SESSION X USES OF COMPUTERS AT THE NAVY PERSONNEL RESEARCH AND DEVELOPMENT CENTER

Thomas G. Sticht, *President*

Computer-based systems for applying psychological knowledge

WILLIAM E. MONTAGUE and WALLACE H. WULFECK II
Navy Personnel Research and Development Center, San Diego, California

Computer-based systems have long been seen as a means for applying psychological knowledge to instructing. However, from many years of research and development on instructional design and on using computers for instructing, we learned that the current instructional techniques are based on an inadequate scientific knowledge base and are poorly implemented. In order to do better, improved techniques based on modern cognitive science must be developed, and computer-based aids are needed to assist their application. Furthermore, a standardization and distribution system is needed to identify effective instructional programs and make them available. This seems especially important if we hope to have broad impact on education and training.

Recent advertisements suggest that computer-based instruction (CBI) is effective and fun, can reverse the "decline" in educational quality, and can provide schools, business, industry, the military, and even parents with efficient and effective means of instructing. If one examines our ability to develop and implement high-quality instructional programs, the advocacy of CBI as a solution for many difficult educational problems seems naive. It is not that CBI is ineffective. Some recent analyses summarize many demonstrations of the effectiveness (Kearsley, 1983; Kulik, Bangert, & Williams, 1983; Orlansky & String, 1980, 1981). But, although affordable hardware is a necessary ingredient for widespread effectiveness of CBI, it is not sufficient. Several other ingredients are necessary: good instructional design that uses computer power in appropriate ways, supportable and transportable software, and attention to the ongoing instructional systems in which CBI may be inserted.

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This paper summarizes what has been learned from our experience in both developing instructional programs and using CBI. We doubt that CBI will improve the quality of education and training over the near term for three reasons. First, high-quality instruction is a design problem, difficult to achieve regardless of how it's delivered; attempts to guarantee quality by using systems-development procedures have not been very successful. Second, the use of computers as instructional tools is in a rudimentary state of development; a bias exists toward using text, rather than adaptive, interactive simulation. Third, improvement in either instructional design or computer-based delivery depends on fundamental changes in the training design methods due to an infusion of theory, methods, and findings from research in cognitive science and artificial intelligence. A system is needed for planning, acquiring, standardizing, and distributing proven instructional programs, and for incorporating them into schooling.

The System for Designing Instruction Has Weaknesses

The adequacy of any instruction depends on the amount and quality of the planning that goes into its design, development, implementation, and evaluation. Assuming that computers in the classroom will auto-

matically improve instruction ignores the complexity and difficulty of making instruction effective in the first place. Effective instruction depends on determining what is to be learned, not just at some gross "top" level, but in sufficient detail so that intermediate learning requirements for the eventual development of expertise can be identified. Effective instruction also depends on being able to contrive situations and interchanges to promote student learning. Quality depends on how well the knowledge structures underlying performance can be described, the instructional theory used to guide the learning analysis, the design of lessons, the design of the instruction itself, and the planning for diagnosis and remediation. Only after this design work should decisions be made about whether and how to incorporate computer aids for instructing, how many are needed, how to manage their introduction into the program, and so forth. The process is mostly intuitive and artistic.

For various practical reasons, the military helped pioneer the systematic planning approaches to try to overcome the need for intuition and artistry, which are rare. Early methods relied on teams of experts in various aspects of management and instruction to design and develop instructional programs. During the 1960s, there was a shift away from the reliance upon teams of experts, toward development of more detailed procedures, models, and design decision aids to enable relatively inexperienced persons to design instruction (Andrews & Goodson, 1980; Gustafson, 1978; Montemerlo & Tennysen, 1976).

Evaluation of the effectiveness of these approaches to curriculum specification and development show that there is plenty of room for improvement. In some recent research (Stern & Fredericks, 1982) and in an extensive review of the implementation of instructional system development (ISD) methods (by 33 groups that developed 57 different courses in all the military services), a variety of problems were noted (Vineberg & Joyner, 1980). The procedural guidance has not led to high-quality instruction.

CBI Technology is Rudimentary

Translating what we know about learning and teaching into techniques that teach or tutor well has always been a goal for CBI. But, the model that developed during the late 1950s and early 1960s was the programmed textbook, and "teaching machines" that automated its presentation were devised. It was only natural, as computers became more available, to use these techniques to present the programmed material. The form of material was text arranged in "frames" for study. Tests became multiple-choice rather than fill-in because scoring programs are simpler to write.

Early computers were also expensive to buy, to maintain, and to program. The high costs of preparing and maintaining computer systems led to a concern for amortizing the implementation costs rather than for instructing more effectively. Microcomputers are now

much more affordable, and thus more attractive. However, the programmed textbook model has not yet changed. The result is that, in most existing CBI, instruction is done as it could be done without the computer. Students are given text to read, multiple-choice questions are asked, and answers are chosen. New materials are given if the answer is right, or review matter, if not. Newer CBI looks prettier, to be sure. There is broad use of color. Tricks, assumed to be motivational, are imported from video games, such as "lists of high scorers" or fancy graphic displays to provide reinforcement for correct responses. Systems that use menus seem to be "user friendly." But the fundamental design of CBI has not changed; it is still heavily frame oriented and text based, and relies on selected-response student interaction.

The primary point is that the computer is used to present and manage traditional materials, and not to optimize the conditions of learning. This sort of use has its place, of course. For certain purposes, it may be quite appropriate. But there are at least three problems with the uncritical use of the programmed text model for "modern" CBI. First, the computer is often relatively superfluous; that is, the materials and testing on the computer carry the major instructional function, and the computer simply delivers them and keeps records. Although management efficiencies might occur, in this form we should not expect CBI to be much different from instructor-run versions of the same instruction, and test comparisons show no learning benefits (Orlansky & String, 1980). Second, the computer's capability to simulate tasks and problems and to carry on an intelligent interactive dialogue with a student is seldom seen. And third, the developers of micro-CBI do not have much training in the proper analysis, design, and development of instruction, or in the programming of sophisticated computers to manage instructional interactions. Therefore, the resulting CBI is not likely to be much better than other versions of the instruction.

A Limited Scientific Foundation Exists for Instruction Technology

Successful use of computers to apply what is known about conditions for learning depends not on the ready availability of computers, but on two things. First is the design specifications for those learning conditions that derive from synthesizing and translating research knowledge and theory for practice. Second is the ability to incorporate those specifications into CBI. The problem is that the research knowledge and theory about learning are very limited. Furthermore, the capabilities needed to incorporate complicated requirements into computer systems are rare and labor intensive, as, for example, when we require dynamic, graphical simulations for teaching how systems work or teaching laboratory procedures.

In the 1950s and 1960s, behavioristic psychology was a predominant influence on instructional theory, and is still the predominant influence on derivative

instructional technologies. This psychology was analytic, believing that complex tasks could be broken into their more basic observable components. Then, events could be programmed to teach the components according to principles derived from "operant conditioning" (e.g., Taber, Glaser, & Schaefer, 1965). The "laws of learning and instruction," such as sequencing instruction step by step, allowing students to proceed at their own pace, and providing frequent reinforcement and feedback for responding to promote learning, were derived in part from animal conditioning studies, but also from verbal learning experiments with humans. Because the predominant form of instruction for the past several hundred years had been through books or verbal lectures, and because of the "verbal learning" emphasis in psychology, the resulting instructional delivery prescriptions tended to be concerned with presentation of textual information (Olson, 1977). Nearly all of these studies involved the learning of simple procedures unconstrained by structural complexity or the learning of verbal information intentionally designed to avoid structural relationships in the content to be learned. Therefore, the derivative instructional design and delivery technologies did not emphasize context, structure, or complexity. Both the bias toward text and the bias against contextual relationships and structure became an implicit foundation for both instructional design technology and CBI.

Bruner (1964), in discussing the elements of instruction, also talked of analysis, structuring and sequencing the materials, and providing feedback to students. But, he emphasized the importance of the structure and form of knowledge, the (mental) representation of the knowledge the student learned, and the influence the representation had on the student's performance. This view has been expanded and is now an important part of cognitive science (Norman, 1980). It leads to alternate conceptions of the form that CBI should take, and is only now being implemented and systematically tested.

This recent work suggests that improved guidance can be found to structure instructional information and interactions to promote learning. How well this can be developed into a technology is uncertain, but a considerable advance is possible. How does one describe task conditions and the mental representation the student needs to support performance in sufficient detail to guide the contrivance of appropriate forms of instruction? Interactive CBI systems must provide a phenomenological basis for developing experience. With such presentations, students can learn to operate a system, learn its principles of operation, exercise required vocabulary and procedures, correct errors, etc. In order to accomplish this, the representation needs to show what changes occur because of certain actions by the student. It should allow frequent and rapid practice of procedures to be learned, actively diagnose reasons for performance failure, and provide corrective feedback for errors, not so that the errors can be reduced in frequency, but so that underlying misconceptions can be eliminated.

It is clear to us that research on mental representations and the analytic methods used in that research are changing instructional theory and will change the design of interactive CBI. Designing interactive representations and using powerful computer programming tools will help break the text bias of CBI. By designing appropriate representations that are task simulations, learning can be more rapid and long lasting. Although this notion is hopeful, it is not clear how the methods can be standardized and taught or communicated to those who are responsible for developing the bulk of CBI materials. Therefore, more formal development of the technology is needed.

PROVIDING COMPUTER AIDS FOR DEVELOPMENT AND DISTRIBUTION OF CBI

So far, we have suggested that current instructional design techniques are not applied well and that CBI is in a rudimentary state but might become better through the infusion of new ideas and techniques from cognitive science and artificial intelligence. It seems apparent that this will take considerable time. What should be done in the interim?

If existing CBI programs are to be incorporated into instructional programs, the decision to use them needs to be guided by knowledge and analysis of how and why they were developed, whether their objectives meet current needs, and evidence of their effectiveness and relative efficiency. Because programs and courseware purchased off the shelf often lack information about their purpose and effectiveness, their introduction may actually interfere with or reduce the quality of instructional programs. In our view, the major problem with the implementation of traditional CBI is that prospective users are unaware of the limitations of current techniques and programs. The tendency is to buy a particular program usually on the basis of its supposed manageability, its publicity, or its cosmetics, and then to apply it uncritically. Even if requirements for instruction are carefully identified, and instruction has been well designed, CBI may or may not be the best or only method to deliver it. There may be perfectly good reasons to use a computer to replace a proctor, to deliver pencil-and-paper tests, to present written text, to guide students through a workbook, to provide extra practice, etc. Decisions to use a computer for any instructional purpose should be based on careful requirements analysis coupled with good prescriptive guidelines about what interventions are likely or unlikely to improve instruction and its management. At present, there is still little substantive evidence to guide the selection and implementation of traditional CBI systems, let alone developing ones. Some means must be found to aid this process.

For constructing new instructional programs, the primary problem is in controlling the quality of the ISD process. And here, computer use for teaching makes things more complicated. Attention must be given dur-

ing the analysis and development phases to instructional logic (which the teacher normally employs), to planning the student-computer interaction and interface, to the types of student-response data required, to the school-house utilization and maintainability of the hardware and software, and to a variety of other issues. In addition, teachers need to be able to modify programs, and must learn to use systems if they develop instruction or even use canned programs. All of this provides a substantial training problem, both in computer use and in programming instruction.

Therefore, to assist the development of CBI programs and to assist distribution, two kinds of developments are needed: automated authoring "tools" for the ISD process and a central standardization and distribution system.

Automated Aids for Instructional Design and Development

The continued lack of progress with ISD implementation seems to be due to the variable skills of those doing the implementation, and the lack of usable "how to do it" procedures. Computer-based aids to authoring instruction can make substantial differences in the quality of instruction whether it is on-line or off-line, and of course in the efficiency of development. Computerized ISD-aiding systems can assist with the formidable record-keeping problems involved in instructional development. More impressively, they can facilitate the development process itself by providing guidance for test and instructional development and similar tasks. Moreover, computer-based systems can ensure that guidance is followed by monitoring and evaluating developers' performance, especially by forcing attention to the delivery options available and the tradeoffs among them, and by assisting developers as they proceed. Computer systems can also provide training for instructional developers, who can fit it into their work schedules. Finally, these systems are essential for aiding implementation and utilization of CBI. Today, most CBI users, such as teachers, school boards, military training activities, and businesses, want to customize and adapt instructional software. They cannot do this unless tools are available for modification and refinement of CBI programs.

The most desirable reason for using computer tools, however, is that the modern design and development tools, such as an "Instructional Developer's Workbench" or powerful graphics editors, can be incorporated into the ISD process. This provides the only mechanism whereby developing science can improve day-to-day practice. As we build better tools, they can be added. Computer-based author aids, then, must be developed to support both ISD for CBI and utilization of CBI.

Improved Distribution and Maintenance of CBI Programs

The transfer of software is a problem. There are attempts to catalog programs and annotate them (e.g., CONDUIT at the University of Iowa; the Minnesota Educational Computing Consortium). Although these ef-

forts serve to acquaint people with the range of programs available, several major problems remain. First, many schools, businesses, and military activities are buying computers. Unfortunately, these systems are often incompatible, so common software packages cannot be developed and shared without substantial recoding and duplication of effort. A second problem is the tremendously repetitive nature of the programming efforts. One program or another develops programs that present questions and require selected answers or fill-in answers, present text descriptions, etc. All of these require functionally the same code. Computer software companies have recognized the same sort of repetitiveness in computer programs and are developing ways to use code already developed in new programs. This speeds up the development process and reduces errors by a large factor. A third problem is that most current CBI programs are not supported by appropriate authoring support and instructional management aids.

We believe that a solution to these problems is to develop families of CBI software to support computer-based instruction in a wide variety of education applications. This can be done by developing libraries of computer-based instructional programs, sufficiently flexible to support development, delivery, and management to meet many instructional requirements. The library should also be concerned with demonstration of and specifications for generic hardware systems capable of executing library software, and with planning for and assisting institutionalization of CBI programs. By providing transportable, carefully tested CBI software and development tools, compatibility and supportability problems are solved, user requirements are more efficiently addressed, implementation and life-cycle costs are reduced, standard data on student performance and CBI cost-effectiveness can be obtained for budget justification, and acquisition costs of training can be reduced. Most importantly, institutional software libraries can achieve a "critical mass" so that evolutionary improvements through application of new technologies like authoring aids can be achieved.

The Department of Defense is currently developing such a library, called TRIADS (Dallman, Pohlman, Psotka, Wisher, McLachlan, Wulfeck, Ahlers, & Cronholm, 1983). The intent is to synthesize efforts in all the services related to CBI technology. Initial programs in the TRIADS library are those that have already received rigorous testing and evaluation within the developing service. Later programs will be accepted in the library only after such analyses have been conducted, and only if they interface with existing authoring and management support aids or include new ones. The purpose of this effort is to develop software quality standards and instructional quality standards for programs to be included in the system library, adapt and enhance existing programs for this system library, demonstrate the programs, and develop user training. This effort involves the following work.

A quality assurance process including software-

engineering standards and instructional quality standards that computer-based educational applications programs should be required to meet for acceptance into the system library is being prepared.

Another major task is to design, develop, and write "authoring" support programs that enable instructional-content specialists who are not computer programmers to enter instructional content to the appropriate database for each of the software programs developed. These authoring programs will take the form of "authoring environments" that provide support for database construction and entry.

Another task is to design, develop, and write instructional management programs for each of the instructional programs in the library. These programs will allow instructors who are not computer programmers to track student progress through the instructional programs and to obtain data concerning student performance.

Finally, the effort involves developing a user training course to instruct users who are not computer programmers in the operation of all software developed. Training materials will include operations aids and manuals for all software, and a decision aid to assist users in determining which of the CBI systems is most appropriate for their particular instructional needs. This development will include validation of the training materials by providing training to a selected number of users in the operation of the system, including database construction.

In general, efforts like TRIADS are essential if CBI is to be widely implemented and, again, provide a more straightforward vehicle for evolution of the scientific base into practice.

CONCLUSION

The availability of relatively cheap computer power in the schools has led people to assume that microcomputers are an easy solution to the problem of quality in education and training and that through them the scientific knowledge can be applied simply and directly. We feel that this is misleading. The technology for designing instruction on computers is based on an inadequate model for teaching. The computer sophistication of most people doing instructional program development is poor. Quality in CBI still depends on intuition and artistry. Yet this artistry and intuition are rare commodities. We think that substantial improvement in the implementa-

tion of CBI can be made: first, through the use of computer-based tools that help in the systematization of the process of development and in decisions about teaching strategies; second, via a system for standardizing and distributing proven programs; and third, by supporting efforts to synthesize and translate research knowledge into useful tools and guidance to include in the systems.

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