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ABSTRACT

The exponential increase in the availability of microcomputers will have a tremendous impact on educational research. Already, the microcomputer has provided the key to the solution of some previously overwhelming methodological problems. It has enabled investigators to conduct exciting new lines of research while creating more general implications for future disciplined inquiry within the educational community. Educational researchers, aware of the importance of this new technology, are seeking guidance. There are primarily three areas of application for the researcher who is considering the use of a microcomputer: (1) use of the microcomputer to control experiments, (2) use of the microcomputer to collect data, and (3) use of the microcomputer to process data and results of research. This monograph reviews state-of-the-art microcomputer applications and provides guidance for evaluating and comparing microcomputers, for pursuing research objectives with microcomputers, and for ferreting out further information concerning microcomputers. Resources for microcomputer research applications, checklist of product performance, and a microcomputer top ten buyers' guide are included. (Author/PN)

MICROCOMPUTERS IN EDUCATIONAL RESEARCH

ERIC/TM REPORT 82

by
Craig W. Johnson

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ERIC CLEARINGHOUSE ON TESTS, MEASUREMENT, & EVALUATION
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Microcomputers in Educational Research

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December 1982

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Abstract

The exponential increase in the availability of microcomputers will have a tremendous impact on educational research. Already, the microcomputer has provided the key to the solution of some previously overwhelming methodological problems. It has enabled the conduct of exciting new lines of research while creating more general implications for the future conduct of disciplined inquiry within the educational community. Educational researchers, aware of the importance of this new technology, are seeking guidance.

There are primarily three areas of application for the researcher who is considering the use of a microcomputer: (a) use of the microcomputer to control experiments, (b) use of the microcomputer to collect data, and (c) use of the microcomputer to process data and results of research. This monograph reviews state-of-the-art microcomputer applications and provides guidance for evaluating and comparing microcomputers, for pursuing research objectives with microcomputers, and for ferreting out further information concerning microcomputers.

The invention of the inexpensive microcomputer has placed an amazingly powerful and flexible instrumentality, capable of launching a quantum methodological leap forward, within the grasp of the typical educational researcher. Like Skinner's invention of the cumulative recorder, it represents a milestone in behavioral technology. But, unlike the cumulative recorder, whose applications and significance were most appropriate for animal behavior, the microcomputer has most direct relevance and application to human behavior. Microcomputers are revolutionizing the technology for controlling and replicating experimental procedures while facilitating more effective integration of research with classroom practice. Microcomputers are revolutionizing procedures for precise measurement and accurate analysis while facilitating quick communication of multifaceted experimental results to the research community. And microcomputers are simplifying implementation of experiments, lending economy to both basic and applied investigations, while more generally enhancing the credibility of research in education.

Research applications of microcomputers to educational pursuits have entered a seminal stage. Already, previously inconceivable and previously impossible kinds of research are being conducted on an ongoing basis. Such efforts are still relatively rare, but that will change as quickly as the amazing versatility and growing power of the microcomputer's capacities to control, monitor, and analyze information become more widely known.

Why a microcomputer? What is a microcomputer? How does the microcomputer work? What are the comparative advantages and disadvantages of microcomputers versus mini or mainframe computers? How can the microcomputer help ferret out knowledge about the processes of learning and instruction? How is the microcomputer presently being used in the conduct of educational research? What should you know about the microcomputer to use it most effectively? These are some of the important questions addressed in the following pages.

Why a Microcomputer?

For years, psychological and behavioral journals (e.g., Behavior Research Methods & Instrumentation) have presented impressive descriptions of the successes achieved by computerized learning research laboratories with equipment costing tens or hundreds of thousands of dollars (Scholz, 1978). Advances in computer technology have been so rapid, however, that many of the dedicated laboratory minicomputers which served the elite of the research community during the late seventies have become obsolete and are primitive in comparison with state-of-the-art microprocessor techology.

The microcomputer of today typically has more programmable memory, is easier to program, has quicker access to a greater memory storage area, and costs considerably less (by factors of 10 or 100, depending on the system) than the average laboratory minicomputer of the very recent past. Sophisticated control and data acquisition processes are now readily accessible to individual investigators in small institutions. Consequently, it has become vitally important for the educational research and evaluation community to know what microcomputers can do and how they can be made to do it.

A small program written in BASIC and in use in ongoing research (Johnson, 1982a, 1982c) demonstrates some of these capabilities. It conducts a totally automated double blind experiment. The experiment compares the effectiveness of two keyword techniques (Atkinson, 1975; Levin et al., 1979) of vocabulary acquisition with a "use your own method" control on both an immediate and a delayed, or follow-up, occasion.

The program (1) collects identification information; (2) obtains scores on a prior knowledge covariate; (3) randomly assigns subjects to three treatments after obtaining prior knowledge ratings; (4) presents different instructional sets to the three different treatment groups; (5) presents 15 abstract and 15 concrete to-be-learned items to the three different treatment groups for identically specified time intervals (15 seconds per item); (6) presents retention test instructions; (7) presents the 30-item retention test; (8) for each subject, independently randomizes the presentation order of all items in all phases of the procedure; (9) randomizes the order of alternatives within items of the test of retention; (10) monitors, scores, and stores (on diskette) prior knowledge covariate and retention test performances (including rating task, learning task, and total treatment completion times; rating responses; and item, subscale, and total test scores for each subject); and (11) administers the individually randomized follow-up test on a second occasion, storing the identification information, completion times, and scores. As powerful and flexible as the program is, it occupies less than 11K (1K is the amount of computer memory needed to store 1024 letters, numbers, or characters).

Using a telephone-link communications device, or modem, the data, which are stored on a small 5 1/4-inch floppy disk, may be transmitted directly to the institution's mainframe computer for sophisticated multivariate repeated measures analyses. Simpler analyses may be performed using only the microcomputer. After analysis, results of the research may be typed up using the same microcomputer's powerful word-processing capabilities.

Understanding the Microcomputer

A microcomputer is a complete computing system technologically fabricated from large-scale integrated circuit silicon wafers, or chips, interconnected on a printed circuit board. The typical microcomputer system includes a memory and input and output connections, or ports, for attaching printers, plotters, TV monitors, disk or cassette drives, and other peripheral devices.

When you turn on a typical microcomputer system, a set of instructions, called a bootstrap program in nonprogrammable memory (ROM, or read-only memory) clears the programmable memory (RAM, or random-access memory), sets up input and output devices, and loads and runs the operating (OS) from ROM, disk, or cassette where it is stored. The operating system is another set of instructions (program) which, when activated, manages the microcomputer system's physical components, or hardware. It is a sort of master control program which, like a traffic cop, directs and keeps track of information flow to and from the central microprocessing unit (MPU), memory storage areas, and peripheral devices. It typically includes utility programs (utilities) for developing, loading, perusing, running, saving, copying, modifying, and erasing data and applications programs. The operating system usually includes a disk operating system (DOS) for controlling disk drive functions. The disk or diskette has become the primary medium for storage of programs and data for microcomputers.

All instructions operate on the MPU: perhaps a 6500 series microprocessor (used in Apple II, Atari, Commodore, Ohio Scientific), a Z-80 (TRS-80 Models II & III), a 8088 (IBM-PC, TI 99/4), or a 68000

(TRS-80 Model 16). The MPU is equipped with at least one arithmetic logical unit (ALU) for arithmetic, logic, and data transformations. Within the MPU there are also a number of internal registers, which are temporary memory storage locations. When instructed to do so, the MPU can access data stored anywhere in the system's addressable memory and operate upon them, copy them, or transfer them to another area of memory. All data are stored and transferred as sequences of on-off or 1-0 (binary) states, or bits. A sequence of eight bits forms a byte. It takes one byte to uniquely represent and store a letter, number, or special character. One kilobyte (1K) is 1,024 bytes, so a microcomputer having 64K of RAM can store up to 65,536 characters in RAM.

Human beings do not process long strings of ones and zeroes particularly effectively. Consequently, shorthand codes have been invented to ease the process of instructing the MPU. At the next level of complexity above binary, the representation of instructions is usually in the base 16 number system, hexadecimal. Hexadecimal represents the four-bit binary "1001" as "9" and "1111" as "F." Consequently, eight bits or one byte may always be represented by two hexadecimal digits. Specific sequences of binary or hexadecimal code then are reserved to represent specific instructions to the MPU. For example, the binary sequence "01100000," which is represented as "60" in hexadecimal, is entered as the last command of a subprocedure (subroutine) in a machine language program for the 6502 MPU and tells it to return to the main program.

Since hexadecimal has no inherently great mnemonic value for human beings, mnemonic codes have been invented to represent the hexadecimal representations of the sequences of binary states the MPU can process. In

6502 assembly language the above command to "return from subroutine" would be represented as the mnemonic "RTS" operation code (opcode). Assembly language allows construction of rapidly executing programs using meaningful mnemonics at the level of direct MPU commands, but such programs must be assembled into hexadecimal or binary machine language before they will execute. Programs may be assembled by hand, but the use of an assembler program which converts assembly language source code into machine language object code is customary. Unfortunately, different MPUs have different instruction sets. The 6502 alone has 56 different opcodes, many of which have multiple ways of coding where information is stored (addressing modes), so the task of assembly language programming is also complex.

Higher-level languages (e.g., APL, BASIC, COBOL, FORTRAN, FORTH, LISP, Logo, PASCAL, PILOT) have been designed to ease programming and improve transportability of programs across systems having different microprocessors. A typical BASIC program without graphics manipulations will usually execute on a sytem from a different manufacturer with relatively minor program syntax changes. However, because each language has multiple dialects, it is usually impossible to run a program developed for one system on a system built by a different manufacturer unless the second system has an emulator, which enables it to behave like the first, or a standardized operating system like CP/M or UNIX. Such operating systems still do not allow a user of a computer to routinely transport programs for use on other computers made by different manufacturers without transcription, because the formats in which information is stored and retrieved are typically incompatible across manufacturers. For example, different manufacturers typically use different disk formats, and formats are changed as technological improvements are made.

Higher-level language programs must also be translated to machine code before they can be executed. Such programs may be translated line by line by an interpreter in an ongoing process. This method is slow but allows interactive use of the computer and is a key element in the popularity of BASIC and Logo. Programs may also be translated all at once before execution by a compiler, as has been customary with COBOL and FORTRAN. This process results in speedy execution, but it necessitates a separate compilation step.

Fortunately, telecommunication between machines is relatively standardized in the form of the American Standard Code for Information Interchange (ASCII). (There are also two other codes: EBCDIC, used by IBM, and Baudot.) In ASCII code the uppercase letter "A," for example, is represented by hexadecimal "41." So, in practice, given the appropriate communications software, it is not difficult to transmit or receive a file of information which has been constructed as consecutive organized groups, or records, of ASCII characters. The information is transmitted over a telephone line using a device called a modem to connect the microcomputer to the telephone line. Consequently, data, messages, and programs may be transferred from one microcomputer to another or between micro and mini or mainframe computers using this standardized ASCII code. The capaability is especially important because it allows instantaneous transmission of previously stored information over long distances at high rates of speed and allows microcomputers to access the computing power of mainframe computers.

Micros and Minis: Computer Evolution

For a better understanding of the diminishing differences between microcomputers and minicomputers, it is informative to place comparisons in an historical perspective. The perspective also vividly illustrates the rapid rate of advance in computer technology.

The Digital Equipment Corporation (DEC) PDP-8 was the first "powerful" laboratory computer widely used in psychological research (Polson, 1978, p. 140). Early versions had 4,000 characters, or bytes, of memory (4 kilobytes or 4K), a Model 33 ASR TTY for both entry and output of programs and data, and some type of primitive display. The total system cost was usually from $22,000 to $24,000 and did not include a real-time clock.

The computerized psychology laboratory in the mid and late seventies typically had a dedicated minicomputer able to store from 4,000 to 64,000 characters (bytes) in programmable memory (e.g., Digital Equipment Corporation's PDP-8, PDP-11, PDP-12, PDP-15; the Xerox Sigma 3). Usually it was shared by departmental faculty and students and might have been linked to the university mainframe or other computer. It might have used a specialized experimentation-oriented language (PEPL, FOCAL, VOCLAB, SP-12, SKED) in addition to assembly or machine language programming (Getty, 1975; Link, 1975; Mullen, 1976; Pitz, 1975; Posner, 1980).

Among the advantages of such systems listed by Aaronson and Grupsmith (1976) were precision and reliability, ease and flexibility, and capabilities not possible without computers. Disadvantages included cost (tens or hundreds of thousands of dollars initial investment), environmental modifications (temperature, humidity, repair, and maintenance), electrical power, time to learn to use the machine and to write initial programs, long and uncontrollable downtime, lab and time sharing, and hardware and software systems problems.

By 1978, however, it was apparent that a revolution had begun. A system functionally equivalent to the PDP-8, based on the INTEL 8080A microprocessor, was available from Heathkit for under $2,000. (It was called the H-8.) The price equivalent of the old PDP-8 was the DECLAB 11/03 with 28K, dual floppy disk drives, digital and analog signals, television monitor, and disk-based FORTRAN callable subroutines.

It was at this time that the KIM-1, the PET-2001, the TRS-80, and the Apple II microcomputers appeared in the instrumentation literature (e.g., Criswell, 1978; Durrett, 1978; Thompson, 1979). McLean (1978) commented, "The popularization of microcomputers makes available computer control of experiments at a price under $1000....Hardware interfacing is simple and the programming is done in BASIC" (p. 472).

At about the same time, the first applied educational research using the microcomputer as a research tool appeared in the literature; and microcomputer applications in educational research entered a seminal stage.

The microcomputer can now perform tasks previously handled by dedicated laboratory minicomputers at a fraction of the cost, with little if any environmental modification, with far less power, with greater programming flexibility and ease of expansion, and with greater system reliability (cf. Yost, 1978). A typical state-of-the-art microcomputer system used for educational research or evaluation might consist of the following: the microprocessor associated circuitry and from 32 to 896K combined programmable memory (random-access memory, or RAM) and nonprogrammable memory (read-only memory, or ROM); a cassette tape drive; at lease one disk drive for fast data storage and retrieval; a television monitor (CRT) with high-resolution graphics; converters for changing analog information to digital and vice versa; a printer; and connections for other peripheral equipment (e.g., video disk, light pen, joy sticks, modems, voice synthesizers.

Such systems are beginning to be employed in a diversity of exciting new educational research pursuits. Most applications involve experimental control, data collection, or data processing, with the emphasis on each depending upon the individual investigation.

The Microcomputer and the Control of Experiments

The microcomputer is an instrument of extraordinary power and flexibility for controlling information processes. It invites the implementation of methodological procedures which only a few years ago either could not be accomplished at all or could be accomplished only through extremely laborious and resource-consuming efforts. Although still in an early stage of development, it already offers a most powerful and flexible technology for controlling automated experiments.

Johnson (1982b) has pointed out some of the more impotant features of this technology. It creates a generally more rigorous, controlled environment for research. Specifically, it permits rigorous and precisely replicable equating of experimental treatments. Particularly relevant to instructional, prose, and verbal learning research, programmed experimental procedures make it possible to vary critical passages of experimental instructioal sets easily by making minor program alterations. Individuals can respond to treatments without the presence of highly trained experimenters. Such procedures eliminate control problems arising from the human facors involved in having different experimenters implement different treatment sessions.

The microcomputer can easily be programmed to assign subjects randomly to treatment groups without either the knowledge or the presence of experimenters. Consequently, it creates access to the rigorous experimental control of the double blind experiment. Furthermore, it is a simple matter to program random assignment to occur only after performance on covariate measures have been obtained. Prior knowledge ratings of to-be-remembered words can be obtained within a program, for example, before random assignment to treaments. The computer can be programmed to randomize the order of item presentation for each different subject or for the same subject at different times. Not only is it easy to randomize the order of the items, but it is also easy to randomize the order of alternatives within items, for multiple-choice formats. Consequently, microcomputer control can reduce order effects and other nuisance variability.

Additional power and flexibility issue from the developing graphics capabilities of microcomputer systems. Early microcomputer graphics capabilities were relatively awkward and burdensome to implement. Recent develoments in computer languages (like Logo; Papert, 1980) which have powerful graphics capabilities have begun to make the learning of programming techniques literally child's play. These, together with recent developments in video disk and video cassette technology and with the development of "sprite" graphics, have vastly augmented the video display capabilities of microcomputers. Microcomputer control applications range from computer-based tachistoscopes to prosthetic aids for the handicapped. What is particularly striking is that microcomputer systems offer the possibility of totally replacing nearly all the functions served by traditional experimental equipment like memory drums, tachistoscopes, response counters, and timing devices for less total cost (cf. Flowers & Murphy, 1979).

Computer-based tachistoscopes

The December 1978 issue of Behavior Research Methods &

Instrumentation contained a special section on computer-based tachistoscopes. Perera (1978) described how the TRS-80 microcomputer in its most basic form provided a wide variety of stimulus display capabilities at an extremely low price. Illustrative programs demonstrated its ality to present any number of visual stimuli in sequence while recording response latencies, thus performing the functions of a multiple-field tachistoscope and aociated responseee-recording instrumentation. BASIC listings of a 16-line tachistoscope program and a 10-line phi phenomenon program demonstrated the simplicity of programming such procedures.

In the same issue, Green and Shwartz (1978) reported a comparative evaluation of computer-based tachistoscopes. They compared three general approaches. In one system the inestigator prepares only a file of input data in proper format for a general-purpose tachistoscope program. In a second approach the investigator writes a program in a language oriented toward tachistoscopic experiments (e.g., Perera, 1978; Rugg & Feldman, 1979). The third approach involves a package of subroutines that can be called by a program written in one of the programming languages of the system. Green and Shwartz were referring primaly to minicomputer systems, but their conclusions have relevance for microcomputer-based tachistoscopes because the three approaches generally define the major options on a mirocomputer system. They favored the third approach, using a system of callable subroutines, because it combines some degree of flexibility with programming ease, although if the system has a small memory, a file-driven system or the second approach might be appropriate. File-driven systems (the first approach) were generally considered to be overly restrictive.

Programmed experiments

Commentators, (e.g., Phillips, 1980) recently have described a growing state of disenchantment and skepticism, if not cynicism, regarding educational research, stemming from a perception that researchers have not been able to discover generalizations reliable enough to form a basis for policy decisions. Until very recently, however, the technology for carrying out rigorously controlled, precise experimental observations in education was relatively primitive. The history of science illustrates that the progress of a science is, in part, a function of the capacity to carry out and replicate rigorously controlled, finely tuned observations or experiments. Consequently, the advent of the programmed experiment has green importance for research in education.

Johnson (1982b) argued that inconsistent, ambiguous, and mixed research findings have arisen partly from methodological artifacts (procedure by treatment interactions) associated with those primitive instrumentalities. Investigators who address the same issues frequently use methodologies that involve subtle yet substantive differences. These differences make it unclear whether differences in experimental outcomes are methodological artifacts, results of Type I or Type II errors, or are truly indicative of underlying differences in states of affairs for which, as yet, there is inadequate theoretical understanding (e.g., Kolotkin, Billingham, & Feldman, 1981, pp. 539-540).

Fortunately, the microcomputer enables a real leap in systematic replication capabilities. Why? Because all experimental procedures implemented by microcomputer must be programmed. Availability of the program listing or its inclusion in the method section or appendix of a research report allows precise systematic replication, interinvestigator affirmation and/or extension of experimentation. Reliability of generalizations, and therefore the credibility and impact of educational research, is consequently enhanced. Researchers in education are already beginning to use these new capabilities for automating experiments. The keyword study previously described (Johnson, 1982a, 1982c) provides only one illustration of the power and flexibility of microcomputer-automated experimental procedures.

The state of the art. DeLuca and Scouten (1980) explored the use of a microcomputer system as a tool for research in logical thinking. These investigators used an Apple II microcomputer with 32K, an 8-inch dual floppy disk drive, a video monitor, and a 6522 Versatile Interface Adapter (to allow accurate timing) to study college student performance on Piagetian tasks. Five programs totaling about 80K bytes were developed to explore performance in separation of variables (bending rods), with chemical combinations, on the balance beam, with switches and lights, and on the Bem Sex Role Inventory. In most cases subjects were asked to experiment, to learn as much as possible about the variables, to solve the problem, or to show proof of understanding. At other times they responded to multiple-choice questions. Some variables measured were number of combinations tried, time per try, number of errors, and correctness of responses to questions.

DeLuca and Scouten concluded that, for the researcher in logical thinking, the advantages of programmed tasks are far greater than the disadvantages. Programmed tasks can provide for precise standardization of testing procedures and data collection; control for misleading perceptual cues, task familiarity, and content bias; increased comprehensiveness and accuracy in data collection; reduction of task bias against female subjects; lower cost of data collection and analysis; and accurate measurement of time throughout the task. Disadvantages listed were initial cost of hardware and software, increased time and money required to maintain and repair hardware, and reduction of flexibility when interacting with different types of subjects. They suggested microcomputer systems were at the threshold of a major impact on research in logical thinking.

CONCEPTS (Turnbull, Mikiten, & Mikiten, 1980), a program for microcomputer-controlled experimentation in concept attainment, was developed to study ways in which personality and instructional variables interact to affect concept-attainment skills. The program, written for the Apple II, occupies only 5K and may be used as an aid to teaching about concepts. The task involves serial presentation of items. Each presentation consists of two rows of colored dots. Each row contains eight dots, with four specific dots composing the criterial attributes of the concept. The program collects data by delivery of a series of questions presented during each trial. The four measures are (1) number of trials to solution; (2) number of inferences, (3) number of hypotheses on negative instance trials, and (4) nonutilization of information.

Czerny (1979) described a data acquisition and control program for the PET microcomputer (Godot) that may be used to record the amount of time a human infant spends attending to one of two stimuli presented via 35-millimeter slides and a slide projector. The program records the number of attention episodes for either stimulus, the duration of slide presentation, and the number of slides presented. Also controlled are the transfer of data onto cassette tape at the end of the session, the detection of button presses from an external keyboard, and the changing of stimuli.

More general-purpose microcomputer programs to control and record events have also been developed. In a somewhat technical article involving some machine language, Rayfield and Carney (1981) reported development of a set of BASIC and machine language programs for the AIM-65 microcomputer and, more generally, 6502 microprocessor-based machines that control experiments and records data (the AIM-65, Apple, Atari, KIM, Ohio Scientific, PET, and SYM microcomputers are all 6502-based). BASIC programs for controlling simple reinforcement schedules are used as examples.

More elaborate control languages for microcomputers have been patterned after SKED, an experimentation-oriented language designed for relatively expensive minicomputers (Snapper, Knapp, & Kushner, 1970). The SKED system divides an experiment into "states" that completely describe the contingencies that are present at any given moment in an experiment. Perera (1981) described one such system, written in BASIC for microcomputers, which allows simplified programming of experiments using the "state" concepts of SKED. Rather than being concerned with the complex syntax of BASIC language programming, a researcher can simply specify the states that are to exist. The experimenter selects the state parameters before beginning the experiment by responding to a series of prompts that request information on the number of outputs to be activated by the state, the number of inputs that can initiate a transition, and the time delay after which a transition will occur.

MicroSKED, a different system developed by Butler (1980), was designed around the 6502 microprocessor and eliminates some of the restrictions of SKED. MicroSKED is housed in an 18 x 8 x 3 centimeter plastic package. It has a 16-character display, which can be used to display the state of outputs, inputs, values of variables, and successive program lines. It has a 4- by 16-key keyboard, a time-of-day clock, and 1K of RAM.

Graphics

Microcomputer graphics, or visual display capabilities, have attracted much attention among the general population. The popularity of video games like Asteroids, Gorf, Pac-Man, Space Invaders, and Missile Command attest to the compelling power of animated graphics displays in catching and holding the attention of children and adults alike. What may not be understood is that these animated graphics and sound displays are usually produced by computer programs written in assembly language. Both the ease of programming and the capabilities of microcomputer graphics have improved steadily over the past few years with the advent of programmable sprite graphics, graphics-oriented languages like Logo, graphics additions to extended BASIC languages, and hardware like the microcomputer paintbrush and the Apple graphics tablet. Microcomputers priced under $200 now have color graphics capabilities far beyond those of computers which only a few years ago cost five or ten times as much.

Graphics capabilities of microcomputers have been used to some extent in more basic behavioral research (Braddick, 1977; Eddy, 1979a, 1979b; Flowers & Murphy, 1979; Olch & Hecht, 1979). But a thorough review of the literature reveals that these capabilities have not been exploited to any appreciable extent by educational researchers, perhaps because of the newness of the technology and the relative awkwardness of programming graphics in BASIC using Cartesian coordinate systems.

It is in part for this reason that other new computer-based media such as microcomputer painting and its principal tool, the microcomputer paintbrush, are receiving increasing attention. One of the more useful devices for graphics programming is the graphics tablet. A graphics tablet allows one to "draw" the visual display on a specially designed board. The design is then reproduced with colors designated by touching a palette section of the board. The process is generally faster than the generation of pictorial graphics displays using Cartesian coordinate systems or graphics characters.

One of most powerful display systems for programmed presentation of video images is the video disk system interfaced with a microcomputer. Over 50,000 independent video images may be stored on one video disk. Interfacing a video disk system and a microcomputer system results in what might be called an "intelligent video disk" system that allows interactive video disk programs. Such a system allows instant access to any of the over 50,000 individual frames. The frames can be displayed individually for indefinite periods, run in sequence for animation, or run in slow motion or backwards. Merrill and Bennion (1979) present brief discussions of ten educational applications of video disk technology.

Hooper (1981) described a particularly innovative pilot project in the use of a video disk system for investigating how people generate representations of spatial layouts and develop these representations over time. The entire city of Aspen, Colorado, was filmed from different perspectives for a study at M.I.T. called the Aspen Project. Also included on the video disk were cultural data, printed materials, and maps. A primary source of information was from footage shot from the top of a moving truck which traversed every street within the city. Pictures to the front, sides, and rear were taken every 9 feet, providing a set of alternative trips through the town.

The intelligent video disk system provided the researcher with a surrogate travel system which controlled environmental sequences and at the same time recorded subject responses and choices concerning them. It provided a simulated interactive trip through the environment with the viewer choosing the way as if driving a car, but being able to look out all windows. One might think of the system as an interactive map.

Subjects used various strategies to learn about the town. They initially moved in a rather random fashion, learning general features of the town. Then they began moving through the town in a more systematic fashion. Objects viewed first from one direction were frequently not recognized to be the same objects when viewed from another direction. Curves that took viewers to the right or left without their making a decision were frequently forgotten. The Aspen study suggests some of the research applications that become feasible when a video disk system is interfaced with a microcomputer.

Interfacing

Interfacing--connecting the microcomputer in a communications network with other electronic devices--further increases the power and utility of microcomputers in controlling experiments. Several devices can be controlled simultaneously. The computer may be interfaced not only with video disk units, but also with servomechanisms, video sensors, light pens, joy sticks and game paddles, voice synthesizers, digitizing pads (for freehand drawings), sound effects generators, AC appliance controllers, acoustic couplers or modems, speakers, plotters, car readers, tape and/or disk drives, external keyboards, and many more (Edwards & Athey, 1979).

CAI applications

The microcomputer is being used not only as a controller of research and experimentation, but also as an object of research in computer-assisted instruction (CAI). Henney (1981) compared microcomputer displays of all-capital print with regular mixed print to determine whether reading speed and accuracy were affected. Results indicated that students read mixed print in paragraphs and sentences significantly faster than they read the all-capital print. While there was no difference in accuracy for sentences in either print type, accuracy was greater for all-capital paragraphs than the mixed-type paragraphs.

A number of recent dissertations have investigated microcomputer CAI. Caputo (1982) concluded that a combination of microcomputer-based instruction in tandem with graphics display techniques provided an effective medium for conveying and upgrading certain basic mathematical skills. A CAI treatment including verbal material plus graphics was more successful in removing math skill deficiencies than either the verbal material alone or a placebo control treatment. Participants strongly agreed that microcomputer-based CAI was an effective and enjoyable method of instruction.

Kolomyjec (1982) found that costs involved in teaching an introductory course on computer graphics increased directly proportionally to use in the batch mode. In the microcomputer mode costs decreased as enrollments increased and as the number of students per microcomputer graphics system increased. Furthermore, the microcomputer had interactive graphics capabilities, whereas batch mode graphics processing was passive. Micros were recommended for introductory computer graphics instruction, particularly for engineering and computer science majors.

Steele (1982) concluded that the use of computer-assisted instruction for mathematical drill and practice significantly improved both the affective and the cognitive computer literacy of fifth-grade students. The comparison between CAI instruction and an individualized instruction mathematical kit, however, revealed no significant difference in the acquisition of math skills.

Keenan and Keller (1980) described a set of ten computer programs written in BASIC that allow students to participate as subjects in well-known experiments selected from the current literature on memory and cognition. The experiments address five major areas: levels of processing, encoding specificity, semantic memory, sentence-picture verification, and constructive processes in prose comprehension. Keenan and Keller observed that enthusiasm ran so high that students often included roommates, friends, and even parents in the experimental simulations.

Simulation programs provide a particularly innovative CAI approach. Greitzer, Hershman, and Kelly (1981) described an elaborate simulation program used by the Navy that sounds like a video game. Called the Air Defense Game, the program is written in BASIC and simulates significant features of a Navy tactical problem. The game simulates a radar screen on which hostile air targets approach the player's ship at one of three speeds, and the player defends by launching missiles. The entire scenario unfolds on the Tektronix 4051 (32K) microcomputer screen. Targets are identified by a two-digit track number and enter the display as blips at the outer circle. Each target heads directly toward the ship, and its position is updated at 11.7-second intervals by another blip that corresponds to the next sweep of the simulated radar. The player launches a missile at a target by entering its track number via coded function keys on the keyboard. A full play of the game constitutes an engagement ending only when all targets have either been killed or have hit the ship.

The computer records the player's actions and displays feedback at the end of each engagement. The summary includes average range for kills, total number of kills and hits, number of splashes and in-flight launches, and a skill rating that reflects overall proficiency. More fine-grained measures can be obtained with a separate off-line program that analyzes the data stored on magnetic tape. Program listings are available at no charge from the authors.

Research methods

A CAI area of particular interest to researchers is that of instruction in research methods and statistics. Lehman (1980) described some aspects of what computer simulation can do for statistics and design courses. He wrote a set of data-generated programs that handle common experimental designs. Using this approach, students might run simulated "experiments" analyzing the data in lieu of conventional problem sets, or they might design their own experiments and then use a data-generator program to generate the data. In another option, a full research community might be simulated if students distribute results of previous simulations to others in the class.

Gordon Rae (1980), of the New University of Ulster in Northern Ireland, has developed an interactive program written in BASIC. It is intended to help students decide which statistical technique is best for analyzing a particular set of research data. Tests concern both measures of relationship between variables and comparisons among observations from two or more samples. The computer chooses the most appropriate statistical technique after the student responds to a series of questions concerning the nature of the variables, distributions, number of samples, and so on. The assumptions involved in the use of the technique are listed along with references to popular statistics texts and relevant journal articles.

A particularly innovative example of computerized evaluation of a student's capacity to find the most appropriate statistical method for a given piece of research was reported by Depover (1982). Depover, from the University of Mons in Belgium, used a 32K Commodore microcomputer with dual disk drive and printer. The original aspect of this work lies in the capacity of the computer to process not only the student's answers but also the questions that the computer is asked. A dialogue is established between the student and the computer via the keyboard and the screen. The computer projects on the screen a description of the research situation to be analyzed and then invites the student to question by showing a question mark. The computer responds to the question providing additional information about the situation. This process is repeated until the student has enough information to suggest a statistical method. If the suggestion is correct, the student may go on to the next situation; otherwise the dialogue continues. Each examination is based on random selection out of 30 situations. Evaluation is based not only on appropriateness of the method suggested, but also on relevance, preciseness, and order of questions asked, along with economy of questioning.

Hutcheson (1980) described the use of live, interactive demonstrations of large and small sample selections from a population of 1,000, for teaching sampling distribution concepts. The live demonstration sparked students to begin speculating on the effects of selecting other sample sizes. Hutcheson hypothesized that microcomputers might assist instruction by developing mathematical concepts that are remembered better through a live demonstration.

Aid to the handicapped

It has been said (e.g., Finke, 1981) that the microcomputer is one of the most significant aids to enrich the lives of the handicapped. In general, the microcomputer expands capabilities, extends the reach, and, because of its great power within a limited size, gives control. In the case of the handicapped, the microcomputer gives more control over more things than previously thought possible.

A PET is being used at Miller School in Brighton, Michigan, with students who have a variety of handicaps. Children who have physical or other health impairments, emotional impairments, or learning disabilities are among the populatio n of students using the computer (Brown & Schillinger, 1981). Brown and Schiilinger concluded from initial informal observations that the keyboard eliminated the need for a written response, that the dexterity required to manipulate keys on the keyboard was minimal, and that in some instances fine motor dexterity was increased through the use of video games like Aliens played on the computer. For students with limited manual dexterity, light pens further reduced the need for a fine motor response.

With recent developments in higher-quality and lower-cost synthetic speech chips, the voice synthesizer is enhancing the prospects for blind students to gain wider acces to computers. The TRS-80 Voice Synthesizer, for example, is capable of producing 62 phonemes generated through the use of slightly modified BASIC PRINT statements. Virtually any word in the English language can be produced using the 62 phonemes (Vincent, 1982). The Texas Instruments voice synthesizer at approximately $139, when coupled with the Terminal Emulator module (about $40), can say almost any word. A talking laboratory microcomputer has even enabled visually handicapped students t perform infrared spectroscopy (Cetera et al., 1980).

Kleiman, Humphrey, and Lindsay (1981) reported a brief sumary of an initial experimental study conducted with hyperative children at the Child

Development Clinic, Hospital for Sick Children. Eighteen children performed additon problems by hand one day and on a PET computer another day. Problem difficulty levels were adjusted for each child. On each day children were instructed, "Do as man problems as you want and stop when you think you have done enough

Results showed that the average child did almost twice as many problems on the computer as with paper and pencil. The children spent an average of over 23 minutes working on the computer—an unusually long time for hyperactive children to voluntarily attend to one task.

Almost certainly, some of this improvement is a novelty effect. However, instructors who have been using microcomputer systems for many months insist there is more than novelty involved in this new motivation. In a nationwide visit to most special education institutions in England, Nicholls (1980) encountered much the same enthusiasm wherever microcomputers were being used. Hart and Staples (1980) have argued that one could perhaps justify using them in special education for their motivational value alone.

Even more important for Hart and Staples, though, was the fact that every time a child pushed a button or made a response, information was made available which could be analyzed--immediately or when more convenient. No teacher can do this sort of rigorous empirical observation and measurement consistently. In the past, teaching and educational research have usually remained apart. Now the opportunity exists to combine teaching with dynamic research. Consequently, the microcomputer can more effectively integrate classroom practice with educational research, enabling the teacher to develop more effective strategies to do the best job possible.

The Microcomputer and the Collection of Data

Education, sociology, psychology, anthropology, ethology, and other social sciences have a common interest in the technology of observation. Throughout the history of science, advances in the technology of observation or measurement precision have been a powerful impetus to advance in science. Prime examples are the historic achievements of Galileo with his telescope, the invention of the microscope and its subsequent impact on biological and botanical research, the recent history and subsequent contributions of the cumulative recorder, the standardized test, the electrocardiograph, the use of the electromyograph and the thermistor in biofeedback research, and, even more recently, the PETT scan. The microcomputer represents the latest advance in our capacity to observe and measure human behaviors precisely.

Skinner's invention of the cumulative recorder was an important advance in animal behavioral technology. But the microcomputer promises to play a more important role in monitoring and recording a broad variety of response classifications in human beings. These classifications range from Flanders' analysis of interaction patterns in the classroom to measures of instructional effectiveness, including response latencies and rates, number correct, number incorrect, total time measures, numbers of anticipated wrong responses, biofeedback measures, and even eye movement instrumentation for reading research.

Interaction patterns

Gordon (1979) has described how researchers at the University of Cincinnati have developed microcomputer programs to convert a set of raw codings into matrix form for Flanders' analysis of classroom interactions involving student teachers. The system also computes percentages of teacher talk, student talk, and level of indirectness in the teacher's verbal behavior. The system is highly accurate, rapid, and portable. Teaching supervisors have used video and audio tapes recorded by the teacher. Results have been made available to teachers in 24 hours, much more quickly than had been possible previously. Prior to development of this system, it had not been possible to do such analyses on a regular basis. Supervisors have reported greater acceptance of results by student teachers; the computer seems to possess high credibility. The program is written in Radio Shack's Level Two BASIC for the TRS-80 and occupies 2K. There is also a FORTRAN IV version.

Typically, interaction analysis data are collected using paper-and-pencil measures. Wadham (1979) has pointed out that with such recording techniques, there is considerable difficulty in identifying the sequential flow of behaviors, the simultaneous occurrence of several behaviors, and the duration of the behaviors. So that these problems could be overcome, the Timed Interval Categorical Observation Recorder (TICOR) was developed. TICOR is a specialized portable, battery-powered microcomputer designed to automate collection of behavioral observations and their durations. The researcher may define up to 64 variables, which are coded by depressing one of the 64 keys on the TICOR keyboard and then stored. Summary reports of variable frequencies and durations are available. The microcomputer is programmable in FORTRAN and has the capability to collect covert responses from student response pads and analog input from autonomic responses (e.g., heart rate, GSR). Using TICOR, McIntire (1980) found that there were significant differences among teachers in terms of the duration of attention given to students in their classrooms. Christenson used the TICOR-7 system in the development of the Christenson Analytic System for Coding Teacher Behavior (CASTEB) in physical education. According to Wadham, the TICOR system has facilitated teacher effectiveness studies, bilingual education studies, mental health research, and physical education research. Four data gathering procedures were described by Wadham. STUDAT monitors student attention to task. INSTAT monitors teacher instructional strategies and their relationship to teacher attention. EQUAT monitors teacher equity of attention to the minority learner. QUAT monitors teacher questioning and student attention.

Crossman and Williams (1978) used the PET microcomputer to collect and analyze data concerning human interactions in the classroom. According to their report, several different types of behavior can recorded as they occur in time using the PET's built-in real-time clock. The system provides for calculations of frequency, duration, and latency data for the behavior observed. An observer can accurately record sequential teacher-student interactions. Crossman and Williams found the system to be well suited for observing behaviors in naturalistic settings. As stated in the report, some of the system's advantages are:

1. It is not necessary to stop watching a child while recording data, as with paper-and-pencil techniques.
2. The system is unobtrusive.
3. Rather than recording the target behavior alone, the PET enables the observer to precisely identify the antecedent and consequent events surrounding the behavior.
4. The real-time clock provides precise measurement of the

events influencing the children's behavior.

5. The system is not expensive.
6. The system is self-contained.
7. The system is portable. The computer may be placed on a wheeled table and follow as the observer moves from place to place.

Becker (1981) described how segments from dramatic narratives presented on educational channels were videotaped and how a program of observation and recording of elements for video programs was developed. This program was modeled after the observation program developed by Gordon Stephenson at the primate center, University of Wisconsin at Madison. An Apple II computer interfaced with a Betamax recorder/player was programmed to record the time of appearance, frequency, and duration of televised critical units. The computer not only recorded the frequency and duration of the units under study, but also supplied a printout for appraisal of the data.

Palmer (1981) adapted an Apple II microcomputer to assess the effects of teacher wait-time training on class wait-time and student achievement in introductory physical science classrooms. Palmer concluded that teachers can be instructed to increase their individual wait-time by means of the short, yet intensive, training program devised for the study.

Time measurement

The microcomputer is particularly well suited to obtaining measurement of time-related variables. These capabilities are especially important in the light of Faw and Waller's (1976) comments regarding the importance of controlling time-related variables in educational research.

There are two types of microcomputer clocks: (a) the software clock and (b) the hardware clock.

A software clock typically consists of a subroutine which executes a loop a known number of times during a given time interval. For example, on the CBM 32B upgraded to BASIC 4.0, the BASIC interpreter consistently executes the following timing loop 10,000 times in approximately 54.4 seconds.

```
10 FOR I=1 TO 10000
20 GET A$:IF A$<>""THEN PRINT I
30 NEXT I
```

A single execution of the loop is completed in .00544 second. Consequently, multiplying the number of complete loops (I) by .00544 provides a measure of elapsed time accurate to about 5/1000 second. The primary disadvantage of a software clock is that the MPU is saddled with executing the timing loop, which severly restricts its utility for other chores.

A hardware clock, on the other hand, operates independently of the MPU so that intervals may be timed independently of other computing activities, but perhaps not as accurately as the software clock routine above (e.g., accuracies to 1/60 or 1/100 second are common for typical build-in hardware clocks). You can determine if a given system has a build-in clock by referring to the computer's documentation, which will include procedures for setting and reading the clock. It may be referred to as a real-time clock (e.g., Commodore machines). The presence of a hardware clock simplifies keeping track of time durations measured over multiple responses or activities (e.g., test completion times).

In either event, only a few lines of BASIC typically are needed to program the computer to compute accurate measures of response times or to compute measures of response accuracy per unit time. If you include a few simple rate equations in the program, the computer will determine the rate of responding across previous responses and compute it after each response. Such information can be used as instantaneous or delayed feedback. If the system does not have a build-in hardware clock, one may usually be interfaced with the system (e.g., by adding a real-time clock board to the existing system), but it may need to be accessed by a complex assembly or machine language program.

It is important for the educational researcher to have some awareness of the accuracy of microcomputer timing procedures. Programs which are interpreted line by line (e.g., BASIC) into machine language by the computer run much more slowly, by factors of from approximately 5 to over 500, than programs which are written in machine language or compiled into machine language before being run. Because each statement must be interpreted into machine code at execution time, the delay build into a program timing loop is a function not only of the execution of the statements but also of their interpretation. Consequently, although microprocessor speeds have been increasing, depending upon the speed of the microprocessor and the interpreter, software timing resolutions very much finer than 1/100 second typically are still rare in interpreted languages (Lincoln & Lane, 1980; Perera, 1979; Price, 1979). More precise measures may be obtained, however, by using compiled programs or simple machine language timing loops, if millisecond accuracies are a critical concern (e.g., Owings & Fiedler, 1979).

Covert responses and biofeedback

Covert responses play an active mediational role in determining what is processed, how it is processed, and therefore what is remembered. While it is generally acknowledged that objective information concerning student cognitive or affective processes during instruction would be valuable, such information has been relatively inaccessible in educational settings. In the literature, looking "inside" the learner has usually taken the form of self-reports or biofeedback types of instrumentation. Such procedures have typically been awkward and burdensome. The microcomputer makes accessible or simplifies and enhances the practicality and precision of both types of data collection.

Clark and Rogers (1980) described a microcomputer system called ECHO which allows the collection of student self-reports easily, accurately, and continually during instrution. The ECHO system uses a PET microcomputer, 16 student response pads, and an interface, or connection box. Each pad has two rows of five buttons. The top row accesses the menu of covert reactions (e.g., "I'm paying attenion," "I'm understanding"). The bottom row accesses the five-category response scale: Yes!, Yes, Somewhat, No, a No!

There are two primary data collection modes.. In the cued mode, upon hearing a beep, the student looks down and ses a light over the menu item to which he or she is to respond. In the free mode students respond to any menu item tey choose whenever they want to. Some students respond frequently; others respond only occasionally or not at all.

Data are tabulated and instantly displayed on the microcmputer screen ahd recorded on a form by the operator. The system is designed to tap student covert reactions at each stage of an instructor's presentation. The class session is taped. Each time students are cued, the operator taps the tape recorder. As the operator records summaries, the tape count is indicated, permitting synchronization of students' responses with classroom events. After class, the instructor is handed the summary along with the tape. The teacher can then relive the class session having access to students' thoughts's. Initial piloting of the system indicated that self-reports could be unobtrusively solicited from students during ongoing instruction.

The microcomputer may be interfaced in a similar manner with physiological instrumentation measures to tap student reactions at each stage of an instructional process. Consequently, measures of responses to instruction need not be confined exclusively to student self-reports.

Krausman (1978), for example, has described how the microcomputer may be connected in a physiological monitoring system to provide a heartbeat-by-heartbeat simultaneous display of systolic blood pressure, diastolic blood pressure, and heart rate. The method interfaces relatively inexpensive component and chip-level devices with a standard INTEL microcomputer board.

Prokasy (1974) has described a FORTRAN IV subroutine (SCORIT) for scoring skin resistance sampled at a rate of 20 per second. The subroutine assesses response latency, base resistance, peak resistance, and time from base to peak.

The small size and portability of the microcomputer opens the way for automated biofeedback systems to tap typically inaccessible covert reactions during ongoing instruction. Kolotkin, Billingham, and Feldman (1981) have argued that although few automated systems are in existence, the use of computers to automate biofeedback systems will have numerous advantages, including precision, accuracy, reliability, and the specification of an easily replicable structured protocol for delivering the procedure.

Eye movements

Bieger and Hirschfeld (1981) have described eye movement instrumentation used to collecting eye movement data for reading research in nonlaboratory settings, such as classrooms. The minicomputer system provides precise information regarding the location, duration, and sequence of eye fixations while a person is reading materials composed of both text and pictures. Although the method and apparatus involve a 64K minicomputer, the methodology transfers to a microcomputer-based system in a relatively straightforward manner.

Quizzes, testing, and diagnostic surveys

One important use of microcomputers in education is for interactive testing. Automated testing is potentially a more efficient and economical procedure than is manual testing; and it also results in reliable test data (Elwood & Clark, 1978). Assessment batteries may be administered, scored, and interpreted via microcomputer.

The increasing availability of microcomputer systems has also increased the practicality of adaptive testing—a form of test administration in which the test is tailored to the individual by choosing most informative items depending upon the individual's previous responses. The machine may even be used to conduct interviews.

One of the earliest tests children can be given is the shapes recognition test—the old "square peg and square hole" game. The test provides information concerning ability to recognize shapes, eye-hand coordination, attention span, reaction time, ability to follow directions, and ability to complete a task. If a child has impaired motor coordination, however, the test typically cannot be used because of the motor coordination needed. Computer simulation can be very helpful in this area. Pegs and holes can be simulated on the computer screen. Semancik (1981) developed and provided the listing for such a program. If the child has enough motor coordination to hit any of the keys of the keyboard, the peg over which the moving cursor is currently displayed may be selected. The selection can be timed.

The shapes recognition testing program offers but one example of interactive testing. Computer-controlled administration of the Peabody Picture Vocabulary Test (PPVT) to children between the ages of 4 and 13 years has been shown to be feasible without the presence of a live examiner (Elwood & Clark, 1978). Test-retest correlations were not significantly different from those obtained with manual administration in the standardization sample. Practice effects and IQ differences between the two forms of testing were also nonsignificant.

Such interactive testing programs may be designed to be used not only directly by an instructor, but by a secretary who inputs questions and information previously prepared by the instructor. Cavin (1981) has recommended that a large number of questions or test problems be generated to be chosen randomly on a given occasion so that a quiz would have little chance of being identical on repetition. Such interactive prelaboratory quizzes have been used for a number of years in the science majors' general chemistry laboratory course at the University of Texas at Austin. Using this method, students may arrange their own time to take or repeat a test.

Bremser and Davidson (1978) described using a North Star microcomputer to administer an assessment battery to patients referred by physicians. The purpose of the assessment was to evaluate eligibility and obtain consent to participate in a behavioral research and treatment program in alcoholism. After a brief introduction, patients appeared to be fascinated with the messages sent and received through the system.

Byers (1981) described the use of an on-line, microcomputer-based testing system in a private clinical psychology practice. The system is interesting to researchers in education as a model. Some of the tests administered by microcomputer are the Beck Depression and Hopelessness (BECK); the Intellectual Screening Battery (ISB), e.g., the Shipley-Hartford verbal and abstraction scores and the WAIS arithmetic subtest; the Minnesota Multiphasic Personality Inventory (MMPI); the Strong-Campbell Interest Inventory (SC-II); and the Social History (SHX).

Johnson, Giannetti, and Williams (1978) have described a similar self-contained microcomputer system for psychological testing including on-line administration, scoring, and interpretation of psychological tests. The Lab-II, manufactured by Psych Systems, is a self-contained, on-line, microcomputer-based psychological testing station located at the user's site. It is programmed to administer, score, and interpret the Strong-Campbell Interest Inventory, the Shipley-Hartford Intelligence Scale, the Minnesota Multiphasic Personality Inventory, measures of arithmetic and memory ability, the Beck Depression and Hopelessness, and an index of test dissimulation. It is clear that it is now possible for researchers and practitioners in education to locate a self-contained microcomputer system in a remote setting to obtain computerized test interpretations on a real-time basis at an affordable cost.

Adaptive testing is a different and relatively new form of test administration. The test is tailored to the individual taking it by choosing items most informative about that person. Methods for determining which items are most appropriate take on a variety of forms, some requiring extensive computation, and almost all requiring administration by computer.

Interviewing computers have been used in mental health settings. Evidence suggests (Angle, 1981) that the computer interview may equal or excell the interview accomplishments of some clinicians who are unknowledgeable about asking certain clinical questions, who forget to ask these questions, or who fail to record crucial patient facts. Angle asserts that the interviewing computer is a practical device for gathering precise and comprehensive documentation on mental health patients, including intake assessment, information on therapeutic progress, and follow-up evaluation.

The increasing availability of inexpensive microcomputer systems has made adaptive testing and the interviewing computer more feasible in educational settings. So that of a variety of adaptive testing methods can be implemented on a microcomputer, it is necessary that the system be efficient from both the examinee's and the test constructor's perspectives. Vale (1981) has briefly outlined the item-selection strategies of adaptive testing developed to date. Vale has grouped them into three general categories (interitem, intersubset and model-based) and has described techniques to make the extensive computations feasible on a microcomputer.

The Microcomputer and the Processing of Data

One of the most obvious research applications for microcomputers is that of data proccessing. Available software is diverse, powerful, and comprehensive. Tasks as different as reading level determination and evaluation, item analysis, multivariate and univariate statistical analyses, Monte Carlo simulations, and bibliographic data management and word processing are easily implemented by microcomputer. Many programs may be obtained simply by sending a disk to the program developer and asking for a copy.

Reading level

Noonan (1981) developed and provided the listing for an interactive computer program in BASIC to analyze and evaluate the reading level of selections from text. With this program a teacher or researcher may determine the reading grade level of a story or book. More importantly, however, the detailed analysis provided by the program not only determines the reading level but also reveals the basis for its computation by showing the number of diphthongs, digraphs, trigraphs, and blends in the text selections.

Item analysis.

King and Karres (1981) developed INDEX, an interactive computer program for item analysis of objective tests. The program, originally developed for the Digital Equipment Corporation (DEC) PDP-11, was written in BASIC for easy adaptation to most microcomputers. The program accommodates up to 75 questions and 75 subjects and employs only about 16K. In addition to reporting individual item characteristics, the program computes frequencies of responses, the raw score mean, standard deviation, Kuder-Richardson Formula 20 reliability coefficient and difficulty and discrimination indices.

Statistical analysis

A number of comprehensive statistical analysis packages have been developed for use with microcomputers. These procedures offer much of the ease, power and speed of statistical procedures available on mainframe computers without the concomitant on-line time costs.

Buhyoff et al. (1980) have developed a microcomputer-resident comprehensive statistical analysis system. Called SPS and structured similarly to SPSS, it is designed to be implemented on Z-80 based microcomputers (e.g., TRS-80). Thirty two different statistical procedures are available including file creation and handling, descriptive statistics and plotting, tests for differences between means, cross-tabulations, parametric and nonparametric correlations, regression analyses, and factor and principle components analyses with up to 50 variables. Only 32K of memory and one disk drive are needed.

Coovert (1980) developed an elementary statistical package for 6502-based microcomputers (e.g., Apple, Atari, CBM, PET). The package needs a maximum of only 4,000 bytes of memory. Available procedures include one way analysis of variance, independent and related t-tests, chi-square and phi analyses, correlation, and various descriptive indices (e.g., arithmetic, geometric and harmonic mean, median, variance, standard deviation, range).

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Steinmetz, Romano, and Patterson (1981) developed a set of statistical program specifically for the Apple II containing six analysis of variance procedures, two t-tests, and two correlation programs. These programs may be obtained from Dr. Patterson upon request.

Gilbert (1979) developed PSYCHOSTATS, a set of BASIC programs providing, "...a well stocked toolbox for the analysis of experimental data" (p. 464). This comprehensive package is available from the author in the form of a system manual, an operator's manual and a programmer's manual for $13. It includes t-tests; one- and two-way analysis of variance with repeated measures; three-way analysis of variance with repeated measures on one or two factors; simple main effects; Latin squares; analysis of covariance; Hotelling's T-squared; correlation; regression; and Mann-Whitney, Wilcoxon, Spearman, Kendall, Kruskal-Wallis, Friedman, and Cochran tests. All programs fit in less than 4K bytes using program overlays (calling in successive subroutines one at a time from tape or disk).

Anderson's (1980) PSYCHO-STATS 80, on three 5 1/4-inch floppy disks available from the author for $20, represents a translation of most of Gilbert's (1979) programs to TRS-80 BASIC for a 32K Model I machine. Some additional statistical procedures are included as well. As with the original, the programs are all interactive and provide for the recovery of errors in inputting data.

A variety of analysis of variance and multiple comparison programs have been developed for microcomputers (Borys & Corrigan, 1980; Corrigan, Bonelli, & Borys, 1980a, 1980b; Fishbein & Dixon, 1979; Galla, 1981; Hacker & Angiolillo-Bent, 1981; Hartley, 1980; Lane, 1981; Warner, 1980). These programs have varying degrees of flexibility in terms of the number of different designs which may be handled by the program. They range from simple one-factor procedures to four-factor within- and between-subjects designs, trend analyses, and parametric and nonparametric multiple comparison techniques.

Regression analysis programs have been developed for microcomputers as well (Borys & Corrigan, 1981; Gorman & Primavera, 1981). Alan (1978) developed a 63-line BASIC program to conduct path analysis. Watkins and Larimer (1981) wrote a BASIC microcomputer program for the Apple II which calculates a univariable regression model analysis of test bias.

Tsai (1979) and Dreger (1979) have developed chi-square related programs. Several authors have developed programs to deal with various aspects of random number generation (e.g., Kaplan, 1981; Osaka, 1979; Roberton, 1977).

A number of multivariate analyses are also available for microcomputers. A multifactor multivariate analysis of variance program for equal sample sizes has been developed by Lane and Powell (1976). The program has only 100 functional statements and may be run with little or no modificaion on any microcomputer with a BASIC that allows matix operations statements. Output includes Wilks' lambda, Rao's F, cell means, and univariate F's among other statistics.

Schmitt (1977) has developed a factor analysis program written in Basic which also requires matrix functions but which contains only 123 lines of code. A factor rotation program has been developed by Wilson and Frederickson (1980) which will handle up to 70 variables and 30 factors. In the event of nonconvergence in estimating communalities, computations cease after 20 iterations. Robertson (1980) developed a microcomputer program in BASIC to help reestablish the "lost art" of hand rotation and clarify the importance of hand rotation in obtaining a proper understanding of a given factor structure. Varimax rotation is also provided by Roberton.

Some other procedures which have been programmed in BASIC for microcomputers include Scott's pi (Larimer & Watkins, 1980) and Cohen's kappa (Larimer & Watkins, 1980; Wixon, 1979) statistics for interrater agreement, spectral analysis for cycles in time-series data (Warner & Neumann, 1980), interaction analysis (Walkenbach, 1981), and survey analysis (Narkaus & Dippner, 1978).

Data management

The flexible information processing capabilities of the microcomputer allow it to be programmed to handle all phases of data collection, storage, retrieval, and analysis. The properly programmed microcomputer typically makes the following activities obsolete or unnecessarily resource-consuming for collecting and managing data: typing and copying sets of paper-and-pencil materials, hand scoring. keypunching, and even using optical mark-scan cards or sheets. It can save raw and program-scored data immediately on a diskette file, ready for statistical analysis on completion of data collection, or even as an integral part of the program (e.g., Johnson 1982a, 1982c; Kirk, 1980). If one has several machines, it takes only a few minutes to make multiple program copies which may be used again and again by different experimental subjects. Paper-and-pencil tests need no longer be used, and textual changes in experimental materials need no longer necessitate retyping and copying entire drafts. Required changes can be made in the stored program. Materials costs decrease because the same program diskettes can be used over and over. The analysis phase of the research is quick and abbreviated compared with the previous norms. Consequently, principal investigators have more time for conceptual construction, theorizing, hypothesis generation, and other activities.

Microcomputer data management capabilities are important to the researcher not only in data collection, storage, retrieval, and analysis, but also in the writing phase of research. For example, bibiliographies and reprint files can be maintained more completely and managed more effectively by computer. Deni (1977) has described BASIC-PLUS programs for the PDP-11/40 minicomputer which allow a full bibliographic reference file to be searched, selecting items based on the appearance of a combination of specific characters. Bishop (1980) described REFERENCE, a program for the Apple II which enables the user to maintain a "card system" of journal references on floppy disk, with easy retrieval of references by author, subject, or combination of subjects. Earnest (1979) also described the use of microcomputers for bibliographic data input. Actually, far more sophisticated data management or data-base software is available for most microcomputers from national software distributors. Prices range from as little as $50 or $60 for a relatively sophisticated disk-based system to as much as $1000 for extremely versatile data-base management software that includes SPSS-like statistical analysis and report writing features.

Word processing

Word-processing software packages for microcomputers run from as little as $20 or $30 for minimal cassette-based systems to over $500 for the best systems. Extremely good word-processing packages for micrcomputers are priced from $200 to $400. Many of the word-processing packages may be used for bibliographic and other data management purposes, but the optimal systems interface word-processing software with data management software so that "card" files created by the data management software are retrievable by the word-processing software. Because the word processor allows and facilitates editing of text before it is printed on paper, it not only speeds the writing, rewriting, and editing process, but it also typically may help the writer to improve writing quality as well. When editors ask for revisions, you can modify the stored files quickly and simply and then print the edited document to paper. Word-processing software is generally available from microcomputer distributors.

Word processing is facilitated by on-screen formatting, which shows on the video screen how the finished document will look. This important feature is implemented to varying degrees of success among different systems. An 80-column display is desirable, although not absolutely necessary, particularly if the system has horizontal scrolling which successively brings columns beyond the rightmost visible column onto the screen as the point of typing moves farther to the right. The 80-column display allows a quicker, more global view of the finished document before it is printed to paper. Keep in mind that television receivers were not designed for word processing, are not high resolution monitors, and result in blurry word images with create eyestrain at 40-column and especially 80-column screen widths. Consequently, word-processing applications typically require a high-resolution video display monitor.

Matrix printers may be purchased for under $400. Matrix printers with simulated letter-quality print are available for under $800, but publishers and reviewers tend to prefer real letter-quality print in manuscript submissions (it tends to be easier to read). Most good letter-quality printers currently are priced at a minimum of $2,000 to $3,000 although Smith-Carona has made a letter-quality daisy wheel printer available for under $800, and other comparable printers are to be introduced soon.

Future Innovation

By mid-1982 Tandy Corporation had already sold over 400,000 of its popular Radio Shack TRS-80 computers. Jack Tramiel, founder and chief executive of Commodore International, believes 50 million microcomputers will be sold worldwide by 1985. Computer technology, particularly microcomputer technology has been characterized by extremely fast-paced product developments and evolution. The 1982 National Computer Conference revealed that in 1983 the state-of-the-art microcomputer will have on-board programmable memory capable of storing 128,000 characters (128K) expandable to more than 500,000 characters. It will have three-dimension-like, high-resolution, multicolor, programmable, sprite graphics and high fidelity music synthesizer capabilities, and will sell for less than the basic 1982 Apple II. Commodore achieved a significant first in mid-1982 by marketing a machine with similar capabilities, but with a 64,000 character programmable memory, for less than $600.

These new computers will run faster and access more floppy disk storage space than past models. Hard disks capable of storing 5 million, 10 million, and 25 million characters will be used more and will be cheaper. A greater variety of peripherals, including video disks and a greater variety of software will be available. New powerful, all-purpose languages will be emerging as strong competitors to BASIC as the primary media of human computer interactions in the microcomputer domain. The machines to be introduced for 1983 will generally have far more space available for memory and programming than the average laboratory minicomputer of the late seventies. Some prototype machines now have memories expandable to over 1 million bytes.

Given present trends, micros will continue to have more memory; be more user-friendly; have greater ease of programming; have better-quality graphics and sound or music capabilities; more peripherals; and more available, more powerful, and less expensive languages. They will allow greater control, more precision of measurement, and faster analysis. In addition, they will facilitate faster debugging and more sophisticated programming techniques, and they will begin to strongly impact cognitive processes, especially in children.

Changing the way we think

It will become increasingly important to examine the specific impacts of microcomputer usage on cognitive processes in the young. If looked at from a behavioral point of view as a medium for altering the antecedents and consequences of behavior, the microcomputer has the capacity, through interactive usage, to impact cognitive processes directly, on a mass scale, and to an unprecedented degree. The microcomputer may literally change the way we think. Other media have tended to influence the content of thought by placing the human in a passive role as a receiver of information. By contrast, learning to program a microcomputer demands active involvement and adherence to the laws of logic. A child learning to control the computer actively interacts with it and directly experiences the consequences of appropriate and inappropriate use of those laws.

Seymour Papert (1980), the M.I.T. mathematician, educator, and Logo computer language developer, has observed that the computer can concretize the abstract. Critchfield (1979) has observed that the computer's ability to quickly generate examples or demonstrations of concepts which formerly could be grasped only through abstract reasoning should allow students to start looking at quantitative phenomena quite early in their learning careers. Papert argues that the microcomputer is not just another powerful educational tool. It can allow us to shift the boundary separating concrete and formal. In other words, "Knowledge that was accessible only through formal processes can now be approached concretely" (p. 21).

For example, one of the characteristics which Piaget associates with the formal stage of intellectual development is combinatorial thinking, where one needs to think about all possible arrangements of things. A second has to do with self-referential thinking--thinking about thinking itself. A typical experiment in combinatorial thinking asks children to form all possible combinations of colored beads. Generally, children are not able to do this systematically until the fifth or sixth grade. The task can be thought of, says Papert, as constructing and executing a very common sort of program consisting of two nested loops. "First fix a first color and then run through all possible second colors, then repeat until all possible first colors have been run through" (p. 22). The task, presumably, would be as concrete as matching up knives and forks at the table, for a child in a computer culture. Papert suggests that our culture has been relatively impoverished in having models for systematic procedures. Children have not had the incentive or the materials to build powerful, concrete ways to think about problems involving systems. However, computer programs and subroutines now offer both. Papert also says that Logo's "turtle" graphics or "turtle" geometry, has the power to allow the child to create intuitive and concrete analogs of such abstract mathematical concepts as velocity, acceleration, the differential equation, and the line integral (Papert, 1980).

Papert has also observed children in a Logo environment engaged in self-referential discussions about their own thinking. It appears that, in teaching the computer how to think, children begin to explore their own thinking. Papert believes that in learning to imitate mechanical thinking, the child learns how it is different from other kinds of thinking and acquires a new degree of intellectual sophistication. An exploration of future microcomputer research applications, consequently, requires imagining a world where computers are personal intellectual tools and where teaching students how to control the computer has the status of a basic skill (see also Critchfield, 1979).

The impact of learning programming techniques on general problem-solving skills has already been identified by the National Institute of Education as an important area for research. Detailed studies of the ways in which, and populations with which, experience with programming structures might accelerate development and comprehension of abstract mathematical and physical concepts would appear to be likely fruitful areas of investigation. Consistent with DeLuca and Scouten's (1980) conclusion, it appears that microcomputer systems are at the threshold of a major impact on research in logical thinking.

While physiological response measures have been used extensively in the clinic and the laboratory, they have not been used appreciably in the instructional domain. Such measures provide an alternative route of access to covert mediating processes and responses. The advent of the microcomputer may provide the route of entry to practical application of physiological measures in educational research. Kolotkin, Billingham, and Feldman (1981) have argued that the use of computers in biofeedback research will result in improved replicability of findings across studies.

Simulating social interactions

The microcomputer may begin to be used as a device for simulating social interactions (e.g., classroom interactions, disciplinary confrontations). Those who wish to improve social, communication, managerial, and teaching skills might develop, polish, and refine those skills first in nonthreatening simulations in which the computer assumes the role of all or some other parties. The overall quality of the learners' performances might be evaluated in terms of assertiveness, empathy, humor, imagery, economy of expression, and other variables measured quickly and accurately via automated procoessing. Such simulations and the results of associated research might be used to help teachers more effectively handle classroom behavior management issues.

Changing the instructional environment

It has been observed that when there is a conflict between management and instruction, management frequently carries the day. The primary priority of our educational institutions has not always been the cognitive growth of the learner. Rather it has frequently been the managing of instruction under limitations imposed by a relatively rigid set of environmental and societal constraints imposed by the administrative necessities of formal public education. The microcomputer may or may not alter the contingencies. But it is likely to result in a system of implementing instruction which more effectively promotes cognitive development in the learner and simultaneously integrates research and evaluation more tightly into the natural instructional process.

At the same time, the domain of educational research will likely be extended to learning in nontraditional settings as more learning is centered around the home computer and as more informally structured educational settings assume increased importance in overall cognitive development.

Small-N designs

Microcomputer capabilities to effortlessly randomize treatment orders make it practical to use the document small-N, within-subjects designs in both regular and nontraditional school settings. Such designs generally results in greater statistical power (number of subjects being equal) for detecting significant results than do the between-subjects designs, which conventionally might be used to achieve experimental control.

A typical experimental design in education involves the administration of experimental and control instructional sequences, where within each treatment a number of to-be-learned items are presented successively to the subjects. When such comparisons are made within subjects (e.g., the Equivalent Time Samples or Equivalent Materials Samples Designs, see Campbell & Stanley, 1963), there may be confounding carry-over effects. Counterbalancing or independent random arrangements of items and treatments typically control such effects. A few program lines implement this by computer. Consequently, the design becomes easier to implement in practice.

To compare the effectiveness of two ways to learn the multiplication tables (Johnson, 1982b), one could use a group (preferable randomly selected) of ten students, each of which is prompted to alternate using the two methods randomly with successive items from the times tables (similar to Paivio & Foth's (1970) method for comparing image and verbal processing of concrete and abstract noun-noun pairs). The procedure might be repeated for ten trials over random sets of 20 items. The data would be analyzed as a three-factor design with subjects as a random factor and methods and trials as fixed within-subjects factors (Dayton, 1970). The design allows one to test the significance of the comparison between methods, the training trend across the successive trials, and the dependence of the trend on the particular method. Statistical power would exceed that attainable with the same number of subjects in the between-subjects designs which might be traditionally implemented (e.g., one trial for independent experimental and control groups of five subjects each).

Accelerated progress in educational research

The microcomputer's range of applications in educational research can be expected to expand greatly. The beginnings of what will become extensive educational research program and subroutine software libraries should develop within the next few years. Scientific journal articles will become available immediately upon publication to microcomputer subscribers through telephone-link communications hookups and electronic mail. The microcomputer can be expected to become a primary medium of information exchange in the journal review process. It would be expected to assume such a role more generally throughout the scientific world. As a consequence, the rate of scientific progress will accelerate. More interrelated studies will be conducted by independent investigators in less time. Computerized information exchange will soon be expanded in libraries so that extensive literature searches may be conducted quickly and efficiently from the home or office with abstracts and summaries immediately saved on disk. National research data bases will be accessible from the home or office terminal as well. Gammill (1978) suggests that increased use of microcomputers for research could reduce the dependence of scientists upon organizational affiliations, geographic location, and funding agencies, thereby improving the capabilities of relatively isolated institutions of learning and research and making rural localities more.amendable to high technology.

Guidance for the Researcher

What is the best machine? What software is available? What can you actually do with the machine? How can you teach assistants to use it? Who will fix it when it breaks? These are only some of the questions confronting a researcher considering a small computer or computers for research use (cf. Staples, 1981).

Choosing a microcomputer

There is no best computer. All designs are compromises. Even if there were, at the present pace of technological developments, it would probably not be superior within a few months. The question should not be, "Which is the best computer?" but rather "Within the resources that are available, what computer system best suits the needs, objectives, and priorities?" It is a question which each researcher must answer independently.

As an aid, the following brief list of general suggestions has been adapted, in part, from Bork and Franklin (1979) and from Eisele (1979).

1. Acquaint yourself with the general capabilities of micros and their basic operating principles.
2. Specify needs, objectives and priorities (i.e., What do you want the computer to do?).
3. Identify the capacities of systems components needed to do them.
4. Survey manufactures for specifications.
5. Avoid minimal systems.

6. Avoid cassette based systems.

7. Compile comparative checklists to help evaluate the systems (see Checklist).

Attention to the following specifications, adapted in part from Staples (1981), may be helpful.

Cost. Microcomputer systems generally range from about $100 to $8,000. All needed peripherals should be included when estimating cost.

Flexibility. This includes size, portability, cords, modules, environmental modifications, and so on. How portable is the unit? How much does it weight? Is it an integrated, all-in-one unit, or is it primarily modular in design? Is the monitor built in? If it is modular, how many and what kinds of cords and interfaces are necessary? Are environmental modifications needed (e.g., air conditioning, humidity, dust control, static electricity or electric fields, special electrical outlets)?

Interfaces. Can the computer be connected to mainframe computers? What interfaces are built into the unit (e.g., IEEE-488, RS-232C, S-100)? Are telephone modems or acoustic couplers available? What about communications software for controlling the modem? Can data files be transferred to or from a mainframe computer using the communications software? How fast can the information be transmitted or received (Baud rate, i.e., bits per second)? Will the communications software work with all mainframes or only a few? What printers can be connected with existing interfaces?

Keyboard. Does the keyboard optimally suit your needs? Is it integral or separate? Is there a build-in calculator layout for one-handed data entry? Are programmable function keys needed? Does the keyboard facilitate editing? If word processing is important, does the keyboard have standard typewriter or pressure sensitive keys? Is the action of the keyboard fast, sure, and consistent? Does the keyboard provide cursor control and insert and delete keys? Are awkward arrangements of keys (e.g., placing an extra key between the shift key and the "z") avoided? Is an automatic repeat function provided if a key is held down?

Ports. These connecting outlets (e.g., for light pens, joysticks) may be important for research use. Additional ports allow additional peripheral devices. Are there enough of the right kinds of ports to fit your needs? Do they use otherwise available memory? Ports may be either serial(one bit at a time) or parallel (more than one bit at a time)—it is desirable to have both.

Speed. How long does it take to execute a command or a program? What is the speed of the microprocessor in megahertz (the microprocessor may be fast, but the interpreter slow)? How long does it take and how easy is it to load, save, and back up a program? Is a compiler available to speed execution of programs which ordinarily are interpreted? It is generally easier to interact with and program in an interpreted language.

Memory size/accessibility. Usually measured in kilobytes (approximately 1,000 characters, 1K), how much programmable memory (RAM) is there? How much nonprogrammable memory (read-only memory or ROM) is there, and what does it do? What capacities do the extended storage devices have (e.g., cassette, floppy, and hard disk drives)? How much of the total memory is accessible by the interpreter or compiler? How accessible is the extended memory? Can the system be programmed easily for instant access to individual records (does it allow relative records, which may be important for data management)? Can you easily append information to existing disk data files (important for data storage)?

Expansion. Can the system be expanded easily? What are maximum limits of expansion (RAM, ROM, disk drives, etc.)?

Editing and debugging. Depending upon the programming language being employed, does the system have full-screen editing or line-oriented editing capabilities (full-screen editing is easier and faster)? Can characters be easily inserted or deleted from program lines, or must multiple keys be depressed or the entire line be retyped? Are both uppercase and lowercase letters available through standard techniques? Must several keys be depressed in order to get a capital letter? Can editing take place immediately when mistakes occur? Which of the above characteristics does the machine language monitor have? Does the system have a machine language monitor? Are debugging aids available which pinpoint the source and type of error; allow you to insert or delete subroutines as a whole, find all occurences of given character strings; trace program execution step by step, identifying each line as it is executed; merge program subroutines; and automatically number and renumber program lines? If word processing will be a major priority, does the system have an 80-column display?

Peripherals. What available input and output peripheral devices can be monitored or controlled by the micro (e.g., cassette, floppy, or hard disk drives; erasable-programmable-ROM (EPROM) programmers; graphics tablet; modem; game paddles; joysticks; light pens; polygraphs; printers; sound and music generation; speakers; video disks; voice command; voice synthesizers)? Which are important for you?

Software. What languages are available (e.g., APL, assembly language, BASIC, COBOL, FORTRAN, Logo, PASCAL, PILOT)? Which do you need? What are the costs? BASIC continues to be a popular language for educational research applications. After BASIC, the three most-used languages for behavioral research appear to be (Pavel, 1981) FORTRAN, PASCAL, and assembly language in that order. Are experimentation oriented languages available? Do you need CP/M (control program for microcomputer)? What about the UNIX operating system? UNIX has the advantage that versions will run on all major MPU chips (8, 16, and up). Will existing software suit your needs? Have outside companies made additional software? Can existing software be adapted to suit your needs? Are frequently used research subroutines available? As a researcher, much of your software will be highly specialized. Consequently, much of it may need to be written specifically for the research issue to be examined.

Graphics/sound. What graphics/programmable character capabilities does the machine have? Can mathematical symbols, foreign alphabets, or other shapes be programmed or produced? Does it have high- or low-resolution pixel graphics (a pixel is an individual point in the display)? How many graphics modes are available? How many colors, what colors, and what combinations of colors are available? Can the printer handle graphics? Is a graphics tablet or microcomputer paintbrush available? Can the computer be interfaced easily with a television camera or with a video disk or video cassette player to control or monitor output from them? Does the system have sound generation and music synthesizer capabilities? Do they have high-fidelity specifications? How many sound channels or voices are there? What are the frequency ranges?

Build-in instrumentation. What built-in instrumentation capabilities does the system have? Does the system have a built-in real-time clock? How accurate is the clock? Can the system be programmed easily to time events? Does it have built in analog/digital-digital/analog converters to monitor or control analog devices which might be used (e.g., biofeedback, television images)?

Service, support/reliability. Be wary of sales representatives. Will the system really do what the representatives claim without modification or additional purchases in software or hardware? How reliable is the system? What kinds of problems typically occur? Do files load and save t disk or tape quickly, accurately, and consistently without problems? Are programs and data files easily verified or checked for accuracy? How accurate are the computations (4, 7, 8, 9, or more digit accuracy)? Are there bugs in the built-in computational subroutines? Do the disk drives tend to act up? Do glitches appear after the system heats up during prolonged use at one sitting? What do the warranties cover, and how long are they in effect? Can the unit be serviced on-site? In the event of needed repairs, how long will the system be inoperable? Does the dealer/service agent have temporary replacement boards for use during the servicing interval? Can local technicians make necessary repairs? Can the unit be upgraded when additional features have been added to newer models? What are representative service costs? What is the reputation of the local dealer/technician in terms of service support?

User-friendliness. How user-friendly is the system? Can you make sense out of the operating manuals? Does it require extensive searching through manuals to find answers to questions? Will vendors provide on-site training for assistants? At what cost?

General comments. You might use a separate checklist sheet to rate each system (see Checklist), first rating the importance of each specification from 1 to 5, then rating the machine's performance on that specification from 1 to 5, and then multiplying the two to obtain a weighted rating. A quantitative composite measure of fit to your objectives may be obtained by summing the products of the ratings and their importance. A "Comments" column provides space for written responses regarding individual features.

Some general observations regarding different systems are in order. A real-time clock is often important for instructional research. It is desirable not to have to pay extra for it. Graphics capabilities are generally more important in educational settings than in business settings. It is desirable that a general purpose microcomputer system which will be used by many educational researchers have maximum diversity, flexibility, and capacity, plus the greatest variety of peripherals possible.

Pursuing research objectives

Don't start at square 1. Keep in mind the deja vu felt by Polson (1978) as he heard researchers describe how they struggled to develop computerized experimental control systems that, as he saw it, were in most respects equivalent to the system that he had developed in the mid-sixties, "The only real difference is that the new systems are cheaper by about a factor of 10, so that more people can return to the dark ages" (p. 146).

Consider research independently of programming. The computer should be looked at as a tool for achieving research goals. Although there are occasions when it makes sense to make a minor alteration in a research design to make it more adaptable to computer implementation, if the use of the computer hampers efforts to test research hypotheses, it probably should not be used.

Plan programs thoroughly. This point cannot be overemphasized although, in practice, programming is frequently an ad hoc and chaotic process (West, 1982). Planning is particularly important with long and complex programs. If the program is thoroughly and precisely planned beforehand, the coding (converting the plan to language the computer can understand) should be a simple and straightforward process. This sort of planning implies specifying, in detail, what each screen or hard copy display will look like, how long the information will stay on the screen, and what sequences will be followed. It also implies thorough familiarity with the specifications, capabilities, and limitations of the system. If the program is not thoroughly planned, debugging problems are likely to be immense and will consume much more time than it would have taken to write the program developed according to a clear plan. Debugging can be extremely time-consuming and intellectually demanding. If the program is not constructed according to sound principles, the program development process will be like wrestling an octopus. Almost every time you think you've got it licked, you find another tentacle has come loose. Fixing one bug frequently alters the program so that it no longer works correctly in other ways. Hour upon endless hour may be spent in fruitless quests for fixes.

Familiarize yourself with programming languages. Be aware that most microcomputers speak BASIC first. Additional languages will generally cost more money. Acquire some basic knowledge concerning the different strengths and weaknesses of the most commonly used computer languages. Although some investigators have recommended the avoidance of BASIC (e.g., Bork & Franklin, 1979), BASIC may well be suitable. Such recommendations often are based on speed and overall power of the language. The advent of extended BASIC and BASIC language compilers for microcomputers increases the speed and the flexibility of this relatively portable software.

Results of a preliminary survey of psychological laboratories (Pavel, 1981) indicate that BASIC was the most widely used language, (75.5%) with FORTRAN (57.1%), PASCAL (40.8%), and assembly language (26.5%) following in order of usage. Because extreme speed of execution is not generally of crucial importance in educational research and because the extra translation step necessitated by a compiler may be cumbersome, BASIC is likely to continue to be a popular language for educational research applications. In general, higher level languages like BASIC and PASCAL have more ease and speed in programming than assembly language has. However, BASIC and PASCAL have less flexibility and control over the range of control processes which may be implemented than assembly language has. PASCAL, in particular, encourages structured programming.

Logo is coming. This is a powerful language especially suitable to graphics programming and to working with children. Full implementations of Logo have powerful recursive features and allow the user to use names of newly defined subroutines as primitive commands. This capability gives the language a powerful hierarchical structure. Carefully examine the range of languages available, and choose those which most adequately suit your research purposes.

Learn programming from several sources. If you decide to acquire some programming skills, you will benefit by gleaning information from a variety of sources. Programming manuals are notoriously poor in readability, as is much software and hardware documentation. Different instructors and writers generally are able to express difficult concepts or techniques differentially well. You may grasp a piece of the puzzle from each.

Use sound programming principles. You may have a professional programmer write the program, you may have an assistant write it, or you may do it yourse . In any event, programming is quite time-consuming in all but the simplest cases. If you choose to do the programming yourself:

1. Use top-down programming. Start by writing the overall supervisor program. Replace the undefined subprogram with "stubs," which are temporary programs that do nothing, monitor the entry or perform a test. Then test the supervisor, or mainline, program to see that it works corectly.

2. Use modular programming. Do a task analysis. Divide the large task into subtasks. Conceptualize the program as a tidily arranged chain of subroutines. Treat each subroutine as a separate, independent entity having one entry a one exit point. Debug subroutines independently.

3. Be aware of structured programming principles. One way of keeping modules distinct, stopping them from interacting th each other, speeding debugging, and systematizing program design is to use structured programming (see Leventhal, 1979, for a good, short summary). Any program can be constructed of elements from a set of three structures (sequence, conditional, and loop; a case structure may also be helpful), each structure having a single entry and a single exit.

4. Document programs with comments interspersed heavily throughout the program. Such commentary will facilitate debugging, maintainability, and later modification of the program.

Check programs completely. Every program should be thoroughly checked over a wide range of input. You are not usually able to determine whether a program is free of bugs. You can only check the program over as wide a range of situations as possible and know that it works correctly in those situations in which it has been tried. During program development, a number of different individuals should be involved in looking for bugs and testing and evaluating the program.

Work in groups. Read the microcomputer magazines and periodicals as well as the research and instrumentation literature. Locate subroutine libraries. Initiate mechanisms for sharing programs and subroutines. Users' groups, computer clubs, and professional special interest groups provide wonderful forums for meeting to share and develop ideas.

Resources

There is little question that the microcomputer will revolutionize both education and educational research. Microcomputer application to educational research issues has entered a seminal stage. The foundation is being laid now for the startling new developments which lie ahead for educational research in the coming decade. The change is likely to be incremental and quantitative, but it will also probably result in research emphases that are qualitatively different from current research. For one thing, because computer literacy is about to assume the status of a basic skill, the primary foci of research efforts are likely to be the acquisition of computer literacy and of programming skills and the more general impact of these upon cognitive development. It is an exciting prospect.

The following resources along with the extensive appended references should be helpful to those seeking further food for thought and action. Resources (not generally included in the references) may help locate information and include magazines, clearinghouses, networks, and other data sources for those interested in microcomputer research applications. The list has been compiled from a variety of sources including Lopez (1981) and resource guides provided by the ERIC Clearinghouse on Information Resources.

Magazines and Newsletters

Apple Education News, P.O. 20485, San Jose, CA 95160

Apple Educators' Newsletter, 9525 Lucerne, Ventura, CA 93003.

Byte, 70 Main Street, Peterborough, NH 03458.

Classroom Computer News, Box 266, Cambridge, MA 02138.

Commodore Magazine, 681 Moore Road., King of Prussia, PA 19406.

Compute, 625 Fulton Street, Greensboro, NC 27403.

Computer-Using Educators, Mountain View High School, Mountain View, CA 94041.

Computerworld, 375 Cochituate Rd., Box 897, Framingham, MA 01701.

The Computing Teacher, c/o Computer Center, Eastern Oregon State College, La Grande, OR 97850.

Courseware Magazine, 4919 North Millbrook, #222, Fresno, CA 93726.

Creative Computing, 1 Park Lane, New York, NY 10016.

80-Microcomputing, Pine Street, Peterborough, NH 03458.

Interface Age, 16704 Marguard, Box 1234, Cerritos, CA 90701.

Kilobaud Microcomputing, Pine Street, Peterborough, NH 03458.

Microcomputers in Education, Queue, 5 Chapel Hill Drive, Fairfield, CT 06432.

MicroSIFT News, NWREL, 300 Southwest 6th Avenue, Portland, OR 94204.

Nibble Magazine, P.O. Box 325, Lincoln, MA 01773

Personal Computing, Hayden Publishing Co., 50 Essex Street Rochelle Park, NJ 07662.

Popular Computing, BYTE Publications, Inc., 70 Main Street Peterborough, NH 03458.

Recreational Computing, 1263 El Camino Real, Box E, Menlo Park, CA 94025.

Software Review, Microform Review, 520 Riverside Avenue Westport, CT 06880.

Teaching Computer Programming, 1112 Glacial Drive, Minot, ND 58701.

Other Resources

Acorn Software Products, Inc., 634 North Carolina Avenue, S.E., Washington, DC. 20003.

Apple-cations, 21650 West Eleven Mile Road., Southfield, MI 48076.

Apple for the Teacher, 5848 Riddio Street, Citrus Heights, CA 95610.

Association for Educational Communication & Technology (AECT), Task Force on Microcomputers, 1126 16th Street, N.W., Washington, DC 20036.

Association for Educational Data Systems (AEDS), 1201 16th Street, N.W., Washington, DC 20036.

Association for the Development of Computer-based Instruction, Computer Center, West Washington U., Bellingham, WA 98225.

BLS, Inc. 2501 Silverside Road, Suite One, Wilmington, DE 19810.

Classroom Computer News, July-August 1981, 1(6), 24-25. Box 266, Cambridge, MA 02138. Lists 16 software directories that catalog products from more than one vendor. Gives names, addresses, and telephone numbers and describes products of 86 software vendors.

Commodore Software Encyclopedia, 681 Moore Road, King of Prussia, PA 19406.

Computer Systems Design Group, 3632 Governor Drive, San Diego, CA 92122.

Conduit, P.O. Box 388, Iowa City, IA 52244.

New software is available from this NSF-funded organization.

Creative Computing, Box 789-M, Morristown, NJ 07960

Datapro Research Corp., 1805 Underwood Blvd, Delran, NJ 08075.

Offers directory of over 1,000 software vendors and peripheral vendors.

Dresden Associates, P.O. Box 246, Dresden, ME 04342.

Offers instructional software directory for precollege educators.

Educational Activities, Inc., P.O. Box 392, Freeport NY 11520.

Educational Products Information Exchange, Box 620, Stony Brook, NY 11790.

Gathers and disseminates information on instructional systems.

Educational Software, 801 East 6th Avenue, Helena, MT 59601.

Foundation for the Advancement of Computer-aided Education, Educational Program Evaluation Centre, 20863 Stevens Creek Blvd., Bldg. B-2, Suite A-1, Cupertino, CA 94015.

Reviews commercially available educational courseware.

Guide to Microcomputers, Frederick, F.J., 1980, ERIC Document Reproduction Service No. ED 192 818.

Hayden Book Co., 50 Essex Street, Rochelle Park, NJ 07662.

High Technology Inc., Software Dept., P.O. Box 14665, Oklahoma City, OK 73113.

Instant Software, Inc., Peterborough, NH 03458.

International Council for Computers in Education (ICEE), Department of Computer and Informational Science, University of Oregon, Eugene, OR 97403.

Math Software, 1233 Blackthorn Place, Deerfield, IL 60015.

Microcomputer Buyer's Guide. Webster, T., Rochelle Park, NJ, Hayden Book Co., 1981.

Microcomputer Directory: Application in Educational Settings. Cambridge, MA, Harvard University, Monroe C. Gutman Library, 1981.

Microcomputer Index, Microcomputer Information Services, 2646 El Camino Real, #247, Santa Clara, CA 95051.

Microcomputer Reference: A Guide to Microcomputers. Microcomputers in Education Series. 1980. Harrisburg, Pennsylvania State Dept. of Education, ERIC Document Reproduction Service No. ED 205 203.

Microcomputers in Education. Report No. 4798. Feurzeig, W., Cambridge, MA, Bolt, Beranek & Newman, 1981, ERIC Document Reproduction Service No. ED 208 901.

Microcomputer Software Systems, Inc., 4716 Lakewood Drive, Metairie, LA 70002.

Micro Ed, Inc., Box 24156, Minneapolis, MN 55424.

Micrognome, 5843 Montgomery Road, Elkridge, MD 21227.

Micro Learningware, Box 2134, Mankato, MN 56001.

MicroSIFT, NWREL, Computer Technology Program, 300 Southwest 6th Avenue, Portland, OR 94204.

Microsoft Consumer Products, 10800 Northeast 8th, Suite 507, Bellevue, WA 98004.

Milliken Publishing Co., 1100 Research Blvd., St. Louis, MO. 63132.

Minnesota Educational Computing Consortium, 2520 Broadway Drive, St. Paul, MN 55113.

Muse Software, 330 North Charles Street, Baltimore, MD 21201.

National Coordinating Center for Curriculum Development, State University at Stony Brook, Stony Brook, NY 11794.

Nits Software, 680 North Arrowhead Avenue, Rialto, CA 92376.

Periodical Guide for Computerists, E. Berg Publications, 622 East 3rd, Kimbal, NE 69145.

Program Design, Inc., 11 Idar Court, Greenwich, CT 06830.

Programma International, Inc., 3400 Wilshire Blvd., Los Angeles, CA 90010.

Program Store, 4200 Wisconsin Avenue, N.W., Washington, DC 20016.

Queue, 5 Chapel Hill Drive, Fairfield, CT 06432.

Radio Shack Sourcebook (all stores).

Roanoke Exchange TRS-80 Instructional Programs, c/o Craig County Public

Schools, P.O. Box 245, New Castle, VA 24127.

School Microware: A Directory of Educational Software.

Over 500 programs/packages for Apple, PET. TRS-80. Dresden ME, Dresden Associates, 1980, ERIC Document Reproduction Service No. ED 196 431.

SOFTSWAP Program, San Mateo County Office of Education, 333 Main Street, Redwood City, CA 94063. Offers more than 200 public domain instructional programs.

SRA, 155 North Wacker Drive, Chicago, IL 60606.

Sterling Swift Publishing Co., P.O. Box 188, Manchaca, TX 78652.

A Survey of Selected Computer-related Periodicals. Michelsen, J. (Ed.), ERIC Document Reproduction Service, No. ED 208 946.

References

Aaronson, D., & Grupsmith, E. (1976) The impact of computers on cognitive psychology. Behavior Research Methods & Instrumentation, 8(2), 129-138.

Alan, G. J. B. (1978) IPAl: A BASIC program to conduct an interactive path analysis. Behavior Research Methods & Instrumentation, 10(3), 415-416.

Anderson, D.E. (1980) PSYCHO-STATS 80: A basic statistical package for the TRS-80. Behavior Research Methods & Instrumentation, 12(5), 565.

Angle, H. V. (1981) The interviewing computer: A technology for gathering comprehensive treatment information. Behavior Research Methods & Instrumentation, 13(4), 607-612.

Atkinson, R.C. (1975) Mnemotechnics in second language learning. American Psychologist, 30(8), 821-828.

Becker, A. (1981) Toward a grammer of educational television: Part II, method. Paper presented at the annual convention of the Association for Educational Communications and Technology, April 1981, in Philadelphia.

Bieger, G. R., & Hirschfeld, R. (1981) Eye movement instrumentation for reading research. Paper presented at the annual meeting of the American Educational Research Association, April 13-17, 1981, in Los Angeles (ERIC Document Reproduction Service No. ED 200 622).

Bishop, D. V. M. (1980) REFERENCE: An Apple II package for storage and retrieval of journal references. Behavior Research Methods & Instrumentation, 12(6), 627-630.

Bork A., & Franklin, S. (1979) Personal computers in learning. Educational Technology, 19(10), 7-12.

Borys, S. V., & Corrigan, J. G. (1980) A BASIC program for nonparametric post hoc comparisons. Behavior Research Methods & Instrumentation, 12(6), 635.

Borys S. V. & Corrigan, J.G. (1981) A BASIC program for multiple regression. Behavior Research Methods & Instrumentation, 13(1),

Braddick, O. (1977) Real-time generation of random-element motion displays. Behavior Research Methods & Instrumentation, 9(4), 359-362.

Bremser, R. F., & Davidson, R. S. (1978) Microprocessor-assisted assessment in the clinical research laboratory. Behavior Research Methods & Instrumentation, 10(4), 583-584.

Brown, W. L., & Schillinger, M. (1981) The PET as an aid to handicapped students. Commodore Magazine, 2(4), 22-23.

Buhyoff, G. J.; Rauscher, H. M.; Hull, R. B.; & Killeen, K. (1980) Microcomputer-resident comprehensive statistical analysis. Behavior Research Methods & Instrumentation, 12(5), 551-553.

Butler, F. E. (1980) MicroSKED. Behavior Research Methods & Instrumentation, 12(2), 152-154.

Byers, A. P. (1981) Psychological evaluation by means of an on-line computer. Behavior Research Methods & Instrumentation, 13(4), 585-587.

Campbell, D. T., & Stanley, J. C. (1963) Experimental and quasi-experimental designs for research. Chicago: Rand-McNally.

Caputo, D. J (1982) An analysis of the relative effectiveness of a graphics-enhanced microcomputer-based remedial system in a university basic mathematical skills deficiency removal plan. Dissertation

Abstracts International, 42(8), Sec. A, 3482.

Cavin, C. S. (1981) Microcomputer generation of interactive quizzes. Educational Technology, 22(2), 31-32.

Cetera, M. M.; Morrison, R. C.; Lunney, D.; Hartness, R. V.; Sowell, D.; & Locklair, G. (1980) Use of a talking laboratory microcomputer to enable visually handicapped students to perform infrared spectroscopy. Abstracts of Papers of the American Chemical Society, August, p. 13.

Christenson, R. S. (1981) Christenson's analytic system for coding teacher behavior in physical education: A descriptive system of evaluation using a microcomputer (CASTEB). Dissertation Abstracts International, 42(05), Sec. A, 2020.

Clark, D.C., & Rogers, D. H. (1980) The study of student covert behaviors with the aid of microcomputers. Educational Technology, 20(11), 46-49.

Coovert, M. D. (1980) An elementary statistical package for 6502-based microcomputers. Behavior Research Methods & Instrumentation, 12(5), 562.

Corrigan, J. G.; Bonelli, P. J.; & Borys, S. V. (1980a) BASIC programs for one-way through four-way between-subjects and within-subjects ANOVAs. Behavior Research Methods & Instrumentation, 12(4), 468.

Corrigan, J. G.; Bonelli, P. J.; & Borys, S. V. (1980b) BASIC programs for two-way through four-way mixed-design ANOVAs. Behavior Research Methods & Instrumentation, 12(4), 546.

Criswell, H. E. (1978) KIM-1 Microcomputer System--A low-cost high-speed digital data acquisition and display system. Behavior Research Methods & Instrumentation, 10(4), 476-479.

Critchfield, M. (1979) Beyond CAI: Computers as personal intellectual tools. Educational Technology, 19(10), 18-25.

Crossman, E. K., & Williams, J. G. (1978) Using the PET microcomputer for collecting and analyzing observational data in the classroom. Behavior Research Methods & Instrumentation, 10(4), 563-566.

Czerny, P. (1979) Godot: A real-time data acquisition and control program for the PET microcomputer. Behavior Research Methods & Instrumentation, 11(6), 577-580.

Dayton, C. M. (1970) The design of educational experiments. New York: McGraw-Hill.

DeLuca, F. P., & Scouten, D. C. (1980) A microcomputer system as a tool for research in logical thinking. Journal of Educational Technology Systems, 9, 3-20.

Deni, R. (1977) BASIC-PLUS programs to manage bibliographies, reference lists, and reprint files. Behavior Research Methods & Instrumentation, 9(3), 307-308.

Depover, C. (1982) An interactive student interrogation system using a microcomputer. Educational Technology, 22(1), 25-26.

Dreger, R. M. (1979) A chi-square program for a microcomputer using a tape unit. Educational and Psychological Measurement, 39, 685-688.

Durrett, H. J. Jr. (1978) Inexpensive microcomputer systems for research and instruction: A dream or reality? Behavior Research Methods & Instrumentation, 10(2), 345-351.

Earnest, P.H. (1979) Use of the microcomputer for bibliographic data input. Proceedings of the American Society for Information Science, 16, 289.

Eddy, D. R. (1979) Application of color displays to problems in the undergraduate laboratory. Behavior Research Methods & Instrumentation, 11(2), 131-134.

Eddy, D. R. (1979) Color display systems: The state of the art. Behavior Research Methods & Instrumentation, 11(2), 127-130.

Edwards, J. S., & Athey, M. K. (1979) Microcomputer interfacing and input/output hardware. Educational Technology, 19(10), 36-40.

Eisele, J. E. (1979) Classroom use of microcomputers. Educational Technology, 19(10), 13-15.

Elwood, D.L., & Clark, C.L. (1978) Computer administration of the Peabody Picture Vocabulary Test to young children. Behavior Research Methods & Instrumentation, 10(1), 43-46.

Faw, H. W., & Waller, T. G. (1976) Mathemagenic behaviors and efficiency in learning from prose. Review of Educational Research, 46, 691-720.

Finke, J. (1981) Message from the president. Commodore Magazine, 2(4), 5.

Fishbein, B. J., & Dixon, D.R. (1979) One-way ANCOVA: A BASIC program for minicomputers. Behavior Research Methods & Instrumentation, 11(4), 460.

Flowers, J.H., & Murphy, M.H. (1979) An economical microcomputer design for the generation and display of timed visual stimuli: The TDL VDB. Behavior Research Methods & Instrumentation, 11(2), 115-118.

Galla, J. P. (1981) Factorial analysis of variance with unequal observation-a BASIC program for microcomputers. Behavior Research Methods & Instrumentation, 13(5), 699-700.

Gammill, R. C. (1978) Personal computers for science in the 1980's. Paper presented at the conference on problems of the 80's: The Oregon report on computing, in Portland, Oregon.

Getty, D.G. (1975) The PEPL system for control of experiments by a PDP-8 computer. Behavior Research Methods & Instrumentation, 7(2), 131-136.

Gilbert, L. H. (1979) PSYCHOSTATS: BASIC programs for data analysis in psychology. Behavior Research Methods & Instrumentation, 11(4), 464.

Gordon, J.S. (1979) A computer application for assessing teaching behavior. Educational Technology, 19(7), 28-31.

Gorman, B.S., & Primavera, L. H. (1981) BASIC BACKSTEP: A simple backward-selection multiple-regression program for minicomputers and microcomputers. Behavior Research Methods & Instrumentation, 13(5), 703.

Green, B.F., & Shwartz, S.P. (1978) Comparative evaluation of computer-based tachistoscopes. Behavior Research Methods & Instrumentation, 10(4), 789-795.

Greitzer, F. L.; Hershman, R. L.; & Kelly, R.T. (1981) The Air Defense Game: A microcomputer program for research in human performance. Behavior Research Methods & Instrumentation, 13(1), 57-59.

Hacker, M.J., & Angiolillo-Bent, J. S. (1981) A BASIC package for N-way ANOVA with repeated measures, trend analysis, and user-defined contrasts. Behavior Research Methods & Instrumentation, 13(5), 688.

Hart, B., & Staples, I. (1980) Microcomputers in special schools. Special Education: Forward Trends, 7(4), 22-25.

Hartley, L. (1980) BASIC language programs for one-, two-, three-, or or four-factor within- and between-subjects ANOVAs for Apple II and

and Commodore PETs. Behavior Research Methods & Instrumentation, 12(5), 567.

Henney, M. (1981) The effect of all-capital print vs. regular mixed print, as displayed on a microcomputer screen, on reading speed and accuracy. Paper presented at the ninth annual meeting of the Plains Regional Conference of the International Reading Association October 22-24, 1981, in Des Moines, Iowa.

Hooper, K. (1981) The use of computer-controlled video disks in the study of spatial learning. Behavior Research Methods & Instrumentation, 13(2), 77-84.

Hutcheson, J. W. (1980) Computer-assisted instruction is not always a drill. The Mathematics Teacher, 73, December, 689-691, 715.

Johnson, C.W. (1982a) Running a completely automated experiment by microcomputer: An example program in BASIC. Educational Technology, 22(3), 22-24.

Johnson, C.W. (1982b) Microcomputer-administered research: What it means for educational researchers. Educational Researcher, 11(3), 12-16.

Johnson, C.W. (1982c) Watch those keywords: Microcomputer assessment of keyword method effectiveness. Paper presented at the annual meeting of the American Educational Research Association, March 1982, in New York.

Johnson, J.H.; Giannetti, R.A.; & Williams, T.A. (1978) A self-contained microcomputer system for psychological testing. Behavior Research Methods & Instrumentation, 10(4), 579-581.

Kaplan, H.L. (1981) Effective random seeding of random number generators. Behavior Research Methods & Instrumentation, 13(2), 283-289.

Keenan, J. M., & Keller, R. A. (1980) Teaching cognitive processes:

Software for laboratory instruction in memory and cognition. Behavior Research Methods & Instrumentation, 12(2), 103-110.

King, H. A., & Karres, L. E. (1981) INDEX: An interactive computer program for item analysis of objective tests. Educational and Psychological Measurement, 41, 181-183.

Kirk, R.C. (1980) HTERM/CIM and HTERM/BAS: "Smart" terminal enabling programs for the TRS-80 microcomputer. Behavior Research Methods & Instrumentation, 12(1), 71-72.

Kleiman, G.; Humphrey, M.; & Lindsay, P.H. (1981) Microcomputers and hyperactive children. Creative Computing, 7(3), 93-94.

Kolomyjec, W.J. (1982) A comparison of the use of microcomputer graphics systems versus a central batch facility in an introductory undergraduate course on computer graphics. Dissertation Abstracts International, 42(8), Sec A, 3458.

Kolotkin, R. L.; Billingham, K. A.; & Feldman, H. S. (1981) Computers in biofeedback research and therapy. Behavior Research Methods & Instrumentation, 13(4), 532-542.

Krausman, D. T. (1978) Interfacing the microcomputer: A component-level approach. Behavior Research Methods & Instrumentation, 10(4), 519-521.

Lane, D. M., (1981) A general analysis of variance program for microcomputers. Behavior Research Methods & Instrumentation, 13(5), 694.

Lane, D. M., & Powell, R. S. (1976) N-Way MANOVA: A BASIC program for minicomputers. Behavior Research Methods & Instrumentation. 8(4), 382-383.

Larimer, L. D., & Watkins, M.W. (1980) A microcomputer BASIC program to calculate the level of agreement between two raters using nominal scale classification. Educational and Psychological Measurement, 40, 773-774.

Lehman R. S. (1980) What simulation can do to the statistics and design course. Behavior Research Methods & Instrumentation, 12(2), 157-159.

Leventhal, L. A. (1979) 6502 assembly language programming. Berkeley, California: Osborne/McGraw Hill.

Levin, J. R.; Pressley, M.; McCormick, C.B.; Miller, G.E.; & Schriberg, L. K. (1979) Assessing the classroom potential of the keyword method. Journal of Educational Psychology, 71(5), 583-594.

Lincoln, C.E., & Lane, D. M. (1980) Reaction time measurement errors resulting from the use or CRT displays. Behavior Research Methods & Instrumentation, 12(1), 55-57.

Link, S.W. (1975) 4K Laboratory FOCAL. Behavior Research Methods & Instrumentation, 7(2), 137-142.

Lopez, A. M. (1981) Microcomputers and Education. Creative Computing, 7(3), 140-143.

McIntire, P.C. (1980) Assessing teachers' attending behaviors toward students of different special education classifications utilizing microcomputer technology. Dissertation Abstracts International, 40(7-A), 3900.

McLean, R. S. (1978) Using personal computers for experimental control. Behavior Research Methods and Instrumentation, 19 (4), 468-473.

Merrill, P. F., & Bennion, J. L. (1979) Videodisc technology in education The current scene. NSPI Journal, 18(9), 18, 19, 22-26.

Mullen, S. (1976) FOCLAB: A language for computer-controlled psychology research. Behavior Research Methods & Instrumentation, 8(2), 229-232.

Narkaus, G., & Dippner, R. (1978) A survey analysis program for small computers. Behavior Research Methods & Instrumentation, 10(1), 67-76.

Nicholls, C.A. (1980) Micros and motivation. The Times Educational Supplement, June 13, 42.

Noonan, L. (1981) Reading level: determination & evaluation. Creative Computing, 7(3), 166-173.

Olch, R.H., & Hecht, S. E. (1979) Microcomputer graphics in psychological research. Behavior Research Methods & Instrumentation, 11(2), 119-126.

Osaka, N. (1979) A microprocessor-based real-time BASIC random interstimulus interval generator with different probability density functions. Behavior Research Methods & Instrumentation, 11(6), 581-584.

Owings, R.A., & Fiedler, C.H. (1979) Measuring reaction time with millisecond accuracy using the TRS-80 microcomputer. Behavior Research Methods & Instrumentation, 11(6), 589-591.

Paivio, A., & Foth, D.L. (1970) Imaginal and verbal mediating and noun concreteness impaired-associate learning: The elusive interaction. Journal of Verbal Learning and Verbal Behavior, 9(4), 384-390.

Palmer, J. E. (1981) Microcomputer analysis of the effects of teacher wait-time on class wait-time extension and student achievement in introductory physical science (IPS) classrooms. Dissertation Abstracts International, 42(06), Sec. A, 2598.

Papert, S. (1980) Mindstorms: Children, computers and powerful ideas.

New York: Basic Books.

Pavel, M. (1981) Results of a preliminary survey of computer users in psychological laboratories. Behavior Research Methods & Instrumentation, 13(2), 272-275.

Perera, T. B. (1978) A versatile microcomputer-based multiple-field tachistoscope. Behavior Research Methods & Instrumentation, 10(4), 546-547.

Perera, T. B. (1979) A comparison of BASIC language timing loops for the TRS-80 microcomputer. Behavior Research Methods & Instrumentation, 11(6), 592.

Perera, T. B. (1981) A simple BASIC language laboratory control system for microcomputers patterned after SKED. Behavior Research Methods & Instrumentation, 13(2), 281-282.

Phillips, D.C. (1980) What do the researcher and the practitioner have to offer each other? Educational Researcher, 9(11), 17-20.

Pitz, G.F. (1975) Building a programming language for a small computer: Reinventing the wheel. Behavior Research Methods & Instrumentation, 7(1), 42-46.

Polson, P.G. (1978) Microprocessors: Their impact on real-time computing in psychology. Behavior Research Methods & Instrumentation, 10(2), 139-147.

Posner, M. I. (1980) Computers in the training of inquiry. Behavior Research Methods & Instrumentation, 12(2), 87-95.

Price, J. M. (1979) Software timing for 6500 series microcomputers. Behavior Research Methods & Instrumentation, 11(6), 568-571.

Prokasy, W.F. (1974) SCORIT: A computer subroutine for scoring electrodermal responses. Behavior Research Methods and Instrumentation, 6(1), 49-52.

Rae, G. (1980) A guide to statistical techniques in psychology and education. Behavior Research Methods & Instrumentation, 12(4), 469-470.

Rayfield, F., & Carney, J. (1981) Controlling behavior experiments with BASIC on 6502-based microcomputers. Behavior Research Methods & Instrumentation, 13(6), 735-740.

Robertson, S.A. (1977) A BASIC program to produce random samples without replacement. Behavior Research Methods & Instrumentation, 9(4), 363-364.

Robertson, S.A. (1980) A PET-based program for stepwise orthogonal hand rotation. Behavior Research Methods & Instrumentation, 12(6), 637-638.

Rugg, T., & Feldman, P. (1979) 32 BASIC programs for the PET computer. Portland, Oregon: Dilithium Press.

Schmitt, J.C. (1977) Factor analysis in BASIC for minicomputers. Behavior Research Methods & Instrumentation, 9(3), 302-304.

Scholz, K.W., & Holly, B. (1975) A 64-station computer-assisted teaching and research facility. Behavior Research Methods & Instrumentation, 7(3), 301-304.

Semancik, S. (1981) The Delmarva Computer Club. Commodore Magazine, 2(4), 24-27.

Sholz, K. W. (1978) Hardware and software: A floppy disk operating system for the 80 80 and the 80. Behavior Research Methods and Instrumentation, 10(4), 527-530.

Snapper, A.G.; Knapp, J. Z.; & Kushner, H. K. (1970) Mathematical description of schedules of reinforcement. In The Theory of reinforcement schedules, edited by W. N. Schoenfeld. New York: Appleton-Century-Crofts.

Staples, B. (1981) Van helps schools select the right computer. Creative Computing, 7(3), 106-112.

Steele, K.J.S. (1982) The effect of computer-assisted mathematical instruction upon the computer literacy of fifth-grade students using a microcomputer. Dissertation Abstracts International, 42(8), Sec. A, 3433.

Steinmetz, J.E.; Romano, A. G.; & Patterson, M.M. (1981) Statistical programs for the Apple II microcomputer. Behavior Research Methods & Instrumentation, 13(5), 702.

Thompson, G.C. (1979) Behavioral programming with the Apple II microcomputer. Behavior Research Methods & Instrumentation, 11(6), 585-588.

Tsai, S.W. (1979) CHI-B: An interactive BASIC program for analyzing the the power of chi-square tests. Behavior Research Methods & Instrumentation, 11(3), 404.

Turnbull, S. K.; Mikiten, T. T.; & Mikiten, S. (1980) CONCEPTS: A program for microcomputer-controlled experimentation in concept attainment. Behavior Research Methods & Instrumentation, 12(6), 631-632.

Vale, C.D. (1981) Design and implementation of a microcomputer-based adaptive testing system. Behavior Research Methods & Instrumentation, 13(4), 399-406.

Vincent, T. (1982) Computer assisted support for blind students- the use of a microcomputer linked voice synthesizer. Computers & Education, 6, 55-60.

Wadham, R. A. (1979) Microcomputer applications in interaction analysis. Paper presented at the annual meeting of the American Educational Research Association, April 1979, in San Francisco (ERIC) Document Reproduction Service No. ED 175 433).

Walkenbach, J. W. (1981) A microcomputer program for the analysis of interaction data. Behavior Research Methods & Instrumentation, 13(3), 369-370.

Warner, R. M. (1980) Round robin analysis of variance: A BASIC program for microprocessors. Behavior Research Methods & Instrumentation, 12(1), 67-68.

Warner, R.M., & Neumann, P.G. (1980) SPAN: An interactive BASIC program for spectral analysis of time-series data. Behavior Research Methods & Instrumentation, 12(3), 389-390.

Watkins, M.W., & Larimer, L. D. (1981) A microcomputer BASIC program to calculate univariable regression model analysis of test bias. Educational and Psychological Measurement, 41, 219-221.

West, R.C. (1982) Programming the PET/CBM. Greensboro, North Carolina: COMPUTE! Books.

Wilson, G.A., & Frederickson, W.A. (1980) Factor rotation in interactive BASIC. Behavior Research Methods & Instrumentation, 12(3), 382.

Wixon, D.R. (1979) Cohen's kappa coefficient of observer agreement: A BASIC program for minicomputers. Behavior Research Methods & Instrumentation, 11(6), 602.

Yost, W. A. (1978) Structure and use of microcomputers. In Minicomputers in sensory and information-processing research, edited by M. S. Mayzner & T. R. Dolan. Hillsdale, New Jersey: Erlbaum.

CHECKLIST

Category	Importance	Performance	Product	Comments
1 Cost				
2 Flexibility				
3 Interfaces				
4 Keyboard				
5 Ports				
6 Speed				
7 Memory size/access				
8 Expansion				
9 Editing & debugging				
10 Peripherals				
11 Software				
12 Graphics/sound				
13 Built-in instruments				
14 Service/reliability				
15 User-friendliness				
16 Other				

OVERALL COMPOSITE RATING ________

Microcomputer Top Ten Buyers' Guide*

Company/Model/Price**	Comments
COMMODORE MAX: $179 Vic 20: $250-$1,000 Commore 64: $599-$4,000 P-Series: $995-$6,000 B-Series: $2,200-$6,000 Superpet: $1,995-$6,000 PET/CBM: $995-$1,495	Wide range of choices. VIC, 64 and P-series have strong color graphics. Logo available for at least 64. P-series designed primarily for education, B for business--80-column display. Advanced 8-bit 6509 & 6510 & 16-bit 8088 microprocessors. Good software selection.
APPLE Apple II plus: $1,530-$5,000 Apple III: $3,500-$8,000	Abundant software for Apple II plus. High-resolution color graphics capabilities now exceeded by several machines costing less. Logo available. Apple III has been a disappointment. New models expected.
TANDY TRS-80 Color Computer: $399-$2,500 TRS-80 Model III: $699-$5,000 TRS-80 Model II: $3,499-$8,000 TRS-80 Model 16: $4,999-$10,000	Color graphics only on Color Computer. Model 16 has over 2,500K floppy disk drive capability & both Z-80A & 16-bit 68000 microprocessor. Model II & 16 offer 80-column displays. Extensive software library.
ATARI Atari 400: $399-$2,000 Atari 800: $899-$4,000	Strong color graphics including Logo type "turtle" graphics. Primarily for school and home applications.
HEWLETT-PACKARD HP-85, HP-87: $2,750-$6,000	Primarily for scientists & engineers, has a built-in thermal printer.
IBM Personal Computer: $1,565-$6,000	Advanced 16-bit Intel 8088 microprocessor. Color graphics. Software is presently limited.
TEXAS INSTRUMENTS TI 99/4A: $299-$3,000	Logo is available for this small color computer.
INTERTECH Superbrain: $N/A	TWIN Z-80A's, 64K dynamic RAM. 350-700K disk storage, CP/M, limited software.
XEROX 820: $2,995-$6,000	Designed for business & wordprocessing.
ZENITH Z89/90: $2,495-$9,000 Z100: $3,995 & up	48K or 64K. 80-column screen. 160-480K per 8-in. floppy. Z-80 based 16-bit 8085 or 8088. Two configurations, one for color, one with built-in monitor.

* Listed in descending order of numbers shipped worldwide--calendar year 1981 (Data: International Data Corp.). There are significant new machines by DEC, Osborne, & Timex/Sinclair, as well as a growing number of other 16-bit machines.

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