DOCUMENT RESUME

ED 373 740 IR 016 750

AUTHOR	Mills, Steven C.; Ragan, Tillman J.
TITLE	Adapting Instruction to Individual Learner Differences: A Research Paradigm for Computer-Based Instruction.
PUB DATE	94
NOTE	23p.; In: Proceedings of Selected Research and Development Presentations at the 1994 National Convention of the Association for Educational Communications and Technology Sponsored by the Research and Theory Division (16th, Nashville, TN, February 16-20, 1994); see IR 016 784.
PUB TYPE	Information Analyses (070) -- Speeches/Conference Papers (150)
EDRS PRICE	MF01/PC01 Plus Postage.
DESCRIPTORS	Academic Achievement; *Computer Assisted Instruction; Educational Research; Educational Technology; Elementary Secondary Education; Experiments; *Individual Differences; *Integrated Learning Systems; Knowledge Level; *Learning; *Media Adaptation; Models; Regression (Statistics); Research Design; *Student Characteristics; Teaching Methods; Technological Advancement
IDENTIFIERS	*Adaptive Instructional Methods; Computer Curriculum Corporation CA; Microanalysis

ABSTRACT

This paper examines a research paradigm that is particularly suited to experimentation-related computer-based instruction and integrated learning systems. The main assumption of the model is that one of the most powerful capabilities of computer-based instruction, and specifically of integrated learning systems, is the capacity to adapt instruction to the individual differences that exist among learners. The model is applied to an instructional treatment through a popular integrated learning system from Computer Curriculum Corporation (CCC). The problem of adaptive instruction is to diagnose, in any group of learners, where each is located in relation to individual learning characteristics and the knowledge and performances required at a given point in instruction. The research paradigm to be applied uses a microanalysis technique, based on a regression model proposed by previous researchers, that operationalized variables for each individual. Three figures illustrate the model and discussion. (Contains 49 references.) (SLD)

Title:

Adapting Instruction to Individual Learner Differences: A Research Paradigm for Computer-Based Instruction

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Classrooms of the twenty-first century will experience great changes due to emerging technologies and the development of new instructional delivery systems. Several companies have attempted to incorporate many of the instructional strategies of effective instruction into computer-based instructional programs called integrated learning systems. An integrated learning system (ILS) consists of computer hardware and software that is generally configured as a local area network (see Figure 1). An ILS provides a comprehensive package of software called courseware that provides computer-assisted instruction on a network of computers or terminals. The courseware also includes a management system that tracks individual learner progress and adjusts the instruction to a level appropriate for each learner.

COURSEWARE

CMI Management System	CAI Programs Curriculum

USER INTERFACE SHELL

NETWORK OPERATING SYSTEM SHELL

OPERATING SYSTEM SHELL

HARDWARE PLATFORM

File Server	Workstations
Printer	Network Interface Cards

Figure 1. A Conceptual Model of an Integrated Learning System.

Computer-based instruction is having a profound impact on both the field of education and our society. ILSs are experiencing enormous popularity and sales for most of the major systems have grown, some at a near phenomenal rate (Sherry, 1992). Large textbook publishing companies have purchased ILS companies and are investing heavily in reshaping them for the future. ILSs account for a large portion of the computer-based instructional systems currently used in public schools and many educators believe that these systems will continue to become more common in public schools (Sherry, 1990a).

In the 1950s educational researchers attempted to solve learning problems by applying the techniques of behavioral analysis as theorized by B.F. Skinner through programmed instruction. The concepts of programmed instruction were then applied to crude teaching machines which first appeared in the late 1950s and the early 1960s. Teaching machines and programmed instruction were used throughout the decade of the 1960s by colleges, public schools, and the military services. Price (1989) submitted that although research on programmed instruction generally indicated that it was effective, programmed instruction never achieved a high degree of popularity because it was tedious and dull and did not fit well with group-oriented, fixed-schedule school settings.

Computer-assisted instruction (CAI) was one of the earliest and most significant applications of computer technology to education. The computer industry itself was among the first to use CAI in the late 1950's when CAI was used to train industry personnel (Suppes & Macken, 1978). At a time when programmed instruction was the focus of educators for individualizing instruction, CAI emerged as a natural integration of computer technology and the programmed instruction movement (Schoen & Hunt, 1977). In the early 1960's federal funds to education provided a stimulus to develop CAI models (Atkinson & Wilson, 1969).

Early efforts to use computers in instruction developed from the guiding principles of programmed instruction. One such effort was a project at Stanford University headed by Patrick Suppes that created a complete system for computer-based arithmetic skills practice. The Stanford Project was begun in 1963 and its purpose was the development of a tutorial system to provide instruction in elementary mathematics, language arts, and reading. By the end of the second year of operation approximately 400 students received daily computer-assisted instruction in either reading or mathematics (Suppes, Jerman, & Brian, 1968). Computer Curriculum Corporation was formed in 1967 as a direct consequence of the Stanford Project and the need for curriculum-relevant CAI courseware. Computer Curriculum Corporation marketed computer-based instruction for minicomputer systems. Suppes and Morningstar (1972) validated the use of computers as effective teachers. Suppes and Morningstar maintained that the creation of many articulated programs instead of isolated topical lessons is required for computers to be used effectively to deliver instruction.

The purpose of this manuscript is to examine a research paradigm that is particularly suited to experimentation related computer-based instruction and integrated learning systems. This model for research is relevant when an experimental treatment incorporates an individualized or adaptive instructional strategy. Computer-based instruction possesses the attributes necessary to provide both the adaptive learning strategies and management capabilities for highly individualized instruction. The model is applied to an instructional treatment using a popular integrated learning system by Computer Curriculum Corporation (CCC).

Theoretical Bases for Research on Integrated Learning Systems

Recent theory development in human learning and cognition has narrowed the focus of educational research to variables and conditions that are directed to the promotion of learning rather than the improvement of teaching. The research paradigm for educational technology has evolved from testing an instructional technology, media, or method versus conventional instruction to one that identifies possible instructional variables that facilitate learning. A large number of the studies concerning the use of computers for instruction are described as media comparison studies (Parry, Thorkildsen, Biery, & Macfarlane, 1985). These studies generally emphasize the instructional capabilities of the media with little or no regard to the components of instruction and learning including instructional objectives, instructional strategies, learner characteristics, or the content of the instruction.

Salomon and Clark (1977) attribute the migration of educational research away from media comparison studies to a distinction in the ranks of researchers between "research with" and "research on" media (p. 102). Salomon and Clark further explain that research with media considers media as modes of stimulus presentation and provides little knowledge about the specific medium used, nor does it provide insights about how learners learn. Research on media deals with the relevant attributes of media that interact with individual differences to promote learning. Clark (1983) makes the analogy that media are vehicles that deliver instruction but do not influence student achievement any more than a truck that delivers groceries causes improvements in nutrition. While media comparison studies may indicate that one method of presentation is better than another under a given set of circumstances and based on student achievement measures, the studies fail to demonstrate which attributes of the instruction are responsible for the results (Stowitschek & Stowitschek, 1984). Media comparison studies limit the extent to which component variables are defined and operationalized (Parry et. al., 1985).

Differences in learning using instructional media should be attributed to certain characteristics of the instructional medium that provide conditions to facilitate learning. Research using media first considers a medium's attributes and determines its ability to actually relay these strategies. What is implied here is to study the capabilities of the medium and determine which instructional strategies it effectively conveys. If computers are utilized as a modern delivery system for instruction, research questions regarding the effectiveness of computer-based instruction should concern variables related to media attributes and instructional design.

One of the primary goals of computer-based instruction is to optimize learning through individualized instruction (McCombs, Eschenbrenner, & O'Neil, 1973). Computer-based instruction provides adequate technology to produce a learning environment that adapts instructional presentations to the individual differences of learners than would be possible under instructor management alone.

Since computer-based instruction is a relatively new instructional tool, many researchers and educators are interested in its potential to enhance learning. Much of the research comparing computer-based instruction to other instructional methods or media provides evidence of significant learning gains using computer-based instruction. Although the research indicates that computer-based instruction often promotes more learning than some other medium or method, these learning gains may be attributed to some feature of the media rather than the media itself. Clark (1983) maintains that there is clear evidence of consistent confounding in the research and submits that the confounding variable is the design of the instruction. Computer-based instruction generally requires a greater effort to design the presentation than the comparative media. Clark (1984) concludes that learning gains are attributed to adequate instructional design theory and practice and not from the medium used to deliver instruction.

The main contributions of evaluative and comparative research related to computer-based instruction may be the cost benefits and learner motivational issues to be considered when using computers for instructional purposes. The most constructive insight to be derived from this research is that although the computer as a medium may not possess any intrinsic value for increasing learner achievement, the important issues for research with computer-based instruction are concerned with the design variables used in the development of computer software.

Definition of Terms

Most terminology in this manuscript is used in the conventional sense of educational research. However, some terms require additional explanation for specific usage in this manuscript.

Adaptive Instruction. An adaptive instructional strategy uses one or more procedures to modify instructional activities to adjust for the variance in the aptitudes of learners. For purposes of this investigation adaptive instructional strategies are inferences made by a computer program about the aptitudes of learners that modifies the instructional presentation--usually by increases or decreases in the grade level, quantity, tutorial assistance, or speed of the presentation. Atkinson (1976) describes adaptive instruction as a process in which the sequence of instructional presentation and activities vary as a function of a learner's performance history. Hansen, Ross, and Rakow (1978) define adaptive instruction as a corrective instructional process that facilitates appropriate interaction between the learner and the learning task by systematically adapting the allocation of learning resources to the learner's aptitudes and recent performance. Hativa and Lesgold (1991) state that instructional software systems adapt instruction mainly to learning-rate differences. Corno and Snow (1986) note that the most direct manifestation of cognitive aptitude differences is learning-rate differences and that instructional designers usually build programs that adapt to learning-rate differences through individualized pacing with repetition.

Aptitude. Aptitude is generally considered to be a broad, multivariate concept that refers to the individual differences among learners (Corno & Snow, 1986). For purposes of this study aptitude is defined as a variable that is measured in terms of time. According to Carroll (1963) aptitude is the amount of time that a learner is willing to attend to a learning task in relation to the amount of time required by the learner to learn the task. The amount of time a leaner needs to learn a task under these conditions is the primary measure of the variable called aptitude. The measurement of aptitude is inversely related to time such that Carroll noted that "the shorter the time needed for learning the higher the aptitude" (p. 726). This notion of aptitude is particulary useful for research on integrated learning systems because individual differences among learners may be quantified as measures of engaged learning time and gains as recorded by the management program.

Computer-based instruction. Many discussions of computer-based instruction distinguish between computer-assisted instruction (CAI) and computer-managed instruction (CMI). In CAI the learner receives all of the instruction from the computer including tests and performance feedback while in CMI all learner testing is virtually accomplished on the computer but the learner may be directed to other media for further study (McCann, 1981). In this manuscript computer-based instruction includes both CAI and CMI or any comprehensive instructional system using computer hardware, software, and/or computer networks to deliver instruction.

Courseware. Courseware is software that is designed specifically for educational and training purposes. Courseware is a program or bundle of programs that provides instruction using a computer. In this manuscript courseware includes both the management and instructional components of the software.

Invidivualized Instruction. In this manuscript individualized instruction is a term used to denote the effects of adaptive instructional strategies. Individualization of instruction takes place when adaptive instructional strategies account for individual differences among learners and adjust instruction to a level and mode of presentation that is appropriate for each individual learner.

Strands. Strand is a term used by the CCC integrated learning system to define a set of exercises in one content area and arranged in order of increasing difficulty. A strand contains only exercises involving a particular skill or content area and spanning several grade levels. Skills are linearly ordered within each strand and are assigned approximate grade-level equivalents. Skills are presented in a cyclic pattern by introducing a skill at a lower grade level and then embedding it within another context and in a more complex exercise at higher grade levels.

Description of Integrated Learning Systems

Integrated learning systems are also called integrated instructional systems (IISs), integrated teaching systems (ITSs), or intelligent learning systems (ILSs). Van Horn (1991) describes ILSs as microcomputer systems that contain multi-year curriculum sequences. Maddux and Willis (1992) describe ILSs as comprehensive packages of software and hardware used for accomplishing educational goals, usually utilizing a local area network.

An ILS compiles an instructional program at the level a learner begins instruction and then continuously updates the instruction according to a cumulative assessment of learner progress. An ILS assesses a learner initially and then continuously during instruction and iteratively adapts the instruction to improve acquisition of knowledge. An ILS generally possesses an assortment of instructional variables and conditions to adapt the learning interface to the individual differences among learners. They contend that an ILS demonstrates characteristics generally associated with an experienced teacher such as knowledge and application of learning theory, subject matter expertise, appropriate assessment and measurement, and management of an effective and efficient learning environment.

Norton and Resta (1986) suggest that ILSs are the consolidation of two branches of instructionally related computing: (1) computer-assisted instruction (CAI) utilizes the computer as an instructional medium to provide tutorials and drill and practice of related skill areas; and (2) computer-managed instruction (CMI) utilizes the computer as a management information system enabling teachers to cope with the record-keeping requirements of individualized instruction.

Sherry (1990b) provides a number of general characteristics which describe the design and function of ILSs:

- Computer-based in which a majority of instruction is accomplished on a computer system.
- A networked system of multiple microcomputers or terminals.
- A management system which collects and maintains student records, prints reports, and provides diagnostic/prescriptive information for students based on individual progress.
- Courseware that spans several grade levels and several curricula (math, reading,

and language).
- Ongoing upgrades, revisions, and expansion of existing courseware.
- Links its lessons to an accepted standard curriculum and suggests sequences for lessons.

Maddux and Willis (1992) define ILSs as comprehensive packages of software and hardware used for accomplishing educational goals, usually utilizing a local area network. They suggest that ILS courseware accomplishes the following tasks:

- Assessment and diagnosis of student skills
- Delivery of instruction
- Continuous monitoring of student performance and automatic adjustment of instruction
- Generation of student and class performance data in a variety of formats

Instruction is individualized and personalized with ILSs and teachers are able to identify and individualize remedial activities. According to Bailey and Lumley (1991) the underlying instructional objectives of ILSs are based on individualized instructional strategies. These strategies include random generation of problems, adjustment of the difficulty and sequence of problems based upon learner performance, and provision of appropriate and immediate feedback.

Features of Best-Known Integrated Learning Systems

Several companies have invested heavily in ILSs in recent years. These companies include Computer Curriculum Corporation now owned by Paramount Communications, Curriculum Networking Specialists, Ideal Learning, Jostens Learning Corporation, MacMillan/McGraw-Hill, New Century Education Corporation, PLATO Education Services--The Roach Organization, Wasatch Education, and WICAT Systems. While each ILS may utilize distinctive instructional strategies and management approaches, there are many hardware, software, and instructional features and characteristics that ILSs have in common. These commonalities among ILSs are examined in more detail in this section.

Instructional Strategies

The instructional goals of the various ILSs cover a wide spectrum. Some systems are designed to be used for remediation, others for comprehensive instruction, and others for development of higher-order thinking skills. The instructional strategy used in the development of lessons can be categorized as either "skills-based" or "concept-based" (Wilson, 1990). Skills-based programs are designed to provide diagnostic or prescriptive intervention for remediation of precise skills. Concept-based programs are designed to develop problem-solving and higher-order thinking skills.

While many segments of ILSs consist of drill and practice and tutorials, a number of the systems offer more open-ended activities that combine basic skills development with an emphasis on problem solving and higher-order thinking skills. Many systems are incorporating tools for research and exploration by adding word processors and reference tools (electronic encyclopedias, atlases, and dictionaries) to their systems.

Maddux and Willis (1992) argue that ILSs generally follow a behavioral, competency-based model of instruction that was more popular in the past than it is today. They charge that ILSs do not fit well with the cognitive models of learning and teaching that have largely replaced behavioral theories. They criticize ILS vendors for commercial exploitation and being unresponsive to changing circumstances and developing turnkey systems that reflect the desires of the vendors and not the needs of teachers, parents, and students.

White (1992) declares that one's basic educational assumptions determine if ILS instruction is "good" education. According to White, ILS instruction provides systematic exposure to the curriculum, individualized pacing and review, tracking of errors and re-exposure to more instruction in order to reach the desired mastery level, and accurate and comprehensive records of each learner's progress. ILSs offer systematic drill and practice based on the premise that some learning has to be practiced until it is automatic, such as reading, vocabulary acquisition, and estimating of quantities. The more systematic the practice, the sooner the skills are mastered.

Shore and Johnson (1992) note that ILS vendors follow an instructional design and development process that attempts to ensure that the instructional strategies of the ILS are effective. They explain that the product development process at Jostens Learning Corporation begins by gathering information from teachers, school administrators, and parents in dozens of school systems within and outside the United States. The field data is evaluated and concepts grounded in theoretical, curricular, and instructional design expertise are developed.

Curriculum Areas

The most common curriculum among ILSs is mathematics followed by reading or a combination of reading and language arts. Science, computer skills, computer tool skills (word processing, spreadsheet, database), social studies and foreign languages are included in several of the systems (Wilson, 1990). Several systems include modules for GED preparation and ESL.

Computer Curriculum Corporation (CCC) and Jostens Learning Corporation software both offer learning activities appropriate for the development of higher-order thinking skills and problem solving. Computer Networking Specialists (CNS) specializes in reprogrammed versions of third-party software distributed through its Classworks management system. Customers select software from a list that includes programs from many leading educational software publishers. New Century Education Corporation offers a special reasoning skills module for grades three through nine. PLATO 2000 software offers courseware that includes modules which teach job search strategies, life coping skills, and parenting skills. Students using Wasatch Education System software have access to an online spelling checker, calculator, graphing function, Logo Language, glossary, database, and word processor while performing learning activities. WICAT Systems courseware is designed and keyed to complement major textbooks and several national and statewide tests used in schools today.

According to Power On! New Tools for Teaching and Learning, a 1988 report produced by the U.S. Congress's Office of Technology Assessment, the size and age of an ILS company corresponds to the grade span and scope of the courseware offerings. Bigger and older companies offer greater coverage while newer and smaller companies target fewer subject areas and a narrower range of grade levels.

Management Systems

Generally, ILSs provide sufficient program capabilities to manage a learner's program and measure the achievement of objectives. However, management programs vary greatly among the ILSs. The management approaches range from simple tracking of a student's time spent on a given learning activity to a complete evaluation of a student's programs each time the Enter key is pressed (Wilson, 1990).

In the past several years some of the ILS companies made significant changes in their management systems in response to customers' concerns for more flexibility and openness. Jostens and WICAT developed instructional management tools to integrate a broad set of curriculum materials. Several companies now offer systems that can simultaneously manage several different hardware platforms. Some of the management systems make it easy for teachers to create customized, multidisciplinary course sequences. Several of the ILSs allow educators the ability to customize student reports.

Some companies are favoring an approach that leaves more management control in the hands of teachers over an approach that automatically assesses students and assigns lessons. Additionally, some companies have added new testing and prescription capabilities that reflect the objectives of widely-used standardized tests and then provide individual prescriptions specific to those tests' requirements (Sherry, 1992).

Learner Characteristics

Most educators subscribe to the premise that individual learning differences, characteristics, and abilities exist among learners and that these factors should be taken into account in instruction. In a heterogenous classroom each individual has a different set of prior skills and understandings. Instructional activities are best constructed on an individual basis. ILSs have the capability to evaluate the achievement level and monitor the progress of all learners using the system across all grade levels, domains, and abilities. Learners are automatically channeled to appropriate lessons by the ILS.

Hardware Platforms

The ILS industry has been quick to respond to new developments in the personal computer market. The majority of the established systems operate on an MS-DOS network. However, with the introduction of a competitively priced color Macintosh several ILSs now offer Mac versions of their systems. A few companies still offer Apple II courses, but most new offerings do not run on an Apple II. Many of the ILS companies are moving to support their software under a Windows environment on IBM and IBM-compatible machines. The trend appears to be that within a few years all ILS vendors will offer their systems on Windows and Macintosh platforms only (Sherry, 1992).

Multimedia, Third Party Software, and Other Features

Multimedia is impacting the ILS world with more and more systems offering high-quality sound effects, digitized human speech and music, still photos, animation, and video. Several ILSs use CD-ROM to deliver encyclopedias with a variety of multimedia elements and some systems allow students to record and playback their own voices.

Another trend in the ILS industry is to offer networked versions of popular stand-alone software as options on the ILS. Additionally, many ILS companies are making it easier for school districts to launch third-party software from within the ILS. Some systems are going a step further by allowing third-party software to be included and delivered as part of the basic course activity sequence. This approach allows teachers to implement a combination of ILS courseware and third-party software.

Jostens and WICAT have developed instructional management tools that integrate a wide range of curriculum materials. These tools allow educators to develop a curriculum design that links ILS courseware with school-district objectives, lessons plans, and other off-line materials. Some systems allow teachers to create customized, multidisciplinary course sequences by picking and choosing from available ILS offerings.

ILS Configurations

Although most ILSs are designed around a local area network, several implementation patterns are utilized in different educational settings. In a lab configuration all the computers in the network are physically located in one room or area of a building. A coordinator or aide may schedule students or classes in the computer lab and manage the operations of the computer network (hardware and software). The lab coordinator or aide may also tutor students while in the computer lab.

In a distributed system several workstations in the network are located in various classrooms around the school building or school system. Since computer resources are distributed to various learning areas, a distributed system requires the classroom teacher to manage computer resources.

A Research Paradigm for Conducting Research with ILSs

As the costs of computing technology have steadily declined, the availability of computer-based instruction has become a reality for classroom applications. Most courseware includes advanced features such as graphics and animation, interactivity, and individualized feedback. Although these features certainly enhance the appeal of computer-based instruction, the fundamental questions regarding computer-based instruction ask how well the instruction actually teaches and how much the learners actually learn.

Research findings that examine the effectiveness of computer-based instruction are often positive (Bangert-Drowns, Kulik, & Kulik, 1985; Kulik, Bangert, and Williams, 1983; Kulik & Kulik, 1987), However, these findings are not always convincing or consistent enough to sanction computer-based instruction as better than conventional instructional strategies (Clark, 1983; Salomon & Clark, 1977). One of the goals of research related to computer-based instruction is to determine better ways to utilize its attibutes, features, and delivery capabilities more productively.

The research regarding computer-based instruction is generally organized around the dual role of the computer in providing effective instruction. Some researchers advocate the use of the computer as a problem-solving aid or tutor (CAI) in a conventional educational environment while other researchers champion the computer in the role of managing instruction (CMI). This study considers the effectiveness of of both the CAI and CMI capabilities of computer-based instruction through an investigation of the adaptive instructional strategies used in the courseware of a popular ILS.

The main assumption of this research paradigm is that one of the most powerful capabilities of computer-based instruction and, specifically integrated learning systems, is the capacity to adapt instruction to the individual differences that exist among learners. Through individualized or adaptive instruction ILSs have the potential to deliver an appropriate level of instruction for all learners and, therefore, improve instructional efficiency and effectiveness. The research model described in this manuscript considers the adaptive learning strategies by Computer Curriculum Corporation's (CCC) courseware. The CCC Curriculum Profiles (1989) describe CCC courseware as "performance-based instruction that leads to rapid academic gains" (p. 2) as a result of an individualization process that continuously adapts instruction for each learner.

Adaptive instructional strategies facilitate learning by adjusting learning conditions to the individual learning differences among learners (Tobias, 1976; Rothen & Tennyson, 1978). A computer-based adaptive instructional strategy employs on-line, iterative algorithms to access an extensive data base and adjust the learning environment to the unique learning characteristics and individual differences of each learner (Tennyson & Rothen, 1979). The underlying assumption of a computer-based adaptive instructional strategy is that the effectiveness of the learning process is increased over conventional instructional methods because learners receive only the amount of instruction required to master the instructional objectives (Rothen & Tennyson, 1978).

According to Rothen and Tennyson (1978) the primary data sources for implementing adaptive learning strategies are pretask measures and on-task measures of learner achievement. Pretask measures are used to diagnose a learner's aptitude for learning particular skills and are derived from such measures as scores on an aptitude or achievement tests or pretest scores on the learning task. On-task measures are based on an analysis or evaluation of learner performance during the instruction. Rothen and Tennyson claim that pretask and on-task measures of learner achievement using adaptive instruction differ substantially from data obtained using conventional instructional methods. Conventional instructional methods identify how the learner answers but do not identify the cognitive strategies leading the learner to the answer. Tennyson and Rothen propose that the most important consideration of an adaptive instruction strategy is to identify psychological causes for learning and therefore decrease the probability that mistakes will occur.

The adaptive strategies frequently employed by commercial courseware are often weak and involve merely determinations of pacing and sequencing that are derived internally by the learner or externally by the computer program (Ross & Morrison, 1988). Learner control strategies are adaptive only to the extent that learners possess the appropriate knowledge, maturity, and motivation to apply effective judgements about their learning needs (Carrier, Davidson, & Williams, 1985; Ross, 1984; Ross & Morrison, 1988; Steinberg, 1977). The elaborate management system of ILSs purportedly possess the capability to provide a comprehensive strategy for adapting instruction based on both pretask and on-task measures.

Another assumption evident in this research model is that individual learners require different levels of instruction based on their aptitude in the skills being taught and that measures of prior learning generally constitute strong indicators of learning needs in inverse relation (e.g. low prior achievement indicates a need for high instructional support) (Tobias, 1976). This study hypothesizes that an ILS adapts the magnitude of instructional support for each learner through successive revision of the difficulty, type, quantity, and sequence of instructional activities and exercises based on the on-task learning trends of the learner.

Stated another way, the problem of adaptive instruction is to diagnose in any group of learners where each is located in regard to individual learning characteristics and the nature of the knowledge and performances required at a given point in the instructional process (Seidel, 1971). Once this assessment is made, the control processes of the instructional system must utilize the feedback from the learner to continuously refine the estimate of the learner's progress. The focus of research for the model described in this manuscript concerns the adequacy of the adaptive learning strategies utilized by a model integrated learning system to accurately assess a learner's achievement level and provide an appropriate amount of instructional support.

A Micro Theory of Adaptive Instruction

Most applied individualized instruction models or programs such as mastery learning or Keller's (1968) Personalized System of Instruction (PSI) establish conditions for learning based on high instructional support that features the availability of as much time and resources as the learner requires to achieve the learning objectives. A frequent problem with these approaches to individualized instruction may be the selection of too much support by high achievers and too little support by low achievers due to the fact that personal prescriptions as to how much instructional support is necessary for each learner are not provided, leaving it to the learner to make those decisions (Ross, 1984). Interest in this problem and the potential that computer-based instructional systems possess for adapting instructional support to individual differences among learners has prompted some researchers to propose alternative designs of individualized instructional models.

Ross and Morrison (1988) developed a model for systematically adapting the amount of instructional support to individuals. The pre-instructional components of the model consisted of selecting predictor variables, developing predictive equations, and selecting appropriate instructional prescriptions. The instructional components consisted of prearranging and administering learning materials according to the individual learner's prescriptions, administering a formative lesson posttest upon completion of each lesson, and use of the lesson posttest to refine instruction. The Ross and Morrison model selected pretask (entry) variables as a basis for predicting learner performance. As a result of prior research (Hansen, Ross, & Rakow, 1978; Ross, 1984; Ross & Rakow, 1982) Ross and Morrison developed predictive equations about learner achievement by regressing lesson subtest scores on entry variables.

Data analysis in educational research is traditionally performed using classical statistical theories that compute a coefficient based on some sort of group average. When research projects examine the effects of individualized instructional strategies, the analysis must compute a coefficient based on factors that characterize a different treatment for each individual learner because the treatment is different for each individual learner. Macken, Suppes, and Zanotti (1980) explained that such a design is more appropriate for research projects that analyze individualized instruction because this design considers a different treatment for each individual learner. Macken et al. argued that a global analysis of data involving individualized instruction requires operationalizing on factors that characterize the individual treatment conditions.

Suppes, Fletcher, and Zanotti (1975, 1976) proposed a micro theory for analyzing and evaluating individualized instruction. The model is similar to the Ross and Morrison (1988) model. In the Suppes et al. model the amount of time a learner spends on a learning activity is a function of the learning progress made by the learner. A learner's achievement as related to the course objectives is expressed as post-treatment grade placement. This theory was tested and used to achieve precise individualization of instruction both in the quantity of instruction and the achievement goals for each learner (Malone, Suppes, Macken, Zanotti, & Kanerva, 1979; Suppes, Macken, & Zanotti, 1978; Suppes et al., 1975, 1976).

Suppes et al. (1975, 1976) micro theory of individual performance expresses a predictive equation about expected learner outcomes using variables based on the individual performance of each learner. Each learner's progress through a curriculum, the learning trajectory, is expressed by a family of curves in the form

$$y(t) = bt^k + a$$

where y(t) is a learner's grade placement, t is the amount of time spent in the curriculum, k is a parameter estimated for a particular curriculum, and b and a (slope and intercept) are individually estimated for each learning trajectory.

Malone et al. (1979) refined this micro theory model to predict a future trajectory based on observations of past performance. In an analysis of ten possible models Malone et al. determined that a model in which the learning trajectory increased linearly from the last observed point at a learning rate b that is the slope of a line determined by data for all learners best predicted future achievement. The learning trajectory for this model is expressed in the form

$$y(t) = b(t - t_r) + a(t_r)$$

where y(t) is a learner's predicted grade placement after t amount of time spent in the curriculum, b is the slope of a line that best fits all the points for all students, t_r is the time of the most recent observation, and a is the grade placement at the intercept. This model basically predicts that a learner's estimated grade placement continues to rise from the last observed point at a rate that is about the average rate for the population as a whole.

A corollary of this model postulates that a learner's grade placement increases with the square root of engaged learning time was also determined by Malone et al. (1979) to effectively predict future achievement. This model takes the form

$$y(t) = b(t^{.5} - t_r^{.5}) + a(t_r)$$

Malone et al. (1979) distinguished two uses of this model as curve fitting and prediction. They explained that the model may be used to approximate student learning curves based on data from an entire school year or the model may be used to predict grade placement at some future point based on observed data for part of the school year.

A critical feature of the adaptive models and theories advanced by Suppes et al. (1975, 1976), Malone et al. (1979), Ross and Morrison (1988), and Ross and Rakow (1982) is the capability to formulate prescriptions systematically tailored to the inferred needs of individual learners. This critical feature of adaptive instruction provides a basis for the primary research objective proposed for the model described in this manuscript that it is possible to determine reliable prescriptions for learner achievement when an instructional model is effectively adapting instruction. Furthermore, one way to measure the effectiveness of an adaptive learning strategy is to measure the reliability of predictions about learner achievement based on observations of learners' past achievement during the adaptive treatment. Specifically, this manuscript proposes to extend the micro theory research of Suppes et al. and Malone et al. by correlating the predictive quality of an instructional treatment with the adaptive quality of an instructional treatment.

The present research proposal identifies and describes the adaptive processes and strategies programmed in the CCC courseware and hypothesizes the predictability of learner outcomes based on the adequacy of these adaptive mechanisms. To determine the adaptive quality of the instruction provided by the CCC integrated learning system, several research questions are considered. Is the instructional treatment sufficiently adaptive to formulate reliable predictions about individual learner achievement? Does the CCC integrated learning system provide a better estimate of learner aptitude than an external measure of achievement? Does increased instructional time provide a more reliable prediction of learner achievement?

CCC Instructional Design

CCC courseware is organized into strands that contain a sequence of exercises from the same content area. Exercises within strands are grouped into equivalence classes and ordered according to their relative difficulty. Grade levels are assigned to each equivalence class according to the appearance of similar exercises in elementary textbooks and standard achievement tests (Malone, et al., 1979). During an instructional session a learner receives a random mixture of exercises from all the strands appropriate for that learner's grade level and then the difficulty level of exercises is adjusted to the learner's achievement level in the strand. The management system determines a weighted average of the learner's grade placement across all strands in a course (Macken et al., 1980). This grade placement across all the strands is the variable that is of particular interest for this study in determining the adequacy of the adaptive strategies employed by the courseware.

According to the CCC Curriculum Profiles (1989) CCC employs a mastery learning model in their integrated learning system. The CCC learning model bases proof of mastery on answer patterns rather than on a percentage of correct answers. This strategy ensures that each learner automatically advances within a skill area as soon as mastery is achieved. Progression through a skill area is paced by the learner's actual performance. CCC maintains that this performance-based strategy based on answer patterns keeps learners fully engaged and challenged. The Curriculum Profiles state that CCC courseware can produce rapid academic gains in learners as a result of an individualization process that produces instruction that is continuously adapted for each learner. Several features in the design of CCC courseware contribute to the individualization of instruction:

- The foundation of the instructional strategies employed by CCC courseware is the availability of a comprehensive curricula in several skill areas. In order to individualize and adapt instruction for a large number of learners working at a variety of skill levels a vast amount of instructional material is required.
- Initial placement motion adapts the beginning level of instruction to learner performance. During the first ten sessions a learner spends in a course, the system automatically adapts the level of instruction to the learner's functional level based on the learner's actual performance regardless of initial enrollment level.
- Special tutorial support in the form of focused sequential practice, interactive tutorials, repeated prerequisite instruction, and immediate or delayed review is activated when a learner has difficulty in mastering a learning objective.

CCC Adaptive Instructional Strategies

CCC courseware attempts to improve learning conditions through individualized instruction in which learning activities are continually adapted to individual learning differences. The CCC courseware used for this study is Math Concepts and Skills. The Teacher's Handbook for Math Concepts and Skills (1991) identifies several adaptive strategies that occur in this program:

(1) Motion algorithms. A learner's path through the curriculum is determined by an evaluation of his or her performance by the automatic management system as the learner works each exercise. The management program uses this evaluation to select the next exercise or tutorial. Therefore, each learner advances through a course along a unique path that is shaped dynamically based on the learner's responses. The selection of exercises during a learner's session is based on the learner's performance level in each active content area or strand and the sequence of responses the learner makes to the exercises. A skill remains active until the learner demonstrates mastery of it or takes the maximum number of exercises allowed for the skill. Figure 2 summarizes the decisions the CCC management system makes while a learner works a sequence of exercises in a particular skill.

Evaluate Learner Performance
AFTER EACH SESSION

Current Level OK? — YES → Begin Next Session at Same Level

NO

Difficulty at Current Level? — YES → Subtract .20 of a Grade Year from Each Strand Level

NO

Could Work at Higher Level? — YES → Add .20 of a Grade Year to Each Strand Level

End of Session

Figure 2. Decision process used to determine Initial Placement Motion in CCC's Math Concepts and Skills.

(2) Initial Placement Motion (IPM). IPM is an adaptive process that successively revises the learner's grade level in each strand as set by the standard course motion. Each learner is enrolled in the course based on performance or achievement external to the program. The IPM process is active during the learner's first ten complete sessions and evaluates learner performance and revises the learner level at the end of each session as shown in Figure 3. The assumption is made by the CCC management program that the duration of IPM and the magnitude of its increases are such that the process provides a comparable measure of the learner's performance and stabilizes on the learner's functional level in most cases.

(3) Proportion of exercises. The proportion of exercises presented from each strand is based on a fixed proportion and an individualized proportion. The fixed proportion weights each strand relative to the other strands and is derived from the standard weighting provided in most elementary mathematics textbooks. The fixed proportion sets the initial probabilities the

management system follows in selecting strands and is modified by the management system for an individual learner based on his or her performance in the strands. When a learner falls behind in a particular strand, the proportion of exercises provided to a learner in the respective strand where the learner is below his or her average level is automatically increased. Adjustment of the individualized proportion is independently determined for each learner.

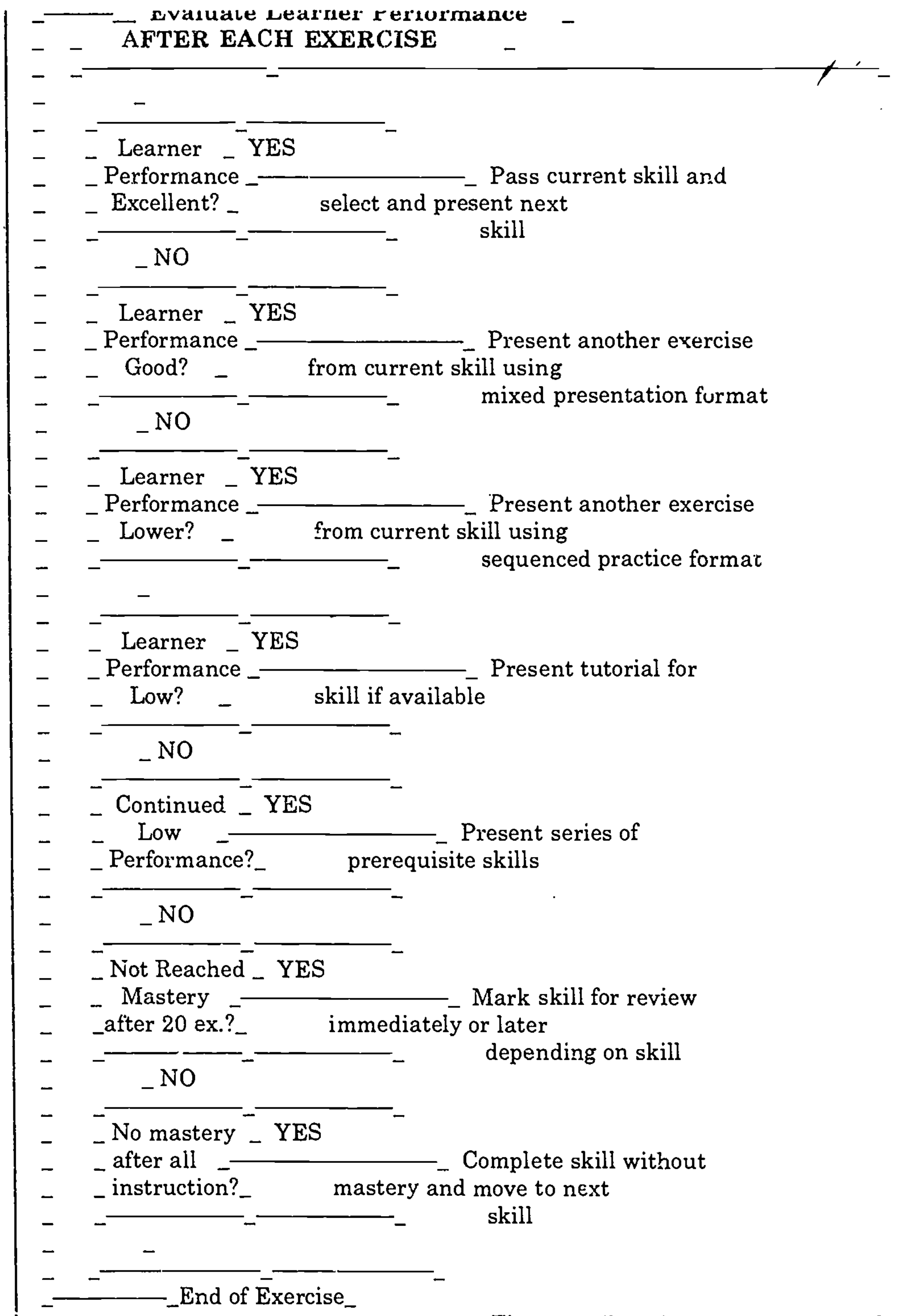

Figure 3. Decision process used to dete[r] standard motion and learner progress in CCC's Math Concepts and Skills.

Several system resources allow learners to control the instructional process. These resources include Help, Audio Repeat, and Tutor. Help provides an example of how to answer a particular exercise. Audio Repeat is present during any session that includes exercises in which audio instructions and reinforcement are available. General tutorials provide examples of how to work a particular type of exercise. Context-specific tutorials explain a specific step or operation in an exercise.

CCC Courseware Content and Structure

According to the Teacher's Handbook for Math Concepts and Skills (1991) the skills presented by the course reflect the content of current elementary mathematics. Course content includes a broad range of higher-order thinking skills to complement the basic skills taught in the course. Math Concepts and Skills is organized by grade level within each strand. Each objective in a strand includes at least one sample exercise. There are 16 content areas or strands and a total of 1,186 mathematics skills that are typically taught in kindergarten through the end of the eighth grade. The CCC management program adds or drops strands as learners progress through various grade levels of the course.

The Teacher's Handbook for Math Concepts and Skills states that the most effective way to ensure long-term rentention of skills is a "mixed presentation . . . in which the student sees a mixture of exercises from all the strands active at his or her grade level" (p. 14). Course sequencing employs a mixed presentation strategy by selecting exercises from several strands during each session.

Math Concepts and Skills uses two formats for presentation of math exercises on the computer screen. Standard arithmetic formats require learners to respond by typing words or numbers. Graphic formats use graphic representations of figures and objects to illustrate concepts and skills and learners respond by clicking the mouse pointer on objects on the screen, moving objects, drawing lines, or entering numbers or words. Both exercise types are instructional, reinforcing, and corrective.

Hypotheses and Research Objectives for Micro Theory Research

There is evidence in research related to learning and instruction that individual learners require different levels of instruction based upon their aptitude in the skills being taught. There is further evidence that measures of prior and on-task achievement generally provide strong indicators of individual learning needs. Computer-based instructional systems possess the potential for adapting instructional support to the individual differences and aptitudes among learners.

Rather than employ classical statistical theories that compute a coefficient based on some sort of group average, research projects that examine the effects of individualized instructional strategies should compute a coefficient based on factors that characterize a different treatment for each individual learner because the treatment is different for each learner. This paper proposes research objectives that examine the effects of the adaptive instructional strategies employed by the CCC integrated learning system by formulating a predictive equation for each learner about expected learner outcomes using variables derived from the individual performance of each learner. This predictive equation is based on a theory developed by Suppes, Fletcher, and Zanotti (1975, 1976) in which the amount of time a learner spends on a learning activity is a function of the learning progress made by the leaner. A learner's achievement as related to the course objectives is expressed as post-treatment grade placement.

Based on the adaptive processes and strategies employed by CCC courseware, this paper proposes four research objectives that hypothesize the predictability of learner outcomes as a result of the adequacy of these adaptive mechanisms. These research objectives are relevant for validation through statistical procedures:

(1) The instructional treatment provided by the CCC integrated learning system is sufficiently adaptive to formulate reliable predictions about individual learner achievement. This hypothesis is intended to test the degree of adaptation of instruction through standard motion and other adaptive strategies by determining if there is a significant difference between predicted learner outcomes and actual learner outcomes.

(2) The CCC integrated learning system provides a more reliable estimate of learner

aptitude than an external pretask measure of learner achievement. This hypothesis is intended to test the Initial Placement Motion strategy of the CCC management system.

(3) Increased instructional time and adaptive iterations using the CCC integrated learning system increase the reliability of the prediction of learner achievement. This hypothesis is intended to determine if the precision of the predictive equation is improved as engaged learning time is increased.

(4) Differences between aptitude and achievement among learners using the CCC integrated learning system decrease as instructional time and iterative adaptations increase. This hypothesis is intended to test the assumption that an effective adaptive learning strategy induces a leveling effect or flattens differences between high and low aptitude learners.

Summary and Conclusion

To improve the effectiveness of their products, ILS vendors and developers must continually analyze how to revise and refine their courseware, basing it on a morecomplete and accurate theory of effective instruction and learning. Computer Curriculum Corporation, as well as most ILS vendors, claims that its system of computer-based instruction provides significant increases in learner achievement based on individualized instruction through adaptive strategies that account for individual learning differences. Research must be conducted to determine the success or failure of instructional strategies employed by ILSs and validate the claims of ILS vendors.

The basis for a school in purchasing technology in many cases is the improvement of achievement scores in all areas (Bender, 1991). Companies that market ILSs often claim that their product can improve scores on achievement tests. If ILSs are proven to improve scores on achievement tests, the next questions asked are by how much and what is the cost? For school officials price is obviously a major consideration when purchasing educational technology. School officials must have the data available to compare the relative advantages of ILSs to other forms of instructional technology in order to determine which technology provides the most education per dollar.

The research model described in this manuscript is intended to contribute to the body of knowledge regarding computer-based instruction as well as propose possible research objectives for statistical validation. This research model attempts to focus on particular design variables of computer-based instruction. When highly individualized instructional strategies are used in a research project, classical research designs often do not produce a satisfactory analysis of the data. The research paradigm described in this manuscript employs a micro analysis technique based on a regression model as proposed by Suppes et al. (1976) and Malone et al. (1979) that operationalizes on variables for each individual.

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