Learn" in this volume).

Gaming and simulation offer opportunities often not possible in real life. While conducive to full emotional and intellectual involvement, games permit players to test solutions (or "strategies") for problems (or "situations") which are in reality either too risky, too expensive, or irreversible. In a benign "simulated" environment, mistakes can be made, their probable consequences scrutinized, and errors turned to positive advantage -- all at no detriment to society. Games-makers Allen, Gamson, Goodman, and Duke readily admit that simulations over-simplify, caricature, and distort the real world systems they represent, but quickly add that a simulation is economical, observable, controllable, and reproducible -- all characteristics rewarding to the student who is willing to experiment.[11]

Despite increased popularity, gaming and simulation remain virtually untapped modes of instruction - especially in CAI. To date, CAI curriculum development has focused on tutorial-drill-and-test approaches, and little formal research or evaluation of the effectiveness of games and simulations has been conducted.[12] Execution of educational games and simulations by computer offers some appealing advantages, including:

1) rapid processing of complex mathematical models

2) accurate branching on multiple conditions

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[11]Research News, Vol. XXI, No. 9, March 1971. University of Michigan, Ann Arbor, Mich.

[12]One noteworthy exception is Richard Wing's research in the use of computerized social science games with elementary school children, Westchester Co., Board of Cooperative Educational Services. He reported several differences in learning, most notably: children using CAI games learned the content in significantly less time than children receiving normal classroom instruction in the same subject. For details, see "Advantanges of Using A Computer in Some Kinds of Educational Games", IEEE Transactions on Human Factors, Vol. 8, June 1967.

3) automatic storage of responses

4) simultaneous usage by students in different locations learning at different rates

5) opportunity for machine competition and "intelligent" interaction

In general, the prospects for simulation and gaming via computer depend on how the educational community regards the question of uncertainty in human existence. The admission of the uncertainty of life is conspicuously absent in modern schooling (when unanswerable questions are raised, they are expediently disposed). Using games in a computer-assisted instruction setting would help restore the legitimacy of dealing with uncertain situations and expose the value of confronting uncertainty in positive and realistic ways. It would encourage development of skills such as planning, organization, strategy formulation and execution -- important powers of reasoning which permeate our everyday thinking but which are not taught in school.

Artificial Intelligence in Computer-Assisted Instruction

In the minds of many people, the IQ of today's typical computer-assisted instruction program is relatively low -- low compared to, say, a human born at the same time and progressing normally since the first general-purpose digital computer was built in 1946. After all, there are many questions Pygmalion might ask of a grade school teacher that a computer program cannot sensibly answer!

In many attempts to use computer-assisted instruction, students have been alienated by the inflexibility and the impersonal nature -- the "dumbness" and "numbness" -- of the computer. A machine with higher IQ would certainly be more appealing. While "intelligence quotient" involves many complex variables and while "intelligence" is usually defined in terms of behavior man himself calls intelligent,[13] it is to the task of developing machines

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[13] One interesting thesis is that man's definition of intelligence is changing (retreating) in correspondence to advances in computer capabilities. That is, as machines become capable of performing more and more mental tasks, those tasks become excluded from those we claim require intelligence.

capable of exhibiting artificial intelligence[14] that some researchers have addressed themselves.

Computers already possess rudiments of intelligence. Some properties intrinsic to computing machines actually dwarf human abilities and, consequently offer potential assistance to human learning.[15] In terms of memory -- one dimension of human intelligence -- the capacity, speed and accuracy of information storage and retrieval of today's computers far exceed human abilities. A mammoth adjunct memory providing 'instant' access to millions of bits of information is invaluable to any serious learner. (Who would turn down the Library of Congress at his fingertips?) In terms of performing instructions -- another popular measure of intelligence -- the computer's speed, reliability and endurance are incomparable to biological organisms. The ability to execute millions of instructions per second flawlessly is obviously a powerful tool to wield. While acts of insight and intuition are still relegated exclusively to the domain of human thought, powers of reasoning and general problem-solving by computer are steadily improving.[16]

Research in the young field of artifical intelligence (AI) has already yielded some programs with potential educational applications. For example, machines have been programmed to solve word problems in algebra (Bobrow, M.I.T. dissertation 1966), to complete visual analogies of the kind that appear on IQ tests and

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14 Artificial intelligence is the generic name for a collection of specialized research topics such as robotics, machine learning, pattern recognition, automatic theorem-proving, simulation of cognitive processes, question-answering systems, and natural language translation.

15 One basic difference is acknowledged between the 'mental' strengths of man and machine: the computer's forte is symbol manipulating, whereas human talents excel in recognizing patterns. It is only by using the information processing capabilities of the computer together with clever programming, that programs can be made to simulate cognitive processes.

16 See Newell, Shaw, and Simon's article on their "General Problem Solver", reprinted in Computers and Thought, ed. Feigenbaum and Feldman McGraw-Hill, 1963. See also Newell and Simon's new book Human Problem Solving, Prentice Hall, 1972.

College Board Examinations with success equivalent to that of an average 15-year old (Evans, M.I.T. dissertation 1964), and to 'understand' and respond in nearly natural English to questions and commands about objects in a world of blocks (Winograd, M.I.T. dissertation 1971).

In general, AI offers CAI qualities which have been heretofore weak or altogether lacking: 'sensitive' and 'intelligent' interaction with a machine. Specifically, application of certain AI techniques can:

1) facilitate information storage and retrieval
2) approach natural language conversation
3) finely discern response patterns
4) autonomously adapt to changing conditions

These goals can be translated into distinct advantages for the learner: one would have greater flexibility and mobility in learning sequences; one would receive more personalized interaction and greater variety of responses; one could control the computer's level of sophistication; and one could expect the computer to 'learn' as a result of its 'experience'.[17] Generally, then, a learner could engage the machine less as a task-master and more as a resource in an educational pursuit.

Several alternative modes of AI in CAI are conceivable. While they all use sophisticated built-in mechanisms to promote learning, these modes employ the computer in different roles:

The Computer As A Benevolent Mentor

The Computer As A Competent Competitor

The Computer As A Problem-Solving Partner

The Computer As A Learner

In the role of a "benevolent mentor", the computer acts as the dispenser

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[17] Machine learning is usually defined as improved performance on a specified task.

and tester of knowledge. The learner depends on it for presenting basic content and direction but is able to influence other factors of instruction, such as sequencing, mode of interaction, and level of difficulty. For the computer to be an effective pedagog, it must be capable of 1) asking questions and processing responses, 2) receiving questions and producing answers, and 3) changing approaches according to the response patterns of the particular human tutee. In a vanguard use of AI techniques in CAI, Jaime Carbonell demonstrated the feasibility of what he called "mixed-initiative dialog"[18] between a student of geography and a computer.[19] His program (called SCHOLAR) could generate text, questions, and corresponding answers as well as answer questions formulated by the student. SCHOLAR could also change its mode of dialog without specific directions by keeping track of information from the interaction. Interaction with a machine programmed in such a way is like learning from a wise teacher who wishes you well.

In the role of a "competitor", the computer provides an active environment for formulating plans, testing strategies, and exercising both intuitive and logical thinking. The most popular environment is a game in which the learner plays against a competent computer program. The 'intelligence' of moves made by the computer game-player can be set at a certain level or may change during the course of play. In either case, the computer's strategic competence must be pre-programmed. For example, in playing the ancient intellectual game of NIM[20], a computer program may use an optimal strategy algorithm

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[18] By "mixed-initiative dialog" Carbonell means that questions and answers are possible from both sides.

[19] Jaime Carbonell, "AI in CAI: An Artificial Intelligence Approach to Computer-Assisted Instruction", IEEE Transactions on Man-Machine Systems, December, 1970.

[20] NIM is a two-person game of taking away sticks (or any items) from several piles. The rules are that some number of sticks must be removed from one (and only one) pile on each player's turn. The player to remove the last stick wins. (The winner can be predicted from the start).

which will guarantee the computer a win whenever a win is possible; alternatively, the program may use an adaptive system by which it can progressively improve its performance.[21] Of course, if it were desired, the computer could be programmed to make all wrong moves or to make its decisions entirely randomly. For complex games such as chess, with no known optimal strategies, clever heuristics[22] are necessary -- for both machine and human competitors. In general, interaction with a competent mechanical competitor provides an environment for active, enjoyable learning -- free from social embarrassments, political overtones, economic constraints, etc.

In the role of a "partner", the computer and learner jointly engage in solving a problem. Usually this requires access to previously written programs which perform special functions. (Instances of problem-solving via computer without such programs will be discussed in the next section, "Ad-lib" CAI.) A simple form of this usage is laboratory problem-solving with a computer. For example, a student wishing to use statistics to summarize data would call upon 'canned' programs which 'explain themselves' as they are used. Whether by request or due to improper usage, the program would automatically offer instructions on how it is to be used properly for data reduction. To assist in planning, organization and execution of more complex problems, methods of problem-reduction[23] may be employed. AI search techniques can assist a person by finding goals or designating the most

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[21] cf. H.D. Block, "Learning In Some Simple Non-Biological Systems", American Scientist, 1965.

[22] A heuristic is any method, rule, or trick which may be helpful in solving a problem, such as the complex decision-making involved in making a move in chess. The word 'heuristic' means "serving to discover".

[23] Problem reduction is a method of breaking a problem into its component parts and attempting to solve the resulting set of hopefully simpler problems.

plausible, the most beneficial, or the least costly sub-goals. There are many suitable problem spaces for the computer-as-partner, including: mathematics (e.g. evaluating integrals in the calculus), physical sciences (e.g. conducting experiments in chemistry), and cryptography (e.g. decoding secret messages). Ideally, the problem-solving partnership involves man-machine collaboration; that is, in a goal-oriented environment, a program might utilize the talents of each system to the fullest -- relegating those tasks for which the computer is best suited to the computer and those tasks in which the human excels to the human. The epitome of such a partnership, in one view, has been portrayed in HAL of "2001: A Space Odyssey" movie fame. Super computer HAL not only monitors all flight controls and the entire life support system of man's trip to Jupiter but also competes against the crewmen in games of chess (with accompanying psychoanalytic critique). In another futuristic view, one can imagine the ultimate intellectual ally as one who says to its human partner "Think!" as an invitation to present a problem to be solved. When the computer is given a properly expressed problem, such as a new theorem to prove, it whizzes forth a result and says "Think again!"

In the role of a "learner", the computer must be capable of receiving instruction; that is, it must be teachable. At the most fundamental level, writing a program in computer programming language is 'teaching' the computer. The student must express himself logically and unambiguously, for the computer will not accept improperly phrased commands. But, suppose a programming language --which enables a student to express how to make the computer perform is supplanted by a higher-order language -- one which enables him to express how to make the computer learn! Then a student may devise and test strategies for teaching. Choosing from a range of pedagogical approaches available, he may train the computer to 'understand' some concept, relationship, or procedure -- such as how to play a board game, how to solve a cryptogram, how to use proper grammar, etc. The computer is, of course, an ideal tutee:

it requires explicit expression; it acts only on information provided: and, if instructed properly, it will perform flawlessly. And, in teaching the computer, the student has an objective reflector of his own understandings. The student himself learns by observing the consequences of his teachings -- manifest in how well the computer learned.

Ad-Lib CAI

In today's world of exponentially increasing information, it is no longer reasonable to expect students (or anyone else) to keep up with all the 'facts and figures'. The well-publicized "information explosion" has obviated the once highly acclaimed skill of memorization. What is becoming important, however, is knowing how to get information and what information to get. If one knows appropriate procedures for sorting thru reams of data and for selecting the desired information quickly and reliably, one is usually regarded as 'informed' or 'learned'. In fact, information is the commodity in the marketplace today; and information processing -- whether by computer or by human brain -- is the marketable skill.

In light of the high premium placed on procedures for processing information, it is surprising that associated with schooling is but one procedure: rote learning. There are a myriad of ways to learn, just as there are many different information processing techniques and problem-solving methods; yet in traditional teaching the materials to be learned and the way in which they are to be learned are usually prescribed[24]. Surely different students learn to

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[24] A critic of compulsory schooling might see the student as a rat in a ten month per year laboratory experiment. There, the student is subjected to a form of operant conditioning in which the behavior being shaped is recall of information. The reinforcement schedule for student-rats is so thorough and well-established that by the end of the sophomore year in high school or thereabouts, many have been completely conditioned to learn only when and how they have been trained to learn. Without specified goals and directions, without appropriate carrots and/or whips, one does not learn.

Unfortunately, this conditioning in schooling today is perhaps so penetrating that we pass on the importance of the same to succeeding generations, oblivious of its effect on us. For an incisive treatment of this subject, see Ivan Illich's Deschooling Society, 1971.

accomplish different tasks in different ways and would profit from experience learning about different procedures for learning. Indeed, if Pygmalion's education is to include opportunities to learn how to learn, a new approach to instruction is needed.

In "ad-lib" CAI learning about learning occurs in an open environment through active exploration of procedures. All that is needed is a "bare-bones" computer system: time-sharing terminals, access to the computer, and a suitable programming language. No prestored curricular materials (as in conventional CAI and simulation-gaming) nor sophisticated software (as artificial intelligence uses) are required. At the heart of ad-lib CAI is the educational value of studying procedures. Even without a computer, students learn a great deal more when they describe what they are doing, how they decided to do what they are doing, what they plan to do next, and what they want you to do (especially if they are teaching you something like juggling). Not data, but procedures themselves are the subject of student attention. When a computer is brought into play, explicit and precise expression of procedures is required, and students impose the need for rigorous and logical thinking on themselves in order to make their programs work.

The study of computational procedures is a particularly rich area of ad-lib CAI learning. Using a programming language as a vehicle for expressing themselves, students can plan, describe, implement, test, and modify procedures all for automatic execution and immediate results. An easy-to-learn language with simple, versatile commands gives a student immediate and direct use of the computer's power to express procedures. Two programming languages with these characteristics are: APL and LOGO.

APL (A Programming Language) is a new, multi-purpose programming language. Originally conceived as a mathematical notation by Kenneth Iverson of IBM, APL provides the user with an extensive selection of tools (mathematical functions) and powerful capabilities for handling arrays of data (both literal and numerical). The tools of the language are mnemonic and designed to permit natural, concise expression of the formal bases of many mathematical and scientific topics. The fundamental ideas of a discipline can be stated clearly and comprehensibly in a program, and additional operations can be defined by the user as functions consistent with the syntax of APL. For example, in a recent paper entitled "APL and Insight: A Strategy for Teaching", Paul Berry of IBM illustrated the use of APL for exposing concepts in statistics (analysis of variance), business economics (curve-fitting), mathematics (number theory), and computer science (systems modeling).[25]

LOGO is a special list-processing language developed by Seymour Papert of MIT's Artificial Intelligence Laboratory. In Papert's applications of LOGO, children learn formal concepts through active, creative exploration of procedures. With simple, English-based commands, they express procedures to control physical devices. On the teletype, for example, children write programs to print geometric figures, to play intellectual games, to generate some 'computer poetry', and even to give CAI quizzes. Another device, an electronic "turtle" known as Irving, is controlled by LOGO commands and will draw polygons, create artistic designs, run mazes, etc., on a flat surface - thus permitting children to learn principles of computational geometry.

Generally, a programming language such as APL or LOGO serves as a conceptual framework for "ad-lib" learning. Given the tools of the language (its functions and commands) and governed by the rules of expression (its syntax), the student writes programs to accomplish particular goals. These

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[25] Other topics suitable for exposition using APL include: elementary algebra, coordinate geometry, statics, calculus, logic, sets, electric circuits, and computer simulation. See Kenneth Iverson, "APL in Exposition", IBM, 1972.

goals may be set by the student himself or his teacher or friend; and they are easily modifiable in light of new and more intriguing goals, many of which are not identifiable in advance.

The activity of programming permits the free exercise of intuition (tempered only by an objective reflector of reality: the computer's response) and fosters heuristic reasoning. The reward for the student who successfully expresses a procedure is immediately apparent: the program works! When the program does not work -- it produces an error report or an unanticipated result -- the student naturally takes responsibility -- for he wrote it -- and sets out to modify it so that it will do his bidding. In any event, the program he produces is a concrete entity, one he can deal with concretely and positively. It is not necessary, as many intellectual failures imply, to start all over again. Engaging in this process of "debugging" (the computer-world term for seeking and destroying errors) is extremely important in developing powers of heuristic reasoning. In fact, as Papert points out, the notion of a "bug" itself is a valuable heuristic idea. It is something to be hunted down, caught, and tamed or killed; and any technique or trick used to do so is fair game.[26]

"Ad-lib" CAI, then, uses the computer in teaching as less of a 'black box' and more of a 'glass box' -- an approach in which the inner mechanisms of a program are made transparent to the viewer. A program serves to expose and clarify concepts; hence, it is in itself a pedagogical agent. This student-initiated, student-responsible, success-oriented approach is in contrast to frantic hand-waving at the blackboard about some abstract concept often seen in classrooms.

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[26] Papert and Feurzeig, "Programming Language As a Conceptual Framework for Teaching Mathematics", Interface, April, 1970.

Conclusion

All of these new directions in instructional applications of computers exemplify an emerging new emphasis: control for the student. In gaming and simulation, approximately half of the interaction is determined by the student's moves, freely chosen while he develops strategic skills. In uses of AI in CAI, sophisticated programming allows the student to take control over his own learning and converse with the computer in as close to natural language as possible. In "ad-lib" CAI, the ultimate control is offered to the student, for he is given full access to the powers of the computer system (plus the corresponding responsibility for making productive use of it).

This new emphasis on control is in marked contrast with conventional tutorial CAI, with the computer in control most of the time. Instead of controlling student learning -- doing things to students -- perhaps educators will seek more human uses of computers in teaching - giving students a menu of things to do.

Perhaps in the near future, Pygmalion will truly be the sculptor of his own education, using the computer as his tool.