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ABSTRACT

This analysis of how the federal government might best promote excellence in education via instructional technology identifies strengths and weaknesses of instructional technology during the 1980's, indicates how technology might aid the teaching and learning process, and suggests how the federal goverment might best assist states and localities in utilizing technology to improve educational achievement. Definitions of terms are followed by a brief review of the role of the federal government in education from the 1960's to the recent return of educational responsibilities from the federal level to the state and local governments. Giving special attention to the role the federal government should play in promoting instructional technology, the remainder of the analysis builds on these definitions and preliminary observations. Specific sections address early development in instructional design, a brief history of federal support for educational research and its consequences, current strengths and weaknesses of instructional technology, using instructional systems design in computer based instruction development, and the use of technology in instruction. Conclusions, recommendations, and a 42-item reference list are included. (LMM)

An Analysis of the Federal Role in Instructional Technology in the Era of the New Federalism *

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The primary aim of this analysis is to determine how the federal government might best promote excellence in education via instructional technology. More specifically, the purposes of this inquiry are threefold: 1) to identify strengths and weaknesses of instructional technology during the 1980's. 2) to indicate how technology might aid the teaching and learning process and 3) to determine how the federal government might best assist states and localities in utilizing technology to improve educational achievement. In the latter regard, a reassessment of the roles and responsibilities of federal, state and local governments, of business and of parents seems imperative.

Any such analysis will necessarily depend heavily on the ways in which "educational technology" and "the new federalism" are defined. We begin, therefore, by defining these terms.

Educational technology connotes different things to different people.

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To some it refers to the use of technology in the educational process. This interpretation, not surprisingly is favored by those charged most directly with the delivery of instruction: administrators, teachers, audio/video specialists, computer specialists, etc. To others, the term "educational technology" refers primarily to the principles and techniques used in designing instructional systems. The resulting systems frequently but not necessarily are intended for delivery via technology. Not surprisingly, the latter interpretation tends to be preferred by those associated with academic and research environments: universities, research laboratories and centers, and even centralized instructional development centers associated with large school districts and states. Those R&D specialists who are most directly involved in instructional systems development tend to emphasize relatively familiar educational design procedures such as behavioral objectives, criterion referenced testing, and task analysis. Correspondingly, academic leaders in the field tend to place more emphasis on basic instructional theory and design techniques derived therefrom (e.g., Gagne & Briggs, 1974; Scandura, 1977).

In this analysis, "educational technology" refers to both instructional theory and design and the use of technology in the delivery of instruction.

For several decades, beginning with the 1960's, the federal government has come to play an increasing role in education. Initially, funds provided for research at universities and later for innovation in schools came relatively free of explicit federal controls. Gradually, regulation and direction came to be increasingly centralized so that by

the late 1970[illegible]ge proportion of funds were being used explicitly to dictate social e[illegible]y means of education. By 1980, the federal role in education was sufficiently pervasive as to greatly restrict and often control the activities of states and local governments. This progressive loss of self-determination frequently made it difficult to achieve local ends and, in many cases, angered parents who felt that their role was being usurped by a large bureaucracy over which they have no effective control.

In the present context, the "new federalism" refers to the return of educational responsibilities from the federal level to the state and local governments. Indirectly, it also refers to the reassignment of educational roles among government, private enterprise and independent agencies, and students' parents so as to more efficiently, effectively and responsibly promote excellence in education. Special attention is given to the role the federal government should play in promoting instructional technology.

The remainder of the analysis builds on these definitions and preliminary observations:

I. Early Developments in Instructional Design

II. A Brief History of Federal Support for Educational Research and its Consequences

III. Instructional Technology: Current Strengths and Weaknesses

IV. Using Instructional Systems Design in CBI Development

V. The Use of Technology in Instruction

VI. Conclusions and Recommendations

I. EARLY DEVELOPMENTS IN INSTRUCTIONAL DESIGN AND CBI

Much was heard during the late 1950's and early 1960's about the science of learning and the technology of teaching (C.F., Melton et. al., 1959). Early realizations of educational technology (e.g., involving programmed learning and teaching machines) were frequently based directly on existent learning theories of the day.

Skinnerians, for example, sought to convince us that schedules of reinforcement, shown to work so successfully with pigeons ~~and~~ lower mammals, would almost certainly save the day for human education as well. Many educators rightly saw the folly of this approach but had very little substantive scientific information on which to base their objections. The alternative idea of instructional "branching" was advanced by individuals like Robert Crowder (e.g., 1959), for example, but little other than intuition was advanced as a basis for such branching.

Early Developments in Computer-Based Instruction.— This was the milieu into which computer-based instruction (CBI) was introduced in the 1960's (e.g., by Suppes and his colleagues at Stanford and Stolurow at Illinois). At that time many were predicting that CBI would revolutionize education, changing radically and permanently the means by which education would be delivered to the mass of our youth. Alas, the predicted revolution did not take place at that time for three major reasons.

1) The costs for hardware and for software development during this early period were prohibitive. Still many demonstrations and some implimentations of CBI systems were developed at several major

universities, in the military and in a few large corporations. All of these efforts, however, were heavily dependent on federal funds. The Plato system at the University of Illinois, for example, utilized many millions of federal dollars. Plato has had limited commercial success despite these federal subsidies and, subsequently, a decade long and to date unprofitable investment by the Control Data Corporation reportedly of about 900 million dollars. Plato's development has been an unlikely scenario made possible largely by the strong continued support of the chief operating officer of that corporation.

2) The second major problem during this early period was reliability. The delivery of CBI was totally and capriciously dependent on the effective functioning of large centralized computers. All too frequently, these computers were down for maintainance or repairs, making it difficult and sometimes impossible to maintain a smoothly functioning instructional program.

3) Perhaps most important, too little was known about how to design effective instruction, especially instruction which by its nature is highly dynamic and interactive. At that time, interactive instruction was considered primarily an art form to be mastered only in varying degrees by human practitioners.

Gradually, things began to change. The 1960's and 1970's saw considerable growth in instructional systems design. Increasingly, it became possible to design instructional systems by systematic means in a manner not unlike the way an engineer might plan a bridge, for example. Widespread use of the term "educational engineering" in this context is no

accident. Then, beginning in the mid 1970's, small, low cost, and reliable microcomputers were introduced. Today, barely seven years later, microcomputers constitute a multibillion dollar industry. Although educational uses have lagged behind those in recreation and business, widespread impact of computers in education seems assured.

II. A BRIEF HISTORY OF FEDERAL SUPPORT FOR EDUCATIONAL RESEARCH AND ITS CONSEQUENCES

Sputnik brought about a vastly increased concern for improving scientific education in the late 1950's. Initially these concerns were centered on mathematics and the physical sciences. In a few years this concern spread to all sciences and later to education generally. Moreover, by the early mid 1960's it became increasingly recognized that little was known about the educational process. It was at that time, for example, that the theories of Piaget and their potential applicability to education were first "rediscovered"—as it turns out 40 years after those theories were first annunciated. Consequently, federal support for scientific investigation in education increased at a phenomenal rate. Although there were notable exceptions, most research supported under the old Cooperative Education Research Act was concerned with such easily measured variables such as class size, method of instruction (e.g., discovery versus expository) and use of computer assisted instruction versus non-use, TV, etc.

From this early research and at the risk of slight oversimplification, only two major and reliable results emerged (both with precursors in the past): 1) students learn what they spend time doing (i.e., what they are taught) and 2) the methods and media used to teach content does not matter much as long as it is taught well. CBI, for example, is neither good nor bad in and of itself. The results of such instruction depend on what is being communicated and the care with which

it is done.

Flush with funds, a number of initiatives can be traced from this period: 1) a competitively awarded research contracts program, 2) educational research centers and, later, laboratories and 3) Title I and Title III programs aimed more directly at the practice of education. A substantial portion of these funds was used to support educational technology. However, most of the money later was increasingly concentrated at a few centers and in some cases was used to subsidize commercially infeasible efforts in computer-based instruction.

In many ways the most productive programs during this period were the small contracts and basic research programs at the Department of Education, including those administered with collaboration of the National Academy of Sciences. At this time during the 1960's a considerable amount of innovative research was begun, much of it breaking necessary ground for the contemporary developments of today.

Although not so intended, establishment of the National Institute of Education (NIE) during the early 1970's, led to the near demise of federal support for serious educational research by independent investigators. By the late 1970's only about 4% of NIE's funds were being awarded on a competitive basis (e.g., Farley, 1980; Page, 1980). A disproportionate percentage of available support was (and is) being awarded by congressional mandate on a preferential basis to the various labs and centers, irrespective of the quality of contribution.

In this austere environment, the limited grant competitions that were held during this period were largely counterproductive. As few as one or

two of literally hundreds of unsolicited proposals were funded annually with the costs of proposal writing alone far exceeding the support provided for actual research. Under these circumstances, it would have been far better not to hold the competition at all.

Consequences of this Federal Intervention. -- Two developments which resulted from Office of Education and NIE sponsored research and development during the 1970's are particularly relevant to this analysis. First, most support for educational research during this period was concentrated at a small number of preferentially funded research centers and laboratories. Indeed, the presence of center and laboratory associated personnel on many research review panels during this period not only allowed the centers to obtain funds on a noncompetitive basis but in large measure to determine their own competition. As one colleague has put it, (federal) government funding patterns beginning in the early 1970's have often had the effect of "watering the weeds."

Even more ominous has been the omnipresent political influence of the labs and centers. According to a recent past president of the influential American Educational Research Association (AERA) (Professor Ellis B. Page, personal communication), the lab/center consortium "packed the Executive Council of the AERA and then acted as a bloc to 'recommend' ... (continued commitment) to the existing labs and centers." Failing this attempt, these groups, in concert with political allies, have apparently succeeded in ousting NIE leaders and council members who have attempted to introduce open competition in research funding. These groups currently are maintaining intense pressure to ensure continued lab and center dominance.

A second major development of concern involved the efficacy of large scale curriculum development efforts supported by the Office of Education during the 1960's and 1970's. Much of this research had tapered off by the mid-late 1970's, so it is instructive to consider the extent to which those development efforts actually impacted on the educational system. Perhaps the best publicized early effort in this regard was the individually prescribed instruction (IPI) project conducted by the Learning Research and Development Center at the University of Pittsburg. This effort was a hastily contrived attempt to impose an incomplete behavioral philosophy on the actual operation of a school. Early on, the IPI curriculum consisted of cutting and pasting curriculum materials from a variety of commercial sources. Later, with considerable federal support, these materials were refined and tested at several levels both by the Center in Pittsburg and by the Research for Better Schools Laboratory in Philadelphia.

One might expect that the results of such an effort would have been quickly adopted by schools and/or commercial publishers. As it turned out, with a few inconsequential exceptions, very little of this curriculum material was thought to have commercial value and simply never made it to either the market place or to schools.

In retrospect, it would have been far better to have used support allocated for CBI and curriculum development for the development and testing of a broader range of prototypes. Such an approach would have yielded far more useful information at proportionately less cost. The IPI illustration is reminiscent of governmental support of Langely to the exclusion of the Wright brothers and illustrates the folly of

overemphasizing one or another approach at the expense of competing ideas. The same money would have been far better spent supporting development of a variety of competing options from which commercial developers and the marketplace could have freely selected.

Similar comments can be made regarding the quality of the research emanating from many of the labs and centers. Generally, the quality of that research has been spotty with an often embarrassingly low proportion of reports being published in reputable and referreed scientific journals (e.g., Tennyson, personal communication). Indeed, it is hard to pinpoint one new idea that was initiated primarily by labs and center personnel — as it was put by Professor Novak of Cornell University (personal communication), "I cannot think of a single significant contribution that has come out of all of the support for NIE Centers and Laboratories (many of whom are still mired in S-R behaviorism)."

The "better" labs and centers, however, have sometimes been quick to capitalize on research and ideas developed by others. Among these ideas are task analysis (e.g., Gagne, 1962), the development of items forms in criterion referenced testing (initially developed by Hively et al, 1968), and cognitive learning and performance (e.g., Scandura, 1971; Newell and Simon, 1972).

Increasingly during the 1970's and 1980's, as justification for future federal support, some purportedly innovative problems have been proposed for study. In recent years, the study of cognitive learning, as opposed to performance, and the application of cognitive theory to instruction fall in this category (e.g., Resnick, 1981). The implication of such proposals has been that they are new, challenging, unsolved

problems for the future. In fact, there is a large body of research in both areas conducted by independent researchers both in this country and abroad (e.g., Landa, 1974; Novak, 1966; Pask, 1975; Scandura, 1971, 1973, 1976, 1977) which has been largely unreferenced although apparently used as a source of ideas in lab and center reports (e.g., see Scandura 1977a; 1977b, Chapter 15; 1980).

An even more recent example of this sort appeared in the APA Monitor to the effect that "the most significant (recent) advance in (cognitive science) is the capability to analyze the cognitive requirements needed t complete complex tasks" (April, 1983, p. 8). This analyst, having been actively involved in such work while the individual quoted was still studying S-R paired-associate learning, cannot help but find such statements both amusing and incomprehensible.

Needless to say, federal support for secondary efforts of this sort is indefensible in these days of highly restricted budgets, especially under the preferentially biased subsidies provided for lab and center activities.

The problem has been put succintly by Robert Tennyson of the University of Minnesota (personal communication), "Without a pipeline to Washington (e.g., in terms of former students or colleagues in the bureaucracy) there is little chance of funding." He further postulates "a direct correlation between the number of former students in an agency anc the amount of funding received." One might add that it is doubtful that the preferentially funded labs and centers could have maintained themselves on merit were it not for strong political support.

III. INSTRUCTIONAL TECHNOLOGY: CURRENT STRENGTHS AND WEAKNESSES

Any consideration of current strengths and weaknesses in instructional technology must distinguish between what is currently known about instructional technology as a methodology (i.e., the strengths and weaknesses of current design and development methodologies) and the current state of educational technology in the sense of the use of technology for learning and instructional purposes.

Theory and Technique. — Among those who believe that instruction may be viewed at least partly as a science or technology, rather than just an art (e.g., Bork, Mager, Popham, Gage, Gagne, Glaser, Landa, Merrill, Pask, Reigeluth, Scandura and Tennyson), it is generally believed that instructional design involves specifying: (1) the goals or objectives of instruction in behavioral terms (i.e., in terms of what the learner is to be able to do after learning), (2) which of the specified objectives the learner has and has not met prior to instruction and (3) techniques for assisting the learner to move from where he or she is toward the specified goals.

Unquestionably, the most widely used technique for specifying instructional goals involves behavioral objectives (e.g., Mager, 1968). Although variations exist, behavioral objectives essentially involve specifying educational goals in terms of observables.

It also is widely recognized that criterion referenced testing provides a sounder basis for planning instruction than does normative testing. In the latter, students are tested on broad samplings of tasks

from at best vaguely defined domains (of tasks). This approach to testing is useful for comparing the generalized achievement levels of students (hence its widespread use in standardized testing). In general, however, normative testing does not pinpoint what individual students do and do not know in a way that lends itself to instructional decision making. Instructional purposes are better served via criterion referenced testing because student capabilities are judged relative to predetermined standards (i.e., the goals of instruction).

Although most instructional designers believe that the above techniques can play an important role in developing instructional systems, there tends to be less agreement as to the sufficiency of these techniques or as to instructional methods. In general, the designer's perspective depends heavily on the role which cognitive processes, rather than just observable behavior, are assumed to play. At one extreme, are those committed to purely peripheral explanation, prediction, and behavioral control. In this camp, for example, are those who espouse such well known Skinnerian techniques as shaping (i.e., reinforcing student responses which tend toward desired goals), fading (providing progressively fewer clues as to what the learner is to do as learning progresses), and schedules of reinforcement. While the validity of these techniques has been demonstrated repeatedly in animal experimentation, most contemporary instructional designers recognize that much more is required for effective instruction. Schedules of reinforcement, for example, have more to do with motivation than learning per se (e.g., Scandura, 1973).

Recognition of the importance of task structure in designing human

instruction led to the development of task analysis in postwar years (e.g., Gagne, 1962). In task analysis, the criterion tasks (specified operationally in observable terms) constitute only a beginning. By repeatedly asking the question of what the learner must be able to do in order to do what is desired, the analyst constructs a hierarchy of tasks to be mastered with the criterion task at the apex. Those tasks immediately below are assumed to be necessary prerequisites for the former in the sense that they must be mastered before the criterion can be (mastered). Similarly, tasks below the prerequisites must be mastered before the prerequisites can — and so on. At the bottom of the hierarchy are tasks that are so simple that they can be assumed available to everyone (in the targeted student population).

With the emergence of cognitive thinking during the late 1960's and early 1970's, two major limitations of behavioral objectives became apparent (e.g., Scandura, 1971). First, specifying behavioral objectives leaves unanswered the question of what (e.g., cognitive processes) must be learned in order to perform as desired. Knowing how an objective is to be achieved is not just an idle concern because any educational objective can be achieved in any number of ways. Thus, one can solve verbal problems in arithmetic, prove mathematical theorems or construct a paragraph by any number of methods. Moreover, even where each method achieves the same educational objective, the long term value of particular methods (e.g., for subsequent learning) may differ dramatically. As a simple example, consider two students, one of whom has learned to pronounce words by "look and say" methods and one who has mastered phonetic analysis. The latter

student would be far more likely to figure out for him or herself how to pronounce a new word than would the former.

The second major limitation is that behavioral objectives would not be sufficient — even if one were to specify the corresponding cognitive processes. As stated by Scandura (1971)

> "Because the characterizing (processes) are discrete, they can not account for behavior which goes beyond the given corpus, except in the most trivial sense. For example, suppose the characterization only included (processes) for adding, subtracting, multiplying and dividing. In this case, the student would be unable to even generate the addition fact (e.g., 5 + 4 = 9) corresponding to a given subtraction fact (e.g., 9 - 4 = 5), although one might reasonably expect this type of behavior from a person who was well versed in arithmetic. One might counter, of course, that it would be a small thing to simply add a new objective or process to the original list (which relates the original ones)... Indeed, this is precisely the sort of reply one might expect from a person of the operational objectives persuasion. When confronted with the criticism that their objectives do not constitute a .... viable curriculum, they would simply say we can add more objectives.
>
> "The trouble with this sort of argument is that it misses the point entirely. Not only would such an approach be ad hoc ... but it would be completely infeasible where one is striving for completeness. ..It is sufficient to note that a new (process) would have to be introduced for every conceivable interrelationship and that the number of such interrelationships is indefinitely large..."

To allow for the unexpected (i.e., to provide for the possiblity of building creativity into instruction), Scandura (e.g., 1971) introduced the idea of higher-order rules. Higher-order rules may be thought of as generalized strategies, together with networks of interrelated knowledge structures, by which new knowledge (i.e., new rules) may be derived as

needed. Thus, for example, even if the creative student has not been taught explicitly how to solve a given class of problems, the possibility exists that he or she may have learned general strategies (i.e., higher-order rules) which allow one to derive solution methods where needed. Various kinds of higher-order rules have been demonstrated to be valid for this purpose, ranging from creation by analogy, to combining known information, to automating existing knowledge (as is necessary in achieving highly skilled performance). For present purposes, it is sufficient to simply note that many such higher-order capabilities exist and may be learned to good effect.

These and other advances in cognitive representation have led to increasing recognition that traditional task analysis per se is not in itself sufficient for purposes of instructional design. It is not sufficient to simply identify prerequisite tasks. For one thing, methods are needed to identify the cognitive processes (i.e., knowledge structures and processes) underlying such tasks. For this purpose, various methods of cognitive task analysis have been introduced independently by a number of investigators (e.g., P. F. Merrill, 1982; Pask, 1975; and Scandura, 1971). The methods introduced by Pask and Scandura explicitly provide for the identification of higher-order processes.

Work on these problems has continued throughout the 1970's and is still underway. No one has yet developed a method of cognitive task analysis which both leads to behaviorally precise cognitive representations and is completely general, systematic and objective;

however, the method of structural analysis (e.g., Scandura, 1982, 1983) appears to go further in this direction than others.

Although cognitive learning is highly relevant to instuctional design, discussion of this topic here would take us too far field. It is sufficient for present purposes to simply point out that introducing higher-order rules into cognitive representations (including structures on which they operate), together with a general purpose control mechanism which has been shown to be universally available to school age children, provides a highly efficient and generalized means for explaining, predicting and, within the limits of behavioral science, enhancing cognitive learning (e.g., see Scandura, 1971, 1973, 1974, 1977). Pask (1975) also has developed an approach to explaining cognitive learning, albeit one based on different although potentially compatible principles.

These advances in cognition have provided more exacting (i.e., precise and reliable) bases for criterion referenced testing. Except when testing with respect to the simplest behavioral objectives (e.g., being able to state the capital of Virginia), the test items associated with any given criterion (e.g., the ability to add numbers) are not necessarily equivalent. In general, students will perform successfully on some of the items but not others. The question arises, therefore, as to what kinds of test items and how many are needed for any given criterion.

Two basic approaches to this problem arose independently and more or less simultaneously in the late 1960's and early 1970's (e.g., Hively, Paterson & Page, 1968; Landa, 1974; Scandura, 1971; Durnin & Scandura, 1973). Hively et al (1968), for example, introduced the notion of item

forms. The item forms associated with any given criterion (in criterion referenced testing) are essentially categories based on the visible forms of associated test items (e.g., as to whether subtraction problems involve one, two or three digit numbers). This method proved useful in some cases in partitioning items into categories which were relatively homogenious, in the sense that students tended to be either uniformally successful or uniformally unsuccessful on items in any given category. Where such homogeneity was achieved, criterion referenced tests could be constructed by simply sampling one or more items from each category (associated with the corresponding criterion referenced objective).

Despite their potential utility, the basis for such categorization (via item forms) remained obscure and the method itself seemed to work better with some kinds of content (criteria) than others. In contrast, the methods proposed by Landa (1974) and Scandura (1971, 1973) are based more directly on cognitive processes.* Items associated with a given criterion are partitioned into equivalent categories based on the actual processes required for solving them. This approach to categorization yielded a method which was at once both more precise and more generally applicable (than in the case of item forms).

*Whereas the methods proposed by Landa and Scandura can be shown to be mathematically equivalent (e.g., Chang & Lee, 1977), Landa was more immediately concerned with applications while Scandura was primarily concerned with broader theoretical implications.

Scandura and his associates (e.g., Durnin & Scandura, 1973; Scandura, 1973, 1977; Scandura, Durnin, Ehrenprise & Wulfeck, 1977) further demonstrated that the categories of items associated with a wide variety of criterion referenced tasks were not only highly homogenious but that they were hierarchically related. This latter result provided a basis for highly efficient sequential testing. Not only could one restrict testing to as few as one item per category but one could infer success or failure on untested categories on the basis of the prescribed hierarchical relationships among categories. Thus, as with traditional task analysis, success on one category (task) would imply success on all prerequisite categories (tasks), while failure would imply failure for all superordinate categories (tasks).

Through the use of such inferencing it often is possible to assess relatively complex capabilities with as few as two or three carefully choosen test items. Indeed, there is reason to believe that the inferencing potential inherent in such a scheme effectively systematizes and is on a par with what skillful diagnosticians (i.e., teachers) frequently do informally in the classroom.

Testing with respect to underlying processes has been shown to have the additional advantage of providing an explicit basis for instruction (e.g., Durnin & Scandura, 1973). Because particular categories of items are associated with particular cognitive processes, it is possible to inter with considerable precision which cognitive processes are known and which are not. This information, together with prespecified relationships

among the various processes, provides a precise basis both for determining what any given student needs to learn and the order in which it might best be taught.

Many of the ideas inherent in the above were adopted either formally or otherwise in other areas of behavioral science, areas ranging from assessing stages of child development (e.g., Seigler, 1979; Wulfeck 1979) to the systematic detection of inadequacies in cognitive processes (called "bugs") by means of computer (e.g., Brown & Burton, 1978). Recently, Scandura (1981) has described how the more basic of these ideas might be implemented in a contemporary microcomputer environment. In the process, he described a general purpose development system of this sort for creating commercially viable software (e.g., Scandura, 1981.)

In earlier more basic research, Scandura (1977) had shown how similar ideas could be extended to arbitrarily complex domains of tasks, involving indeterminately large numbers of different educational objectives. In brief, this was accomplished by introducing and testing with respect to sets of underlying rules, including higher-order rules. With the exception of a few advanced prototype developments (e.g., Wulfeck & Scandura, 1977), however, very little has yet been done to capitalize on these ideas in more applied aspects of educational technology.

To summarize, analysis of the available literature, and of major presentations at national and international symposiums, leads this analyst to the conclusion that a considerable amount of information has been accumulated which would be especially useful in the design of instruction for delivery by computer.

One should not infer, however, that everyone agrees we know as much as suggested about how to design instruction. As recently as 1983, for example, researchers at some of the more influential N.I.E. supported R & D centers have proposed that one of the major challenges of the 80's will be to determine how we can make use in designing instruction of what has been learned in cognitive psychology (e.g.. see Resnick. 1981; Cordes. 1983). Similar proposals have been made with regard to the need to study cognitive learning during the 1980's. These calls for "new" research apparently stem from the facts that computer simulation studies in cognitive science during the 1960's and 1970's were almost exclusively concerned with cognitive "performance" and not "learning" (e.g.. Newell & Simon, 1972) and that the individuals responsible either were not aware of earlier research on cognitive learning (e.g., Ausubel, 1968; Pask, 1975; Scandura, 1971, 1974) or, for whatever reason, did not recognize its relevance. Given this limited perspective, it is easy to see why they might think of cognitive learning as a new problem.

If nothing else, these illustrations show clearly how governmental support of only one line of basic research in an area over a period of time (in this case for over a decade) can lead to a "watering of the weeds" so to speak. Without serious competition in research, as in other walks of life, the country's knowledge lifeline suffers problems not unlike those attributable to other monopolies.

IV. USING INSTRUCTIONAL SYSTEMS DESIGN IN CBI DEVELOPMENT

Developing effective and efficient computer based instruction is not an easy or inexpensive task. At a minimum, it requires: considerable knowledge of computers, or at least knowledge of how to program; intimate familiarity with the subject matter involved; and methods for presenting the subject matter in ways that promote learning.

To aid the process, considerable attention during the 1960's was given to the development of CBI-type programing languages such as COURSEWRITER, TUTOR, PILOT, etc. These languages are relatively easy to learn and have been designed to facilitate the selection and presentation of course and test materials. While designed to be general purpose and easy to learn, the available languages are nonetheless better suited to CBI development in some areas than in others. Moreover, the author is not only free but obliged to specify test and instructional sequences; most CBI programming languages provide little guidance in this respect. In effect, although high level CBI programming languages facilitate CBI authoring, the process still requires considerable familiarity with computer programming, with subject matter and with instructional design—a combination of knowledge and skills not easy to find in any one individual. This fact almost certainly has led as much as anything to the uneven quality of current CBI systems.

To help ameliorate the problem, a growing number of CBI specialists have argued in favor of developing authoring systems in combination with

general purpose "drivers" (e.g., Scandura, 1981; Tennyson, 1981). Authoring systems allow authors to create course material using the English language and easily-learned codes. This material is usually entered into authoring systems in response to specific promps and is automatically coded. The driver program, in turn, operates on the coded material (as data), presenting it in a predetermined, but potentially conditional, sequence determined by the driver and the student inputs (e.g., student responses to questions).

In order for author/driver systems to function properly, various restrictions must be placed on the form of the course material. This is necessary, for example, to insure that the driver is able to locate the right information at the right time. These restrictions typically limit either the variety of subject matter that can be implemented successfully and/or the instuctional effectiveness of the implementation. Thus, for example, while most subject matter can be "forced" into a given format the resulting instruction may be less than optimal.

In spite of the previously cited advances, few commercially available authoring systems make serious use of current knowledge concerning cognitive processes and/or instructional theory—knowledge that is increasingly available to the instructional design community but which has not yet become widely used in CBI development. (The Rule-Example oriented authoring system used in the TICCIT CBI effort was an early attempt to move in this direction.)

Indeed, it is well beyond the commerically viable "state of the art" to contemplate at this time the development of cognitively-based

generative authoring systems that might be used with arbitrarily complex and interrelated content. There are, however, some kinds of content which are sufficiently well understood to provide considerable hope in this regard. As described previously, research over the previous two decades provides considerable insight not only into what has sometimes been called rule-based (or "algorithmic") knowledge, but also into effective and efficient techniques for assessing the knowledge of students and for providing remedial instruction. In this regard it should be emphasized that many topics traditionally taught in schools can be reduced to rule, or algorithmic, terms. The familiar arithmetic algorithms provide a standard but hardly exhaustive illustration. Most manipulations of concrete objects, as well as grammar (adding "ing" to words), for example, lend themselves readily to this type of analysis.

In spite of the relative complexity of cognitive-based development systems, the advantages of such methods would have a number of important consequences. In contrast with fixed-content authoring systems, such as have been described above, content would be intimately tied to the underlying cognitive processes needed for mastery. In this case, rather than having to prepare all instructions, questions, answers and feedback in advance, it is possible to envisage CBI systems in which directions, questions and other instructional content are generated by the computer on the "fly" so to speak, as it is needed by the student. In the same way, diagnostic testing and instructional remediation would follow naturally from analysis of the underlying cognitive requirements of the content in the manner outlined above.

The simplest examples of this type of CBI system, undoubtedly involve simple drill and practice. Such systems currently are available from a number of comercial publishers.

A more general and ambitious CBI system of this sort is the general purpose RuleTutor (e.g., Scandura, 1982). This system takes as input a computer coded version of the rule or rules (i.e., cognitive processes) needed to solve the class of tasks at hand. When this code is combined with the general purpose RuleTutor code, the result is a rather sophisticated diagnostic and tutorial instructional system for teaching and testing the associated content. Given the rule code, the RuleTutor generates problems as needed, presents them to the student, grades them and automatically presents the needed information.

As it stands, the RuleTutor lacks one major requirement for a full fledged computerized authoring system. While the RuleTutor provides a significant degree of generalized instructional intelligence, it does not eliminate the need for programming. In particular, what is needed is the equivalent of a computerized technology (method) for structural (cognitive tasks) analysis. And, as noted above, while recent progress has been made in this direction, the level of research effort required to bring such technology to fruition at present largely precludes such development in a commercial context.

More generally, in spite of these positive uses of instructional systems design, both real and potential, considerably more attention in future basic research must be given to the dynamic, and highly interactive nature of CBI systems. The fundamental nature of such interaction, and

its relationships to cognitive learning, need to be better understood if we are to realize the full potential of instructional systems design in CBI development.

V. THE USE OF TECHNOLOGY IN INSTRUCTION

The technologies used to promote learning in schools range from the printed page, blackboards, overhead projectors, etc., on the one hand, and, on the other, to television and other electronic forms of communications and computers. The main thing all of these technologies have in common is that they can be used either well or badly. Their effectiveness in promoting learning depends far more on the viability of the content and on the way the technologies are used, in most cases, than on the technologies themselves. This fact has been demonstated numerous times in educational research by the lack of reliable effects attributable to particular technologies (or to instuctional methods per se, e.g., Scandura, 1964).

The present analysis is concerned exclusively with the advantages and limitations of interactive technologies in education, most especially with those involving the use of computers. Interactive technologies by definition involve two-way communication as is the case with "live" instruction (and instruction by means of tele-communications). Until the advent of computers, with the exception of outmoded mechanical teaching machines, essentially all nonhuman uses of technology for instructional purposes involved one-way communication. Indeed, this limitation is perhaps the primary reason that television has never achieved the educational impact that was once forecast.

At the present time, the computer has three major but quite distinctive roles to play in instruction: (a) as an object to be

understood both in relationship to the circumstances and society in which we live and as useful means (when combined with appropriate software) for getting things done more efficiently, (b) as an object of study in its own right, as knowledge and skills to be mastered and (c) as a means of assisting the learning process.

Regarding the first role, computers are certain to have progressive and far reaching effects on future society. Developments have reached the point where every child must achieve some degree of computer literacy, if nothing else but to understand what is happening in the world around him or her. Since most educators feel this need personally, considerable attention is being devoted to this problem and little more will be said here.

The second major role for computers in education is sometimes equated with the first but is sufficiently different to warrant separate consideration. The emphasis in this case is on the computer itself. This includes learning how computers operate and developing the knowledge and skills necessary for getting computers to do what one wants (e.g., learning to program). Just as students should become as verbally and mathematically literate as possible, few educators would deny the need for today's youth to get as much training in these areas as they can reasonably absorb.

Some proponents of computer training, however, go considerably beyond these admirable goals. This view seems to be especially widespread among proponents of the LOGO programming language (e.g., Papert, 1980). In general, these individuals view learning in a manner analogous to the long

discredited "mental discipline" view that dominated educational thinking around the turn of the century. To wit: By learning to program, a person develops such skills as learning how to learn and how to create. As it has been put, they "learn how to control the computer instead of being controlled by it." It is undoubtedly true that students who learn how to program may learn (in varying degrees) general higher level skills in the process. But, learning to program is hardly unique in this respect. Higher level skills are a potentially natural outgrowth of any well-designed learning experience (e.g., see Scandura, 1971, Chapter 1).

Learning to program is a valuable skill and should be taught in schools. It would be a mistake, however, to think that learning LOGO, for example, is a viable substitute for learning mathematics or any other subject matter as has sometimes been claimed (e.g., Papert, 1980). To be sure, schools need to put as much emphasis as possible on acquiring learning skills, but this should be done in a variety of content areas, not just in learning to program. As stated by Professor Robert Tennyson of the University of Minnesota (personal communication) "LOGO at best deals with processes — but without a knowledge base, processes are limited in utility."

Just as with the new math of the 1960's, perhaps the greatest limitation of the LOGO movement is that its effects remain undocumented despite millions of dollars of federal money used to support its development. To use the new mathematics as an analogy, it is not unlikely that over emphasis on LOGO as a means of achieving more generalized educational objectives could result in the equivalent of learning the

language of mathematics (e.g., "sets", "relations", "functions" and even theorem proving) with correspondingly lesser abilities in using mathematics to solve problems. The moral of the story, as always, is all things in proper proportion.

The third major role computers can play in promoting school learning is in CBI. As mentioned above, previous attempts to introduce CBI on a large scale were largely unsuccessful. The use of time sharing systems in which one central computer was connected to a number of terminals typically offered variable response times and, for the most part, limited graphic capabilities.

In part because of these hardware limitations, the most successful early applications of CBI tended toward drill and practice — although some of the larger, better financed (but commercially unprofitable) applications, such as Control Data's PLATO (which includes sophisticated graphics) featured tutorial CBI systems as well.

The variety of computerized educational systems which exist today largely defy neat categorization. Nonetheless, contemporary CBI software systems tend to fall into one (or more) of three nonexclusive categories: drill and practice, tutorial systems, and simulations and educational modelling. Drill and practice refers to those CBI systems which are designed primarily to exercise previously learned skills. In arithmetic, for example, good drill and practice CBI systems attempt to build on student familiarity with computational algorithms, providing practice

which leads to higher levels of skill (i.e., to faster more accurate performance). Drill and practice systems have been developed for a wide variety of topics, ranging from enhancing typing skills to expanding foreign language vocabulary. Generally speaking, today's low cost microcomputers provide a highly cost-effective means for developing and delivering drill and practice CBI, a fact which has not gone unnoticed by educational publishers.

As the label implies, tutorial CBI systems are designed to teach new information as well as to excercise previously available knowledge. Building on the previous illustration, for example, a tutorial CBI system in arithmetic might explicitly introduce a student to the computational algorithms, rather than just exercise previously acquired algorithms.

Tutorial systems can be envisaged in almost every conceivable area, ranging from teaching basic concepts and principles (e.g., rules) to teaching complex, highly interrelated bodies of content. Generally speaking, to be classified as a tutorial system, the information taught must involve more than simply learning new facts (e.g., as in learning new vocabulary). The latter generally can be learned by simple drill and practice.

The simulation and educational modelling category is less well defined because the available CBI systems, which might be so classified, range from serious education to pure amusement. One could argue that

every well designed CBI system has some educational value — even PACMAN probably has some redeeming features. The relevant educational question, as always, is the value of what is learned when judged in terms of the time spent, and particularly whether all or some of that time might be better spent on other activities.

Unlike tutorials, which tend (but need not) emphasize instruction by verbal means, simulations emphasize instruction by illustration. In the simplest cases, for example, a simulation might consist of little more than an animated visual illustration showing, say, how an internal combustion engine operates.

This type of simulation, of course, might just as well be accomplished by film or/a mechanical modelling devise. As with all CBI applications, simulations must be interactive if they are to fully utilize the capabilities of the computer.

In this same vein, educational modelling may range from the trivial to highly interactive models with a serious educational message. In the latter category, for example, Howe (1982) and his associates at Edinburg and Bork and his associates at Irvine (1982) have developed a number of ingenious CBI systems which model significant segments of science (e.g., mechanics). These systems are highly interactive and are designed so that the student learns (or discovers) scientific laws governing the domains in question as he or she interacts with the systems.

To summarize, all three kinds of application have a valuable role to

play in instruction. Drill and practice is best where students need a high level of skill in a well defined area. Tutorial systems are best where what must be learned is clearly defined and where learning should be as efficient as possible. Simulations and educational modeling are best where the desired learning is more diffuse and/or less clearly defined. In this type of situation, one wants to introduce students to as wide a variety of related situations as is feasible in the hope that they will acquire a significant portion of what might be known.

VI. CONCLUSIONS AND RECOMMENDATIONS

Unlike many other countries where the federal government determines educational policy, state and local governments in the United States traditionally have been responsible for the implementation of school curricula. Indeed, the rate at which educational technology, particularly in the form of microcomputers, is being introduced into schools across the country attests to local wisdom in this respect.

As regards the federal role in instructional technology, the above analysis clearly demonstates the following: (a) Technology and particularly low cost microcomputers have a very definite role to play in education during the 1980's and beyond. These roles range from incorporating the study of technology into school curricula to the use of technology to improve instruction in other areas. (b) Although CBI systems have been of variable quality, the last couple of years has witnessed rapid growth in the quality of educational software. (c) While much remains to be done, we have learned a good deal about cognitive learning and instructional processes during the past 20 years. (d) Very little of the software which presently is available commercially, makes significant use of this knowledge base.

The foregoing analysis also shows that past patterns of federal involvement in educational research generally, and educational technology

in particular, have been less than optimal in their effectiveness. Specifically, the concentration of resources at a small number of R & D centers and laboratories has greatly diminished research competition and effectively robbed the nation of badly needed intellectual resources. Moreover, recent planning documents released by the N.I.E. suggest that, while serious questions are being raised about the lack of research competition, the concept of R & D centers per se could still be sacrosanct. If so, this could be a serious mistake. Given rapidly increasing international competition from Japan and elsewhere, as well as very real constraints on the federal budget, it seems imperative that the role of the federal government in educational technology be reevaluated without preconditions.

These observations lead to the following recommendations:

(1) Experience shows that commercially viable, large scale development efforts in educational technology may far more efficiently be handled by the private sector. In the present view, government at all levels, specifically including the N.I.E. labs and centers, should gradually withdraw from such efforts almost completely. Whatever savings accrue at the federal level from such changes in emphasis should be reallocated to basic research in instructional technology and to the development of advanced prototypes. The results of such efforts should provide the "seed corn" from which the private sector in the U.S.A. might draw.

(2) Although the long term payoff of basic research has been proven time and time again (as described herein in the case of educational technology), the results typically obtained are sufficiently general and the immediate payoffs are so unpredictable in any specific case, that it would be infeasible, and rarely cost effective, to expect significant direct support for this type of effort from the private sector or from states and local governments.

The federal goverment, therefore, should concentrate its efforts in educational technology on those things that can only or most efficiently be done at a national level. In general, this means an emphasis on basic research, including relevant instructional theory, instructional systems design, and the development of advanced technological prototypes and general informational services not otherwise attainable.

(3) Since the value of basic research is primarily contingent on the worth of ideas rather than simply magnitude of effort, federal support should be directed toward those individuals who propose the most promising programmatic efforts and who have demonstrated the ability to carry such efforts to fruition.

Specifically, whenever feasible, a variety of approaches should be funded. As this analysis clearly shows, putting all of one's eggs in one basket is a serious mistake when it comes to research and advanced development. A variety of smaller programmatic efforts over a period of time has time and time again proven its worth over the cyclic fadism which

too frequently has characterized behavioral research.

(4) In this regard, because of the time and often unproductive effort involved in preparing proposals, federal officials should give more attention both to minimizing such efforts (and correspondingly to placing more emphasis on "end products") and to cost-benefit analysis of the likely benefits of holding "open" competitions when less than, for example, 25% of the proposals can be funded.

Experience at other (non educational) research agencies suggest that it is far more efficient, both for agencies and proposers, for the agencies to make preliminary judgements based on brief letter proposals — if necessary with expert opinion from outside the agency. More complete proposals in such cases are only requested where there is a reasonably high possibility of funding. To insure that competitive ideas are fairly evaluated, reviewers at all levels should both be compensated for their time and held accountable for inaccuracies or bias in their reviews. (Minimizing bias, for example, might be accomplished by making reviewers known to proposers; this practice also might provide a useful mechanism for clarifying misconceptions.) Societal needs in instructional technology are too important to allow form to stand in the way of substance.

(5) Recommendations (3) and (4) implicitly assume that the Congress will recognize both the very real needs in instructional technology and the problems which have arisen as a result of noncompetitive funding of the N.I.E. centers and laboratories. It also assumes that the Congress

will reassign moneys currently mandated to centers and laboratories, making them available for free and open competition. (In this regard, it must be emphasized that the total amount of federal money allocated for research in educational technology is distressingly small when compared with that provided by the Japanese and many European governments. It is apparent, both to this reviewer and to everyone who has reviewed or otherwise reacted to this report that research funds should be increased to the extent that budgetary conditions will allow. There are few areas that could have more bearing on the future competitiveness of American society in a technological world.)

In the absence of Congressional reallocation (of the mandated center and laboratory funds), the definition of what constitutes a center or laboratory should be modified so as to place the emphasis on small, competitive programmatic efforts by independent researchers and their associates. In this context, for example, it could be a serious mistake to start one new center or laboratory in educational technology, not because more programmatic efforts in this area are not (badly) needed. It would be a mistake because such a center would inevitably end up dominated by one or at most two or three themes to the exclusion of otherwise equally competitive ideas.

A better way would be to fund a variety of smaller, competing programmatic efforts by leading investigators under center or laboratory auspices. These leading investigators would normally be scattered at

various locations throughout the country. Rarely are the best people at one institution.*

*Internal center/laboratory communication would not be a problem in this case because of the scientifically competitive nature of the respective efforts. Periodic scientific meetings and modern telecommunications would tend to minimize unproductive political activity and be more than adequate for scientific exchange. Evaluation of the various programmatic efforts within such a center might best be accomplished by independent and philosophically balanced teams of experts from "outside the system."

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