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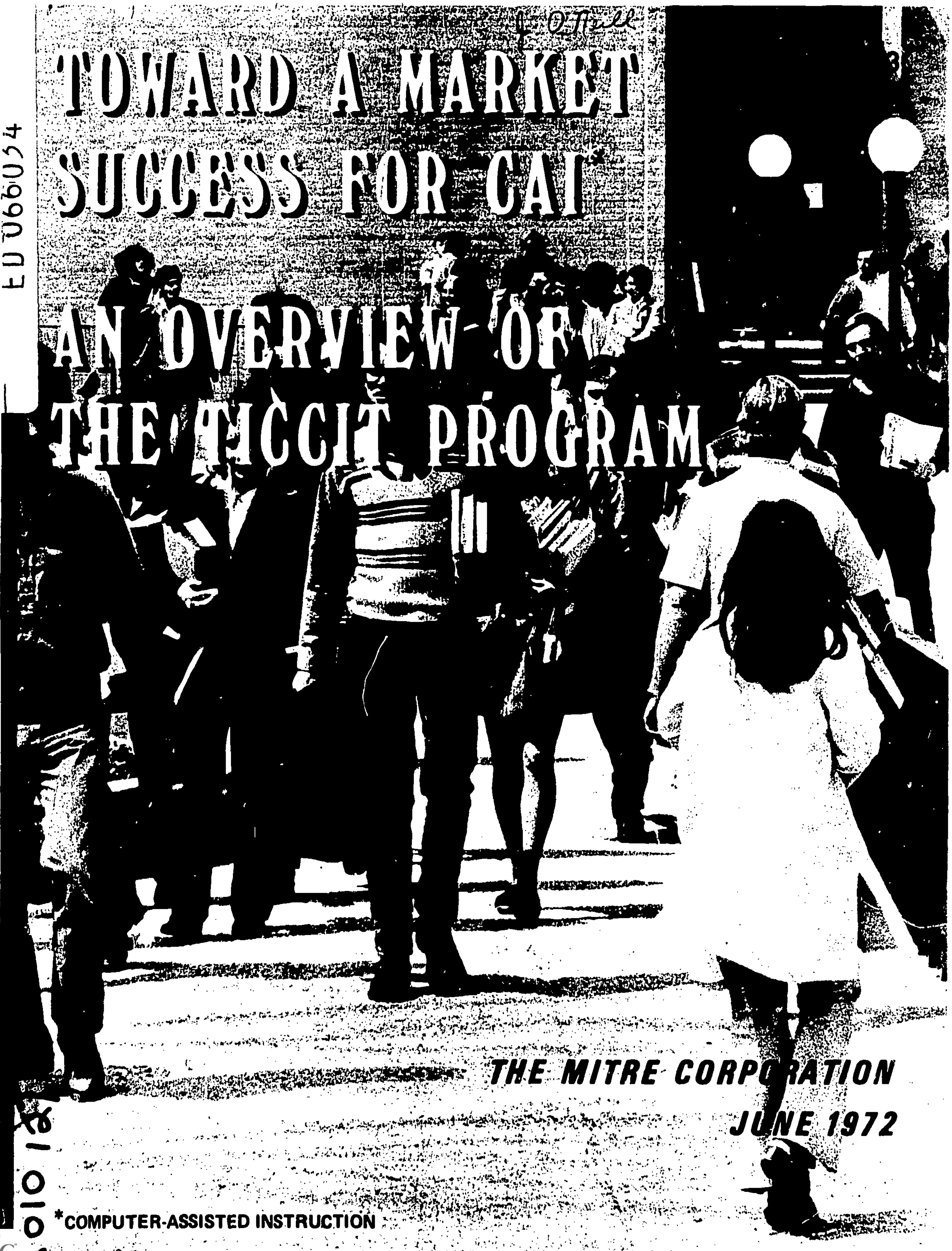
ABSTRACT

A new computer-assisted instruction (CAI) system for college teaching is being tested in two locations by the MITRE Corporation. The system, called TICCIT (Time-Share Interactive Computer-Controlled Information Television), now interacts with more than 100 students, each moving at his own pace, for four semesters of community college math and English. Average response time to student inputs is less than one half second. The student terminal includes color TV screen, headphones and full alphanumeric keyboard. It costs about $900, approximately 25 percent of total system costs per terminal. Operating costs could average less than one dollar per terminal-use hour. A typical hour begins with a short movie followed by presentation of a "menu" showing segments of the presentation which can be accessed any time; for example, "mini-lesson", "instruction", "why take this lesson", "test", and "games". The teaching strategies have been developed independent of content so that different course material can be plugged in the programs at some future date. (MG)

TOWARD A MARKET SUCCESS FOR CAI*

AN OVERVIEW OF THE TICCIT PROGRAM



THE MITRE CORPORATION

JUNE 1972

*COMPUTER-ASSISTED INSTRUCTION

M72-73

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KENNETH J. STETTEN

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THE MITRE CORPORATION
WASHINGTON OPERATIONS

ABSTRACT

The MITRE Corporation is attempting to catalyze the mass dissemination of Computer-Assisted Instruction (CAI) through a multi-year program of development, demonstration, and evaluation, sponsored by the National Science Foundation. The goal of this program is to demonstrate that CAI can provide today better instruction at less cost than traditional instruction in community colleges. Significant products of the program include: two demonstration systems, each with 128 student terminals; four full semesters of community college math and English courses covering 20% of all material taken by the average student, and a complete package of authoring and delivery software. Major innovations include:

- The use of audio and color TV displays (the Digicolor System) in the student terminals to provide voice-accompanied multicolored alphanumeric and graphic displays, as well as full-color movies.
- The use of a pair of minicomputers to provide the necessary computer power in a self-contained system of 128 terminals.
- A low system cost... roughly $450,000 today for one complete, self-contained system with terminals, and a projected cost of less than $250,000 in moderate quantities.
- The capability to deliver CAI and other socially relevant computer services via cable television to homes.
- A new authoring system styled to support the production of high-quality CAI.
- A new and innovative use of "learner control" in CAI.
- A projected commercial cost including hardware, equipment maintenance, and CAI programs of less than one dollar per student contact hour.

Validation of courseware material on a prototype version of the system is scheduled to begin in January, 1973. Full scale demonstration of two systems is scheduled for two community colleges in Sept. 1974.

This CAI system has been termed TICCIT, for Time-share, Interactive, Computer-Controlled Information Television.

ACKNOWLEDGEMENTS

The National Science Foundation, under contract number NSF-C729 and grant GJ32785 supports the programs described in this publication.

The ideas, concepts and designs reported herein are the work of many individuals. The TICCIT staff numbers over 60 people, including those of our major subcontractor for courseware, Brigham Young University. Credits for even those who gave direct contributions to this report are too numerous to properly attribute. Furthermore, close cooperation and consultation with numerous research, academic and industrial organization has been responsible for much of our progress and conclusions. While it was necessary for us to evolve a specific design approach to realize a working system in a relatively short time frame, we recognize that private industry may, in fact probably, will evolve their own different designs when considering mass dissemination. Our point is to demonstrate that todays technology will support the development of the mass delivered services described, in an economically viable manner.

The major task of assembling and writing this document is the work of John L. Volk, Associate Department Head of MITRE's Computer Systems Department, who also assists in managing the programs described. Dr. C. Victor Bunderson, co-principal investigator of the community college program and Director of the Institute of Advanced Industrial Design, Dr. David Merrill, Director of the Instructional Research and Development Department and Dr. Jerry Faust are the principal managers of courseware design and production at Brigham Young University.

Inquiring regarding the TICCIT program should be directed to The MITRE Corporation, 1820 Dolley Madison Boulevard, McLean, Virginia 22101. Telephone (703) 893-3500.

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I. INTRODUCTION

Computer-Assisted Instruction (CAI) has been a commercial failure. It has failed despite instructional research that has demonstrated the effectiveness of CAI, and at a time when the problems of traditional instruction have never been more apparent. CAI systems have been offered by large companies and small, and school systems have never had larger budgets, but the dollars flow toward continuing support of traditional instruction. The commercial failure of CAI has been attributed to many factors: an initial oversell of its capabilities, poorly authored educational content, expensive and unreliable hardware, an educational bureaucracy resistant to the intrusion of computers in the classroom, and the decentralized structure of the American education system that leads to tens of thousands of school systems, each having to be individually sold on the idea. The CAI experience of commercial computer manufacturers in the mid and late 1960's was so bad that only one continues to market a system.

MITRE's interest in CAI, begun four years ago, sprang out of traditional instruction's failure to teach reading in many elementary schools. During these past years, many proposals have been written, systems designed, and some of the enigmas of CAI understood. What became apparent was that neither a lower cost, higher performance CAI computer system nor an improved theory of instructional psychology would get CAI in the schools. The real problem is the making of a market (i.e., creating a supply/demand situation) for Computer-Assisted Instruction.

The National Science Foundation (NSF) has funded MITRE to "catalyze the mass dissemination of CAI" through a five-year program aimed at achieving a major market success for Computer-Assisted Instruction. A goal as lofty as this may be dismissed as puffery by individuals familar with CAI history, but to MITRE, the goal seems realizable We are attempting to sell the CAI concept to the schools as a reasonable, cost-effective approach to individualized instruction, while at the same time convincing the computer/textbook/publishing industries that CAI can be marketed now. To do this, we have selected the community college as a market area on which to focus our efforts.

The community college is particularly attractive as a market entry point because of the rapid growth of community colleges, their receptivity to innovation and emphasis on educational effectiveness, the wide spread of student abilities leading to a dramatic need for individualized instruction, and, to a lesser degree, the trend toward state-wide control or administration of community college systems. We have studied the community college as a market, selected courses with the highest exposure, and sized and priced our system to be suitable for most community colleges. By using generally off-the-shelf components to build our system and by developing courseware (the educational software) in a structured, project team environment, we are attempting to show industry that the hurdle of hardware development is already behind us, and that excellent CAI courseware can be dependably developed by a team of professionals with complementary skills.

But even with good plans, ideas, and designs, one can't succeed without success. For this reason, a major portion of our program is one of demonstration and evaluation. The real selling of CAI will be done by the students and teachers who use the system and the administrators who overlook its operation. Two systems are being built to go into two community colleges for a two-year period. During this demonstration, a major portion of traditional instruction curriculum will be displaced by Computer-Assisted Instruction, with many students spending several hours each day at a computer terminal. To add credibility and statistical strength to the demonstration, a separate firm, the Educational Testing Service (Princeton, New Jersey), under contract to NSF, will evaluate the success of the demonstration.

This paper is divided into five parts: System Concept, Hardware, Courseware, Software, and Cable TV. The rationale for various features of the TICCIT system is reviewed in the System Concept section. The hardware is discussed, with emphasis on its functional aspects rather than technical detail. In discussing the educational content (courseware) being prepared for the system, particular attention is given to the authoring team concept, learner control, and the rationale behind mainline CAI. Next, with the basics of the hardware and courseware in hand, the TICCIT computer software is explained. The TICCIT authoring system, application software, and the operating systems, along with the results of a computerized model of the system's response characteristics are discussed. The paper's final section discusses a new medium for the delivery of CAI and other services to the home–Cable Television.

II. SYSTEM CONCEPT

MITRE's TICCIT system is expected to be the first of a new generation of CAI systems to demonstrate instructional delivery in full cost-effective operation. It reflects much of what others in the past decade of CAI research have found useful, and includes many of the significant advances that have been made in the computer/semiconductor/communications industries. The TICCIT system is conservative. It is based on proven technology, and provides a careful selection of capabilities that foster educational richness while maintaining low system cost.

At any one time, the TICCIT system instructionally interacts with more than 100 students, each moving at his own pace through any of the systems CAI courses. The system retrieves logic, student records, audio, and visual information from its various data bases, and provides an audio/visual presentation for the student at his TV terminal. The student responds to the system by typing on a typewriter-like keyboard which invokes another computer-generated audio/visual presentation. Time-sharing techniques are employed in the system to allow simultaneous access to the data bases.

There are two distinct components of any CAI system: a system to allow assembling of the data bases (i.e., the conversion of the author's material into the computer data bases), and a system to deliver interactively the data bases to the students. In many developmental CAI systems, these two components have been combined into a single system. While this has proven to be useful where the authoring load is substantial, it has resulted in relatively inefficient delivery systems (primarily because of the use of interpreters instead of executing compiled code) and in authoring systems that are overstructured and inflexible. CAI material is expensive. In the future, therefore, it will most likely be prepared by professionals, packaged and sold in much the same manner as textbooks. The authoring component of the CAI system will be physically separated from the delivery components, and, in fact, the authoring component may be composed of entirely different hardware than the delivery system. For reasons of efficiency, better authoring, and the long-term approach to the generation of CAI, the TICCIT system separates authoring and delivery. MITRE's system, as described in this paper, is optimized for the delivery of CAI, however, while "off-line" (i.e., when no students are using the system), it can function as an authoring system.

TICCIT, as most other CAI systems, relies on still (not moving) computer-generated TV displays, featuring alphanumerics and line graphics, for most instructional sequences. A wealth of knowledge on the effective use of this medium of instruction has been assembled, as well as the general system requirements it demands. For instance, it is generally accepted that with this form of instruction, the computer generates a new display for each student on the average of once every ten seconds; and, again on the average, the student responds with one key push every two seconds. As CAI assumes more of a role in every day instruction, the need for variety will grow. The more tools the instructional psychologist has at his disposal, the greater his chances of succeeding in motivating and maintaining and focusing the attention of his students. Certain television programs, such as Sesame Street, have proved this point. The time has come to expand the capabilities of CAI so that the expertise of educational television can be brought to bear on instructional problems.

The addition of audio-to-visual presentation will increase students' attention span and give needed changes of pace in extensive CAI courses. Short audio messages can focus students' attention, provide mneumonic aids, and pace learning. And, audio can broaden the range of instruction for which CAI is an appropriate mode of instruction. In this program's English course, for example, the inclusion of audio will allow the author to demonstrate differences in dialect that will liven discussions of regionalisms and will also make testing of spelling skills possible.

The availability of color presentations on TICCIT terminals is another step toward enlivened CAI. Like the addition of sound, color will increase variety and serve as a motivational tool. Color has long been used in the television industry to add to the credibility and reality of a production. In instructional programs, it can also be used to differentiate and emphasize crucial material and to prompt student responses.

TICCIT's ability to display video tapes on an individual basis at student terminals under computer control represents cost-effective means to project any kind of motion sequence with sound and color. It is MITRE's belief that the use of a mixture of video tape sequences with frame-by-frame CAI interactions is a more cost-effective approach to educating large numbers of students than attempting to store or generate all images from a central computer. By utilizing the great variety of presentation techniques developed in the motion picture and television industries, and by exploiting full-fidelity audio capability and color, the author of educational materials has far more variety at his disposal than if he were provided only with a graphic CRT terminal. Computer-graphic sequences or computer-generated animations as well as sequences with actors, language teachers, etc., that are effective can be mass disseminated through the use of video tapes.

III. HARDWARE

MITRE's TICCIT system (controlled information television) is mostly composed of off-the-shelf hardware and a few specially designed subsystems, but its capabilities add up to something more. To start, it uses color TV receivers as the student terminal display. Its pair of minicomputers (see Figure 1) can support over 100 active terminals. The system not only serves students in centrally located clusters of terminals, but also in dormitories, offices, and even homes off-campus through special terminals connected to the computer system via a standard cable television system.

TICCIT Terminal

The student terminal is the most important piece of hardware in the system. It must provide a pleasant and efficient interface between the student and the computer. From the student's viewpoint, the terminal is composed of a color TV display, a pair of headphones, and a keyboard. The color TV displays, under computer control, alpha numerics and line graphics in seven colors, as well as full color movies. Up to 17 lines of 41 characters each may be displayed. The character set is completely programmable, with up to 512 distinct characters being definable at any single time.

Graphic displays are constructed from straight-line segments drawn on a grid of 200 elements in the vertical direction by 256 elements in the horizontal direction. The color of each character and line segment may be individually specified. Short (about five minute), full-color movies add variety to the computer/student interaction and give the courseware writer a strong tool to dramatize difficult concepts. The student may view movies about five minutes out of each hour.

To further augment the visual display, the pair of headphones under computer control brings pre-recorded messages, such as poetry readings, words of encouragement, and, when all else fails, the sound of breaking dishes. It is expected that the student will be listening to audio responses (selected from a random-access audio data base containing about five cumulative hours of audio message) only 10% of the time he is at the terminal and that audio responses will vary in duration from about one second to approximately 30 or 40 seconds. The hardware is implemented to support the level of use of audio and movies that the authors of our courseware feel is appropriate, but because of the modular nature of the audio and movie hardware, the hardware capability can be expanded or contracted as is appropriate.

An electronic keyboard enables the students to talk back to the computer. While the keyboard is of a standard type, the key layout was selected to simplify operations. As shown in Figure 2, the center of the keyboard is similar to that of a standard IBM selectric typewriter. The keys on the left provide cursor and editing control, the keys on the right

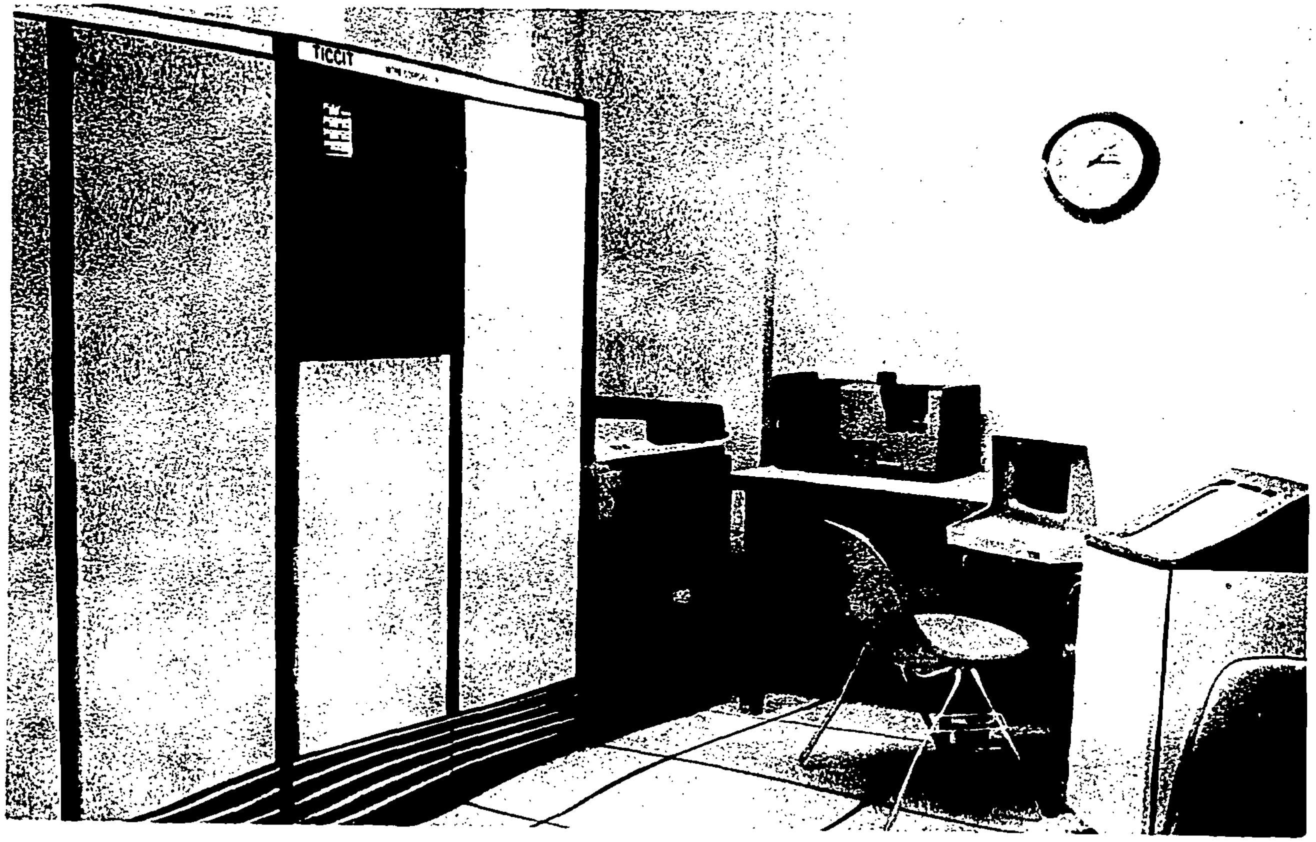


FIGURE 1
TICCIT COMPUTER SYSTEM

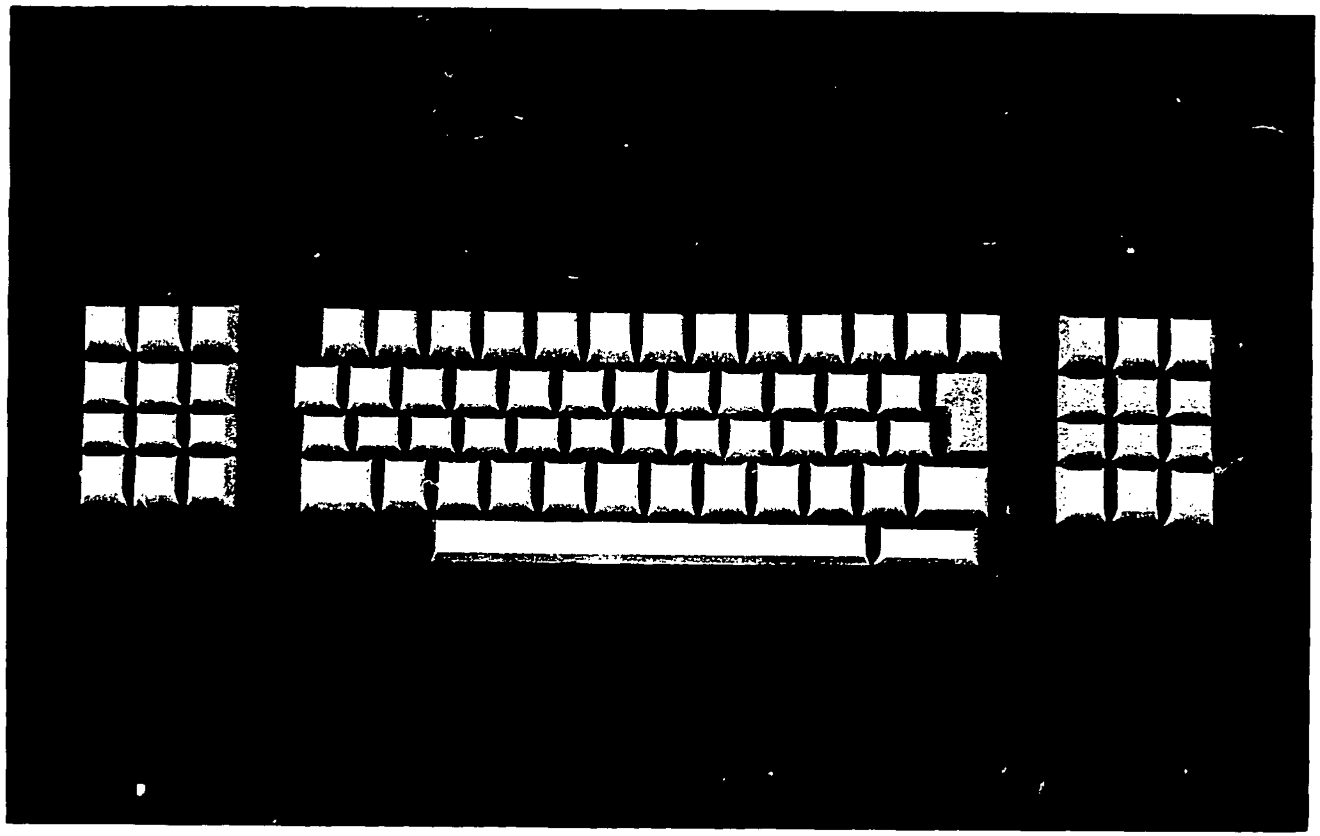


FIGURE 2
DETAILED VIEW OF STUDENT TERMINAL KEYBOARD

provide learner control options. An overlay keyboard allows variations in course-to-course labeling of the keys. MITRE considered other student response devices, such as the light pen, mouse, joystick, etc., to supplement the keyboard, but rejected them because none was available commercially at an acceptable cost and their instructional importance questionable.

TICCIT Computer System

A block diagram of the TICCIT computer system is shown in Figure 3. The system separates foreground (terminal processing) and background (algorithmic frame processing) tasks with the minicomputer devoted to each task to balance and split overall system I/O channel loads. The terminal processor performs all fast-reaction, highly-stereotyped functions, interacting with the TICCIT student terminals, including frame outputting as well as keyboard input multiplexing. The main processor, utilizing the TICCIT data base, generates and assembles frames to be displayed as a function of courseware and student responses. Tasks of the main processor are diverse and relatively slow-paced.

The main processor, a Data General Nova 800, is configured as a time-sharing minicomputer with 32,768 words of core storage, special hardware time-sharing protection features, and the usual host of standard peripherals, in addition to three large moving-head disc drives. The peripherals (card read, magnetic tape unit, line printer and console CRT terminal) are all low and medium speed, low-cost items ideally suited for courseware development and for later use in CAI applications. The TICCIT data base is stored on two IBM compatible removable media, movable head-disc memories (sufficient for the initial four-full semester courses—additional disc drives may be added at a cost of $12,000 each to expand the data base). Between these two memories, almost 50 million characters may be stored and accessed. A third disc memory of the same type holds student records (for more than 3000 students), and, in addition, will be used to implement an overlay memory in which the major parameters and program steps for each active terminal is stored.

The terminal processor, a Nova 800, is similar to the main processor, and, as its name implies, services the TICCIT terminals by receiving and processing keyboard entries and by generating new displays to be sent to the terminal (for instance, "echoing" characters to the student terminal display as they are typed). The buffered computer-to-computer link uses both a fixed-head disc (accessible by both minicomputers) and a direct memory-to-memory data transfer system to provide intercomputer queueing capability and, when appropriate, fast data transfer.

The Digicolor System

Figure 4 shows how TV pictures are passed from the computer center to the TICCIT terminal in the Digicolor System. Under computer control a single character/vector

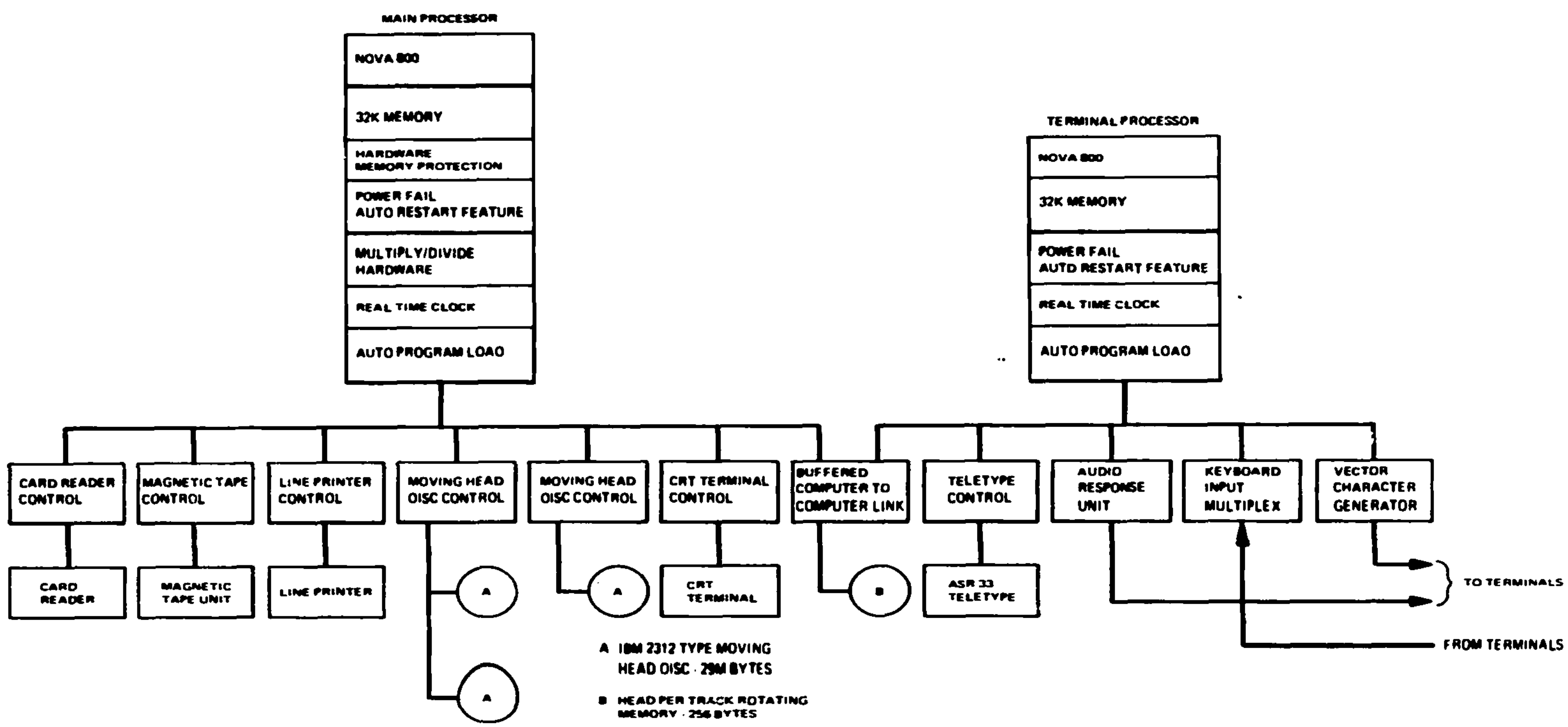


FIGURE 3
TICCIT COMPUTER SUBSYSTEM

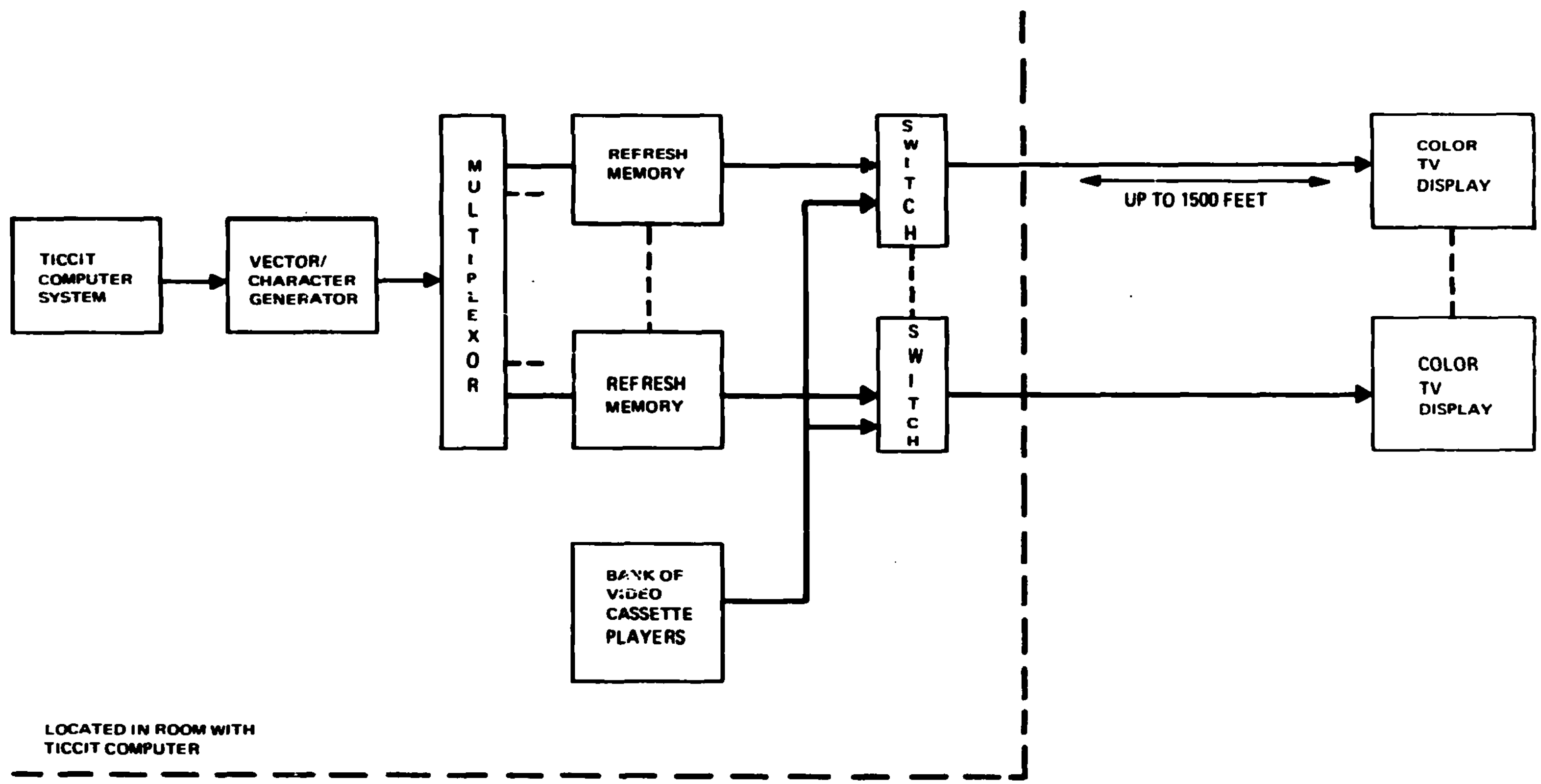


FIGURE 4
SIMPLIFIED BLOCK DIAGRAM OF TV PICTURE GENERATION AND TRANSMISSION FOR CENTRALLY LOCATED TERMINALS

generator is time-shared by all terminals. Its output (typically 1/60th of a second TV picture) is selectively passed to the video-refresh memory of the appropriate student terminal. The refresh memory repetitiously sends a single TV picture, originally generated by the character/vector generator, to its associated color TV receiver.

The refresh memory is composed of two MOS memory subsystems. The first memory, which contains luminance information for the display, is an 88,000-bit dynamic shift register, operating at about a 10MHz rate. The color information is contained in MOS random-access memory, organized as three bits by 1,500 words. The luminance refresh contains the bit-by-bit detail of the display, while the color refresh holds the color on essentially a character-by-character basis. (In fact, color information is stored separately for the top half and bottom half of each character to allow more flexibility with colored line drawings.) The luminance refresh is quite small, requiring only a single 8" x 10" printed circuit board; the color refresh is much smaller—six such units can mount on a similar-sized board. The benefits of this digital solid-state refresh over earlier refresh techniques (such as electronic storage tubes) are much greater reliability, simplified maintenance (no analog adjustments), resolution two to three times better, and comparable cost.

A bank of video cassette tape players (computer directed but manually operated in the demonstration systems) provides the source of full-color movies. Each TV receiver is switched to receive video either from its video-refresh memory or a selected video-tape player. The terminals may be located up to 1,500 feet from the computer center. Audio information being sent to the terminal and keyboard signals coming to the computer are frequency multiplexed on the same coaxial cable that carries the video information to the terminal.

During the demonstration and evaluation period of this program, it is also planned to operate TICCIT terminals in dormitories and homes off-campus via a standard cable television system. Because the TICCIT terminal display is a television receiver and requires a signal similar and compatible with that of normal television, a cable TV system can carry TICCIT signals. Several techniques to deliver CAI to the home via a cable television system have been developed and are being studied in a complementary program at MITRE. The number of terminals to operate in this mode and the technique to deliver the required signals will be a function of the availability, capability, and cooperation of cable TV systems in the vicinity of the selected community colleges. In section VI of this report, the delivery of CAI and other services via cable television is discussed in detail.

Cost of TICCIT

The cost of the TICCIT hardware today is shown in Figure 5. Excluding system integration and installation costs, but including the cost of the computer and all required hardware for audio, color, and video-tape capabilities, the pro-rated cost amounts to $3,600

MAIN PROCESSOR	26,000
TERMINAL PROCESSOR	21,000
CARD READER	4,000
LINE PRINTER	11,000
MAGNETIC TAPE UNIT	9,000
MOVING HEAD DISC CONTROL (2)	17,000
MOVING HEAD DISC DRIVES (3)	36,000
FIXED HEAD DISC CONTROL (2)	7,000
FIXED HEAD DISC DRIVES (1)	5,000
CRT TERMINAL	3,000
COMPUTER-TO-COMPUTER LINK	3,000
CHARACTER GENERATOR	7,000
VECTOR GENERATOR	11,000
KEYBOARD INTERFACE	5,000
AUDIO RESPONSE UNITS (20)	60,000
AUDIO RESPONSE CONTROL & SWITCHING	10,000
TV SETS (COLOR) (128)	38,400
KEYBOARDS (128)	19,200
LUMINANCE REFRESH (128)	76,800
CHROMA REFRESH UNITS (128)	11,000
SIGNAL PROCESSING AMPLIFIERS (128)	32,000
VIDEO TAPE PLAYERS (20)	16,000
REFRESH CONTROL ELECTRONICS	10,000
TV MODIFICATIONS	25,600
TOTAL	$464,000

FIGURE 5
TICCIT HARDWARE COSTS TODAY

per terminal. This is already a very attractive figure, but if the trend in cost reduction continues in minicomputers, moving head-disc drives, and integrated circuits, and if a moderate (25 systems) number of systems were constructed in mass in 1975, the total cost of the system will fall to $2000 per terminal, and probably further. Only 25% of the TICCIT system's cost is in the student's terminal hardware. Today, the equipment in the carrel costs $900 with a projected drop to $500.

Reliability and Maintainability

A special effort has been made on the TICCIT system to reduce both the possibility of system failure and the effort required to quickly repair the system if something does go wrong. In general, this goal is being reached by using proven products, solid state digital technology, modular implementation, and a central location of most system elements.

The utilization of "off-the-shelf" proven products (such as the TICCIT computer and its peripherals) results in a more reliable system because of the countless hours of tests and refinement that only is practical on a mass produced item. Maintainability of the proven product is enhanced by the low cost of spare subassemblies and high quality technical documentation. The predominant use of solid state digital technology in the TICCIT system, for example in the refresh memory, reduces the number of circuits that can be affected by components aging or temperature extremes. In addition with digital circuitry, it is usually easier to find faulty components than with analog circuits. The modular implementation of TICCIT (i.e., the computer's 16 identical memory modules, the 128 identical refresh memories, etc.) speeds maintenance by allowing sparing of parts on a complete module basis. Maintenance is also simplified by the central location of all complicated TICCIT sub-assemblies. When something does fail, it is expected to be at the central location, where the field engineer will have easy access to both the spare modules and test equipment.

We anticipate that a single, on site, field engineer will be required to minimize the possibility that any subsystem failure will result in the entire system being down for several hours. Because of the systems modular form, the structure of the systems software, and the spare parts planned to be stocked on site, it is expected that following most any failure, the system can be made operational (perhaps with a reduced capability, i.e. fewer students on line) in less than thirty minutes. The cost of maintenance includes a non-recurring investment of $20,000 in spare parts and test equipment and an annual expense of about $20,000 for the field engineer's salary and replinishment of the spare parts stock.

IV. COURSEWARE

The educational material (courseware) planned for use in the demonstration is being developed (under subcontract to MITRE) by teams of instructional psychologists, subject matter specialists (individuals experienced in teaching the subjects), media specialists, and programmers at Brigham Young University under the direction of Dr. Victor Bunderson. Dr. Bunderson (formerly of the University of Texas) and his colleagues have been instrumental, not only in the development of the courseware, but have, in addition, been greatly influential in the development of the system hardware and software.

Selected Courses

The selection of courses to be offered was the initial step in courseware development. This was fundamentally a market study to determine what academic courses would both have a wide audience and be significantly less expensive to offer with Computer-Assisted Instruction. Freshman math and English and a computer science course were our candidates when the study began. As our study progressed, however, it became apparent that a significant part of the community college curricula consisted of remedial math and English courses. Incoming students, because of open enrollment policies and the deficiencies of secondary and primary schools, are in need of extensive help in the basics of these subjects before they are prepared to move on to college level material. As a result of the study (and a limitation on the funds available for courseware development) a remedial math and remedial English course were added and the computer science course deleted. A brief summary of the goals of these four courses follows.

Remedial mathematics incorporates a basic review of arithmetic computations and provides instruction through several levels of competency in computation and manipulation. The course is designed to strengthen the students' ability to apply mathematics to everyday life, and to enable the student to become conversant with basic math language, math tables, formulas and their uses, and operations on an ordered field.

Remedial English is essentially a writing course with other skills, subordinate to writing, integrated into the course as they contribute to enabling the student to compose a standard expository paragraph. The course features many of the latest techniques in teaching writing–usage drill, editing, transformational grammar, free expression, generative rhetoric—while avoiding an over concentration on formal grammar. The end objective of the course is to prepare the student to enter a college-level composition course; or, if the student does not wish to take college composition, to enable him to write well enough to meet his personal and vocational goals.

Freshman mathematics is designed to provide a treatment of the function concept with extension to elementary functions including the polynomial, trigonometric, exponential and logarithmic functions with a brief coverage of the conic sections in coordinate geometry. It requires as a prerequisite successful completion of the traditional Algebra II course or the remedial mathematics course. Emphasis is placed on intuitive understanding of the concepts involved, with prudent and sparing use of rigor. Graphic interpretation of problems will be used whenever possible; pains will be taken to help the learner acquire a "feel" for and a common sense attitude toward the material and its place in the subject matter.

Freshman English covers the "second half" of the traditional composition handbook—diction, sentence structure, and paragraph strategy. It differs from the handbook in that it reduces the multiplicity of "rules" and offers maximum student practice with immediate feedback. In this course, CAI is augmented by a writing laboratory with the computer handling specific instruction in grammar, mechanics, diction, sentence structure, and paragraph development; leaving the assessment and evaluation of writing skill to a trained instructor. The end objective of the course is to enable the student to write grammatically correct, lucid and accurate prose.

Our market analysis indicates that these four courses will account for approximately 20% of the total student contact hours of instruction in the average junior college. Each course covers about five semester hours of traditional junior college curricula, and the average student will require about 50-60 hours of terminal time to complete a course.

Mainline Versus Adjunct

In approaching the development of the courseware, it is important to recognize the distinction between the two classes of CAI programs as illustrated in Figure 6; the main difference between them is the role of the teacher. In the adjunct approach, the teacher is the central figure, and the programs are supplements to traditional classroom and laboratory work or serve as a new kind of homework. These uses include problem solving, using the computer for simulation and modeling, drill and practice supplements or remedial units, and use of programs for illustrations during lectures or laboratories. It is the teacher or his students who do the programming in these instances. The products of this "cottage-shop" method of development are heavily dependent on the originator to provide the context; thus, dissemination is difficult.

The mainline approach being taken in this program, in contrast, is designed from the first for mass dissemination. A complete instructional system is redesigned for a substantial block of material, so that the role of teachers is redefined,* and eventually reduced (primarily by relieving the teacher of class presentations) as the system becomes more technologically intensive and less labor intensive. Lock-step scheduling is replaced by a self-paced, individualized scheduling system, with a criterion reference standard for grading to replace grading "by the curve". A design and development team, having total capabilities

*The new role is seen largely as tutor-counsellor/diagnostician and problem solver for individual students.

ADJUNCT	MAINLINE
--- CONTEXT PROVIDED BY TEACHER.	--- REDESIGN OF A COMPLETE INSTRUCTIONAL SYSTEM, INCLUDING THE TEACHER'S ROLE.
--- PROGRAMMING BY TEACHER AND STUDENT.	--- SPECIFICATIONS AND PROGRAMMING BY DESIGN-PRODUCTION TEAMS.
--- FITS WITH STANDARD CREDIT-HOUR SCHEDULING.	--- REQUIRES SELF-PACED SCHEDULING AND GRADING.

SOME CONSEQUENCES OF EACH APPROACH

--- REPRESENTS AN ADD-ONE COST.	--- GREAT ECONOMIC POTENTIAL: SUPPLANTIVE.
--- REQUIRES LOW TO MODERATE CAPITAL INVESTMENT.	--- REQUIRES HIGH CAPITAL INVESTMENT.
--- INCREASED EFFECTIVENESS: OPPORTUNITY FOR RESTRUCTURING OBJECTIVES AND SUBJECT MATTER.	--- INCREASED EFFECTIVENESS AND EFFICIENCY.
--- MODEST BUT VARIABLE SYSTEM REQUIREMENTS; USE SCIENTIFIC OR BUSINESS ORIENTED COMPUTER SYSTEMS.	--- SPECIFIC ENGINEERING DESIGN FOR EDUCATION.

FIGURE 6
A DISTINCTION BETWEEN TWO CLASSES OF CAI PROGRAMS

not often possessed by the individual teacher, is responsible for the courseware development, documentation, and packaging for distribution.

We expect as a consequence of the use of mainline CAI that the reduction of instructional labor costs, through a reduction in total teaching staff and the use of lower-cost paraprofessional proctors, will more than offset the cost of the TICCIT system, including hardware, equipment maintenance, and courseware. The cost difference is complicated by several factors. Not only is it extremely difficult to establish a true cost-per-student contact hour for any educational institution, but the many ways–at many different costs–a TICCIT system could be procured and maintained by an educational institution and the many ways courseware could be prepared and its cost pro-rated further complicate the comparison. A major task of the Educational Testing Service in its role as evaluator in this program is objectively to gather sufficient data to estimate the cost differential between CAI and traditional instruction, in addition to determining the differences in educational effectiveness. MITRE has, of course, analyzed the operational cost of TICCIT and conservatively projects a commercial (leased) cost of less than one dollar per terminal-use hour, including hardware, equipment maintenance, and pro-rated courseware cost.

The cost of courseware development appears quite high–approximately $1.5 million to develop the four courses in this program–but if even moderate dissemination is assumed, the cost on a prorated student contact hour basis can be shown to be quite reasonable. For example, if only one percent of the nation's 2000 community colleges procured TICCIT systems, and used this program's four courses for a five year period, the prorated cost per contact hour for courseware alone would be about 15¢, (based on 20 schools, 1000 hours utilization/year, 100 terminals, and five years, giving 10 million student contact hours). We expect that the effort required for courseware development will be lowered as experience is gained in its production and that substantially more than one percent of the schools will adopt CAI. Together, this should result in nickel-per-hour courseware.

The Separation of Strategy from Content

The courseware developed by the design and development team follows the concept that it is possible to view the way subjects are taught independently from what is taught. This fundamental principle of "instructional science" has led to the specification of guidelines and procedures for the development of course content and to the adoption of instructional strategies which reflect different teaching techniques and styles. The content of each course is "packaged" into all of these strategies which can be reasonably applied (with the specification of parameters which allow the strategies to conform to variations in the content.) The packaging process also allows for the inclusion of whatever "filler" is necessary to make the lessons coherent and interesting. This separation of content and strategy leads to a further breakdown of tasks, and, hence to a further separation of the people and jobs in courseware development.

The Authoring Team

The TICCIT authoring system enables considerable specialization of labor. As Figure 7 shows, the instructional psychologist provides overall guidance; instructional design technicians match the strategies and content; subject matter experts break down courses into topics, rules, concepts, and prerequisites; authoring assistants generate files of examples and nonexamples of concepts and rules; packaging specialists put together the final manuscript for testing, validation and distribution; finally, the empirical design technicians conduct tests to determine the instructional validity of the material. The objective is to produce pedagogically sound, interesting, validated courseware at a far more attractive cost than presently available.

Content development can be separated into content organization and item generation. Course content can be organized by first dividing the entire course into a set of topics, each of which is one lesson, and by subdividing each lesson into a hierarchy of objectives.

The hierarchy of objectives can be viewed in the following way:

- Mastery of a topic can be measured by the students' ability to solve problems in the topic area.
- Problem solving is based on the students' ability to select an appropriate rule to apply at each step of the problem solution and to apply that rule.
- A rule is an association between two or more concepts.
- A concept is a definition based on the jargon of the subject.
- Jargon must be memorized.

The course, then, may take on a hierarchial nature as the concepts and rules of one lesson become the jargon of the next.

On the TICCIT team, it is the subject matter expert's job, as reviewed by the instructional psychologist, to define this breakdown of the course into topics, rules, concepts, and jargon.

Once the breakdown has been completed for a given topic, authoring assistants can begin generating files of examples and nonexamples. To understand the significance of this, it is important to realize that the "meat" of any instructional content is made up of 1) statements of generalities, 2) examples of instances of those generalities selected to

LESSON DEVELOPMENT CYCLE

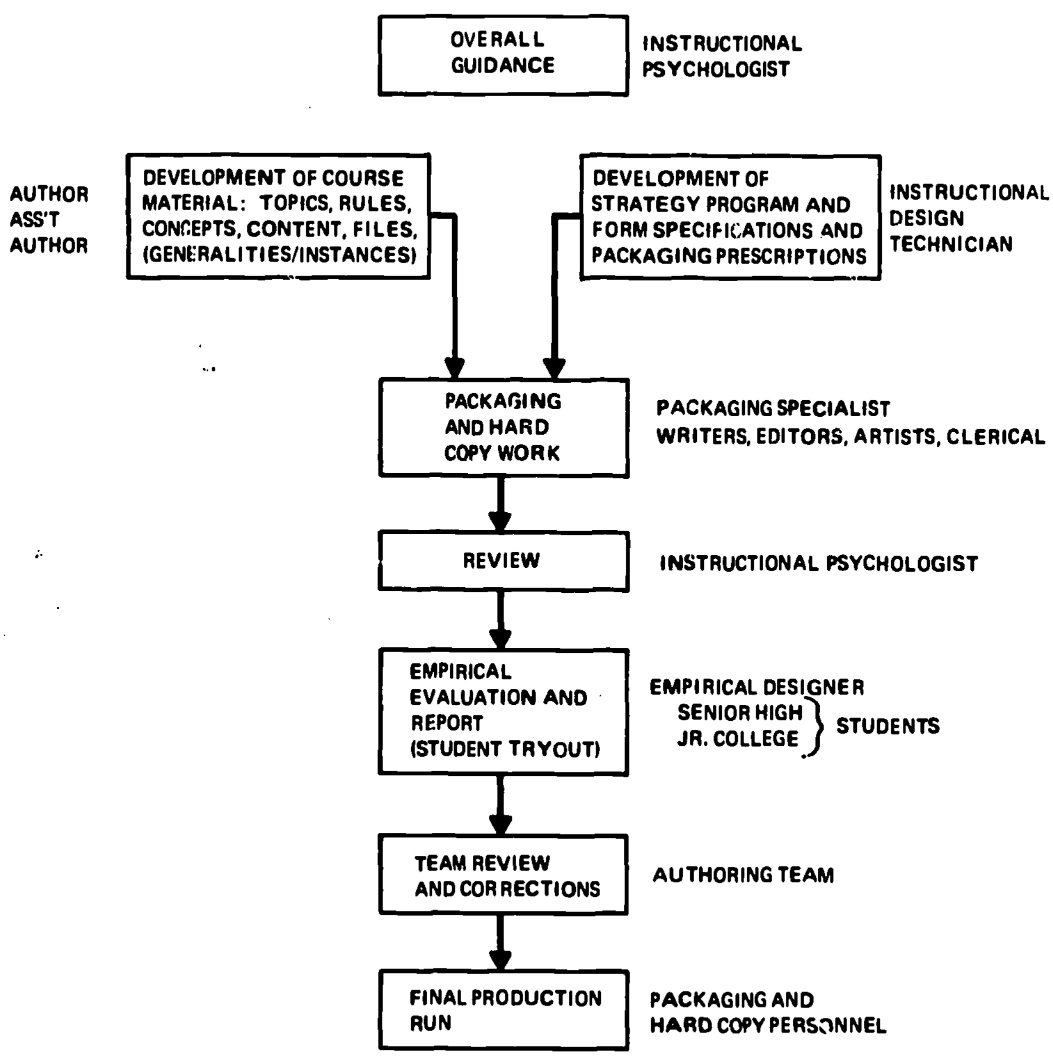


FIGURE 7
INSTRUCTIONAL PSYCHOLOGIST

prevent under-generalization, and 3) nonexamples selected to prevent over-generalization.

Similarly, strategy development can be organized by learning style and by the content breakdown listed above. Learning style presents two options to the student. He may choose to approach the lesson one step at a time on the hierarchy or he may tackle it as a single unit. Within TICCIT, this division shows up in the lesson menu. Here, the student may select to see objectives, definitions, examples, etc. from the entire lesson, or he may select instruction on each objective one at a time.

Another dimension of learning style is related to the order in which the student receives expository presentations, practice, and testing of content. For example, a tutorial style will proceed in the order listed, whereas a discovery style will proceed from practice and expository feedback to testing.

On the TICCIT team, it is the instructional design technician's job, again as reviewed by the instructional psychologist, to define instructional strategies (paradigms) to cover the various dimensions of style and control for each of the content types. Strategies are needed which teach jargon, concepts, rule using, and rule identification.

A third important area of instructional design, packaging, or the application of strategies to specific content to form a cohesive course can be broken into two phases. In the first phase, the instructional design technician selects some gross parameters of the strategies to fit the particular content. Some of these are: determining the appropriate amount and kind of attribute isolation, (pointing out that an example passes the relevant attributes for a concept or that a nonexample does not), defining mastery and failure criteria, defining item selection algorithms, (e.g., in order or at random, possibly relating a difficulty level estimate of the items with a student's performance level), and defining appropriate answer processing logics.

In the second phase of packaging a packaging specialist: fills in the details of display specifications, adds the "filler" messages that provide continuity, and adds to the content where necessary to meet the attribute isolation, answer processing, and other ancillary requirements defined in the first phase.

Courses are prepared lesson-by-lesson (there are about 50 lessons per course). Lesson preparation begins with the production of the content files. These files may consist of as many as 500–600 individual sheets of paper, each representing an individual display frame. Once the content files are ready, they are arranged or packaged in accordance with the packaging prescriptions. The order of the course now set, the next work is to edit and polish the frames of the course. Once this is done, the empirical designer, using high school and college students, conducts tests of the terminal and enabling objectives, as well as of certain elements of the lesson content. His report is used by the team members to revise in all aspects of the course as required. The lesson is then finally reviewed by the instructional psychologist and final touches added.

An Instructional Scenerio

What will it be like to take one of these courses? From the very beginning, it will be different than traditional instruction. The student will be given much more control over his course through the instructional material. For instance, on the first day of a course, he will contract for either "PASS" or a grade. (If he contracts for a grade, he will receive at least a "PASS" if he complete the course, but he may earn an "A" or "B" by mastering additional objectives.) The student will move at his own pace–a bright student will rapidly master the objectives of the courses while the less-prepared student will benefit from the helpfulness and patience of the system. He will also learn how to control the style and strategy of the presentation to fit his changing needs and moods.

Most lessons begin with a short movie that highlights the concepts addressed here. Following the movie, the student is allowed to select an item from the Lesson Overview Menu, as shown in Figure 8. If the student selects "Instruction" he will receive material on each objective of the lesson, one segment at a time (the term "segment" refers to all the content files related to an objective). To access the various materials in each segment, the student uses the learner control keys on the right side of the keyboard (see keyboard photograph in Figure 2). The function of each of these keys is given in Table I. If the student presses the INTERRUPT key he will get the menu of choices listed in Table II. From here he may return back to the lesson overview menu when he chooses. If the student presses the OBJECTIVES key he will be shown the hierarchy of objectives for that lesson, with an indication of how much study he has devoted to each of them. When the student feels ready, he can ask for the test shown on the lesson overview menu.

When he successfully passes the mastery test, the student who is trying for an "A" or "B" will take additional instruction. At the end of a lesson, or at times during the lesson, the student will be given the opportunity to play games, watch movies, or do extra work.

A bank account will be used to control the student options. The student will routinely have points added to his bank account for selection of good strategies (ones that work for him) through the lesson material and for doing extra work. Points may be spent by the student to play games or watch movies. An advisor program will monitor student strategy and the success of the students at passing mastery tests. A student having trouble will be given advice on strategies through the lessons and he may be told to reconsider his grade contract of "A" or "B". On the other hand, a student who has contracted for "PASS" and who is doing well may receive a suggestion to try for an "A" or "B" grade.

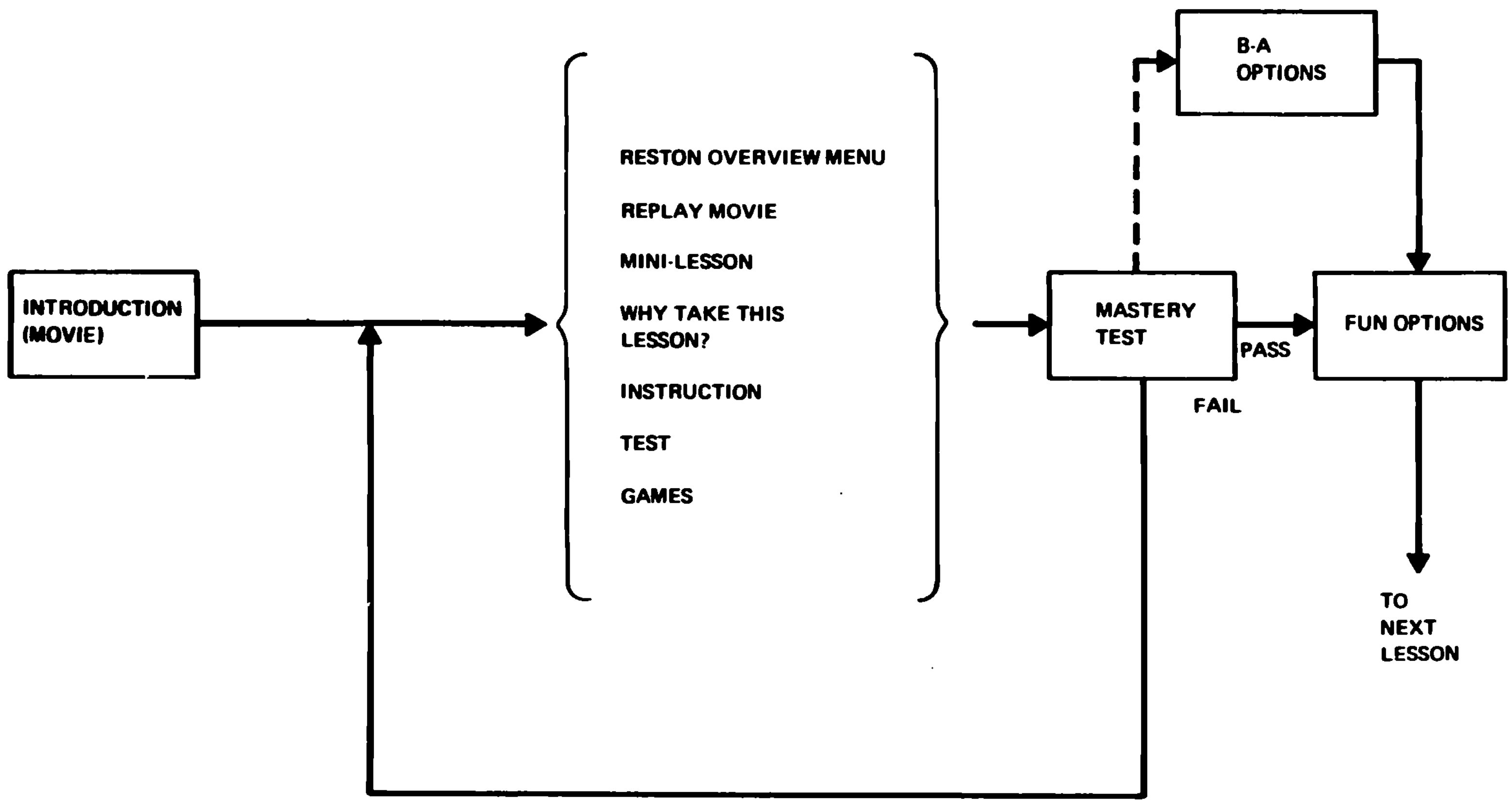


FIGURE 8
GENERAL LESSON FORMAT

It is hoped that this courseware strategy, with its emphasis on learner control, will improve the student's ability to pick good learning strategies in general, to help in achieving a good approach toward the subject material (we don't want him to master the objectives but hate the subject), and to develop a personal sense of responsibility for his own education.

TABLE I
LEARNER CONTROL KEYS

HELP	– Counsels a student on making his next selection from either of the following options, or course, unit or lesson overview menus, or interrupt menus.
INTERRUPT	– Brings the menu shown as Table II to the screen.
NOTE	– Allows the student to enter comments for storage on magnetic tape for feedback to the courseware designers.
OBJECTIVES	– Gives the student a list of the instructional objectives for a lesson and the relationship between them.
BACK	-- Presents previously seen displays or previously skipped test equations.
SKIP	– Skips to the display where a BACK sequence started or allow the student to skip test questions.
RULE	– Presents the generality being taught by the current segment.
EXAMPLE	– Gives the student an example of the application of the generality for the current segment.
PRACTICE	– Gives the student a practice test question.
WHY	– Gives the student an explanation about a rule, example, or practice test question.
HARDER	– Gives the student a harder example or practice test question or a more precise or technical statement of the generality.
EASIER	– Gives the student an easier example or practice test question or a less technical statement of the generality.

TABLE II
INTERRUPT MENU WITH AN EXPLANATION OF EACH ITEM

ON:	To log on system.
OFF:	To log off system.
CALC:	To allow the student to use the system as calculator.
COPY:	To allow a hard copy to be produced on a particular display.
ABORT:	To permit the student to go on to a different lesson even though he has not yet completed the current lesson.
RETURN:	Branches student back to where he left program.
OVERVIEW MENU:	To allow the student to return to the overview menu of the current lesson.
SPECIAL MENU:	To allow the students who are trying for an "A" or "B" grade to select advanced material.
GLOSSARY:	To allow the student to retrieve the definition of any previous generality.
CONTRACT:	To allow the student to return and adjust his course contract.
STATUS:	To allow the student to receive a summary report of his progress in the course.
BANK:	To allow the student to receive a current statement of the points he has available for options.
SCHEDULE:	To allow the student to schedule future lessons on the system.

V. SOFTWARE

The least glamorous, but in many ways the most crucial, portion of this program is the development of the supporting software. The software effort divides into three basic parts: the courseware processing system, application software, and the operating system.

Courseware Processing System

A major problem in the development of quality mainline CAI courses is in designing, coding, and debugging courseware. A single course may easily have more than a million lines of code. Traditional program languages, or even special CAI-oriented languages, by themselves are not enough to be effective instruments to convert an author's thoughts into computer data base on this scale.

Our courseware processing system follows from the instructional science split of strategy and content. While the content (examples and nonexamples, generalities, definitions, etc.) is unlimited, the number of strategies—or logics of instruction—are finite. We have identified 20 general strategies and envision the number growing to 50. The generalized strategies are programmed independent of content (so whatever content is appropriate can be plugged in) and debugged. Packets of forms are constructed for each strategy and are turned over to the instructional design technician for preparation. On these forms, references to the desired content files are indicated, along with notation as to which options in the strategy are to be enabled. Content files are independently constructed—these are literally simply-ordered arrays of displays or portions of displays, though it should not be assumed from this simplified description that computer-generated examples or displays are prohibited. Content files, in turn, reference one of about 25 additional generalized forms (base-frame specifications) that specify how the particular content is to be displayed on the TV screen.

The TICCIT courseware processing system thus separates logic from content in much the same way as in the authoring process. The courseware processing system reduces the number of hand-coded programs to a minimum, which hopefully leads to a great simplification of both coding and debugging. It is also hoped that feedback from validation tests (instructional debug) can be more easily applied. If a strategy is found instructionally inadequate, it may be revised independently of the content. Similarly, if an example is confusing, it can be replaced independently of the logic.

The software that supports the courseware processing system is quite straightforward. The base language is an extended version of ALGOL 60 that Data General has implemented for its Nova line of computers. In front of this language is a moderately sophisticated macro processor. The macro processor converts courseware material (strategy forms, content files, and base frame specifications) into ALGOL, and the ALGOL compiler turns it into machine code. Both the macro processor and the ALGOL compiler can run on the minicomputer system when the system is not delivering CAI.

The major function of the courseware processing system is to place the course material in the data base in the form required for efficient execution on the delivery system. The steps the course material goes through to be placed in the data base are shown in Figure 9. The courseware authoring team supplies the courseware-producing team with six inputs; strategy program specifications, strategy form specifications, the transcribed data, base frames, art work, and any ancillary program specifications. The strategy program and ancillary programs are coded in ALGOL, compiled, assembled, tested, and added to a subroutine library.

The art work, drawings, cartoons, sketches to be displayed on the student terminal in conjunction with a CAI display, must be digitized (by tracing with a digitizer tablet) and converted into a combination of ALGOL and Assembly language programs by a special software package. After compiling and assembling, these programs are added to a library where they can be referenced by the transcribed data.

Strategy forms are filled out by the courseware packagers to supply the parameters used in calls to the strategy programs. The form's specifications are used to write macros that will translate the filled-out forms into the ALGOL programs which contain these calls. The macros are written by a programmer working in conjunction with the authoring team.

The cover form for one of the data files is shown in Figure 10. This form references the base frame GENERALITIES, and the base frame contains the flow chart shown in Figure 12-A. The flow chart indicates that the base frame also contains two displays, the boxes labeled EG and EGG. The specifications for these displays are shown in Figure 12-B.

The base frame logic and display specifications are reflected in the macros that process the data files. These macros, for example, will translate the file cover form shown in Figure 10, and the content of that file (Figure 11) into an ALGOL program which, when executed, will first present to the student the generality contained in that file, and, if the student responds by pushing the "WHY" key, will then present the related expanded generality.

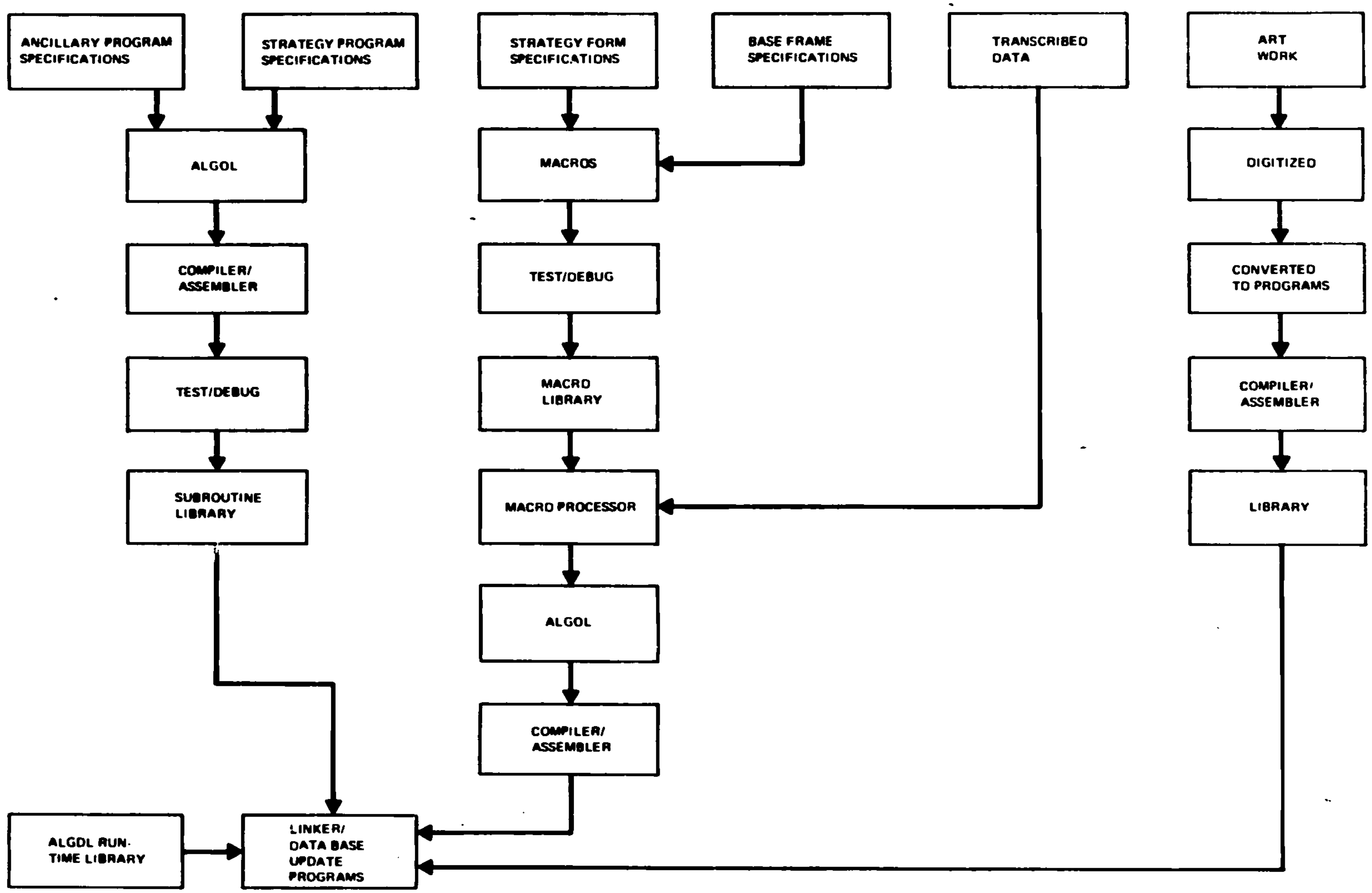


FIGURE 9
COURSEWARE PROCESSING SYSTEM FLOW

FILE FM. U6. L1. S1;

BASE FRAME GENERALITIES

NUMBER OF ITEMS 1;

NUMBER OF WINDOWS PER ITEM 2;

WINDOW	CODE
A	G
B	GG

FIGURE 10
DATA FILE COVER SHEET

FM.U6.L1.SI/G

FIRST DEGREE POLYNOMIAL FUNCTIONS (LINEAR FUNCTIONS)

A FUNCTION WHOSE EQUATION CAN BE WRITTEN:

$f(x) = mx + b, \quad m \neq 0$

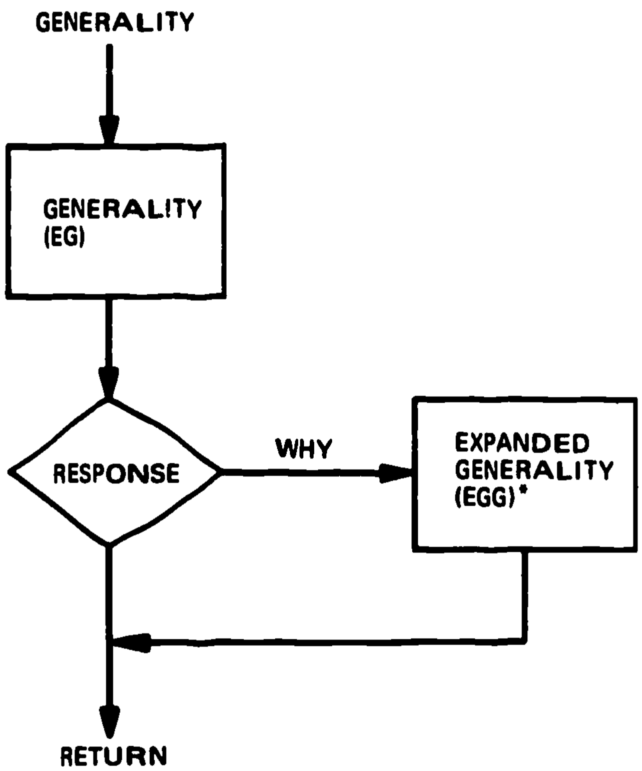
IS A FIRST DEGREE POLYNOMIAL FUNCTION

FIGURE 11-A
DATA FILE CONTENT

FM.U6.LI.SI/GG

THE GRAPHS OF THESE FUNCTIONS ARE LINES WITH POSITIVE (+) OR NEGATIVE (-) SLOPE.

FIGURE 11-B
EXPANDED GENERALITY



*A MESSAGE WILL BE DISPLAYED FOR THOSE CASES WHERE NO EXPANDED GENERALITY IS PROVIDED.

FIGURE 12-A
EXPOSITORY GENERALITY WITH ONE EXPANDED CAPACITY

BASE FRAME generality

DISPLAY E9, E99

ERASE (CHECK ONE):

(✓) TOTAL SCREEN

( ) WINDOWS

( ) NOTHING

DRAW WINDOWS:

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
1	A	(	E	9	)																																						
2																																											
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4																																											
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6																																											
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8	B	(	E	9	9	)																																					
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FIGURE 12-B
BASE FRAME DISPLAY SPECIFICATIONS

The TICCIT program module is compatible with the "core-image save file" produced by the linker for Data General's Disk Operating System (DOS). The data base update program is used to place the program module in contiguous sectors on the disk.

The macro processor is the major software product in the courseware processing system. The macro processor, already implemented on a time-sharing system, is being translated into ALGOL to run on the TICCIT computer. The ALGOL compiler, assembler, and linker are provided by Data General. The data base update program and artwork processing programs are being designed and implemented.

The modular construction of this system should significantly reduce debugging problems associated with any system of this size. The amount of programming that grows with the volume of course material is kept at a minimum. Most of the other programs can be tested exhaustively. System integration can be debugged with a small fraction of the total data base. In this way, systematic errors (rather than random data errors) can be caught in systematic ways, and their correction has system-wide effect.

Errors that occur in the data can be classed as transcription errors, packaging errors, or effectiveness errors. The use of standard transcribe/verify practice should eliminate almost all transcription errors. Reasonableness checks on the data should catch a large portion of the packaging errors. The remaining transcription and packaging errors and the effectiveness errors can be found during validation.

Application Software

The application software consists of the computer programs that implement the courseware. These programs construct the displays to be put on the student terminals, analyze the students' inputs, keep track of where the students are in the courses, and perform other courseware-related control functions.

The application software is divided into the following areas:

- Macro generated programs
- Strategy programs
- Display construction support
- Response processing support
- Data generation programs
- Learner control
- Advisor

The macro generated programs provide the data and control parameters unique to each course, lesson, or display. These data and parameters are used by the other areas listed above. In general, these programs are a sequence of calls to other programs, particularly strategy programs; they may, however, be coded in line.

The strategy programs contain the logic of the instructional and control strategies. There are expected to be about 25–50 such programs, all subject-matter independent. The instructional strategy programs are called by the macro generated programs with parameters that allow the selection of data items for display. The parameters to the control strategy programs allow them to select sequences of instructional or other control strategy programs.

The display construction support routines (graphics routines) provide an interface between the instructional frame programs and the student terminal input/output software in the terminal processor. The display construction support routines translate the data and commands used by the instructional frames to define the contents of displays into the data and commands needed by the terminal processor software and hardware. For example, Data General's ALGOL processes text packed two characters per computer word. This text must be unpacked and control bits added for the character generator. In addition, color information, vector formats, and audio information will be placed in the form needed by the peripheral devices.

The response processing support routines provide the special functions needed to analyze student responses. Examples of these routines are: general lexical routines (divide a response into words and punctuation marks), keyword search routines, and routines to process algebraic expressions, spelling checkers, etc.

The data generation programs serve as a replacement for files generated by authoring teams in those cases where the data may be algorithmically specified, i.e., instead of using people to generate a file of data items, a data generation program will generate one item as it is needed.

The learner control programs provide the facilities needed to enable the student to control his movement through the course material. In addition to the special learner control functions defined for the courseware, the learner control programs provide the data and processing needed to implement the structure of the courses.

The advisor programs implement the functions provided to advise the student on his approach to the course material (e.g., is he going too fast or too slow) and on his progress through the course.

Delivery System

The purpose of the TICCIT delivery system is to present Computer Assisted Instruction (CAI) efficiently to over 100 students simultaneously. Furthermore, each of the students using the system is to be independent of the other students with no necessity for any student to be at the same place in any course as any other student.

The major problem in the delivery system is how to run the courseware programs and the data for the more than 100 students in a minicomputer with a response time of typically .5 seconds. Analysis of the TICCIT system shows that 128 simultaneously active terminals can be supported. When the system is fully loaded 79 milliseconds of processing time is available for each student input. In 79 milliseconds 49,000 instructions can be executed. Experience of other CAI systems indicates that this provides a comfortable margin of safety.

The major functions of the delivery system are:

- Echoing of the keyboard strokes on the display
- Editing of the input messages
- Providing student timing information
- Coordination of the delivery of audio, text and graphic information to the student
- Performing some response analysis of the student input to select the proper courseware program (which in turn do sophisticated answer processing and generate new displays).
- Swapping courseware program and user data in and out of memory
- Scheduling the execution of the courseware programs
- Providing storage for student data
- Maintaining student registration data
- Providing a procedure for orderly startup, startover and shutdown.

Our approach to the problem is to divide the functions of the delivery system between two processors, as shown in Figure 13. The terminal processor handles all of the input and output between the student and the system. The main processor only sees complete messages that are ready for processing and does not have to devote overhead time to editing messages or to the housekeeping tasks that are associated with making efficient use of a variety of delivery equipments. This basic division of functions plus the organization of the user programs and student data in the main processor is that which permits a minicomputer to support such a large number of simultaneous users.

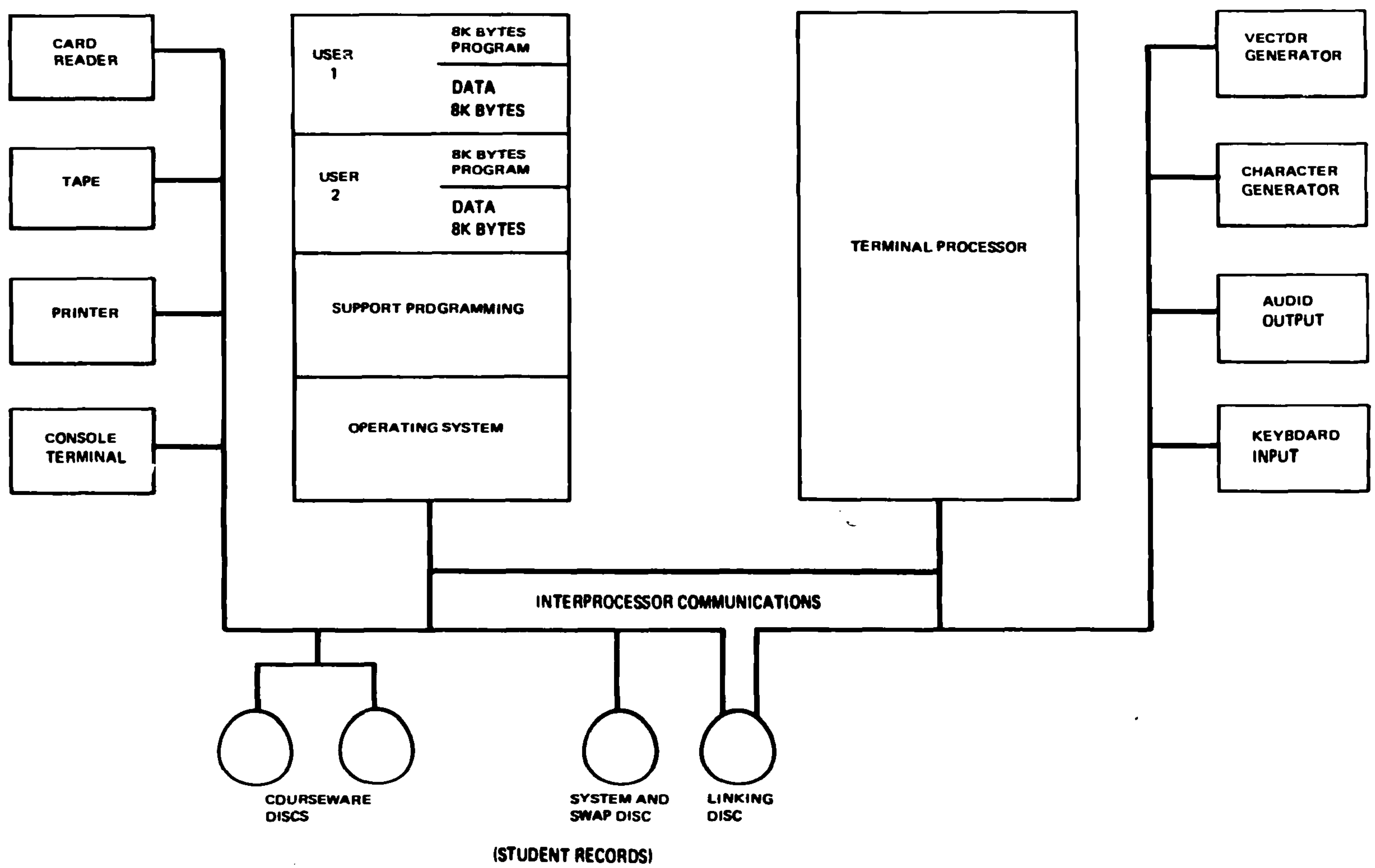

FIGURE 13
COMPUTER SYSTEM ORGANIZATION

A user authorization file is maintained on the system disk. This file contains a record of which students are registered for each course and also contains the student's password. Another file in the system contains student permanent data records. There is one student data record for each course in which a student is enrolled. The student data record contains information that shows the progress of the student through each course and exactly where he is in the course at any given time. When a student logs on the system a copy of his data record is placed on a disc which is organized to facilitate fast swapping in and out of memory.

As a student progresses through a session, the student data record records his progress. Periodically, the temporary copy of the data record is placed into the permanent file (a checkpoint). This feature protects against all of the work that the student has done being lost in case the system goes down because of power failure or certain hardware or software problems.

When the system goes down for any reason, and the disks are still intact, all students resume their session from the record contained in the permanent student record which reflects the last checkpoint. Checkpoints are taken at logical or educationally meaningful points.

Protection against software errors in the courseware programs is provided by the memory protection features of the minicomputer. Before a courseware program is executed, a core memory mapping function takes place so that all courseware programs appear to operate in the same location. In addition, read and write protection is invoked so that a particular program cannot read or write core outside of its assigned area. This means that a courseware program error has limited effects. A program error affects only one terminal user, and cannot interfere with the operating system.

When a courseware program begins execution, a timer is started. A "time-slice" is used to prevent one student from using more than his share of the computer time. When a time-slice runs out, this student's job is put at the end of the input queue. The time-slice duration is a system parameter which can be adjusted to time the system. Experience with CAI systems indicates that a time-sliced termination of a courseware module will be infrequent.

All courseware programs are divided into modules of 4000 words or less. Each module is reentrant and contains pure code and constants. All data that is student specific or is subject to change is kept in a student data record. This division means that while both programs and data must be brought into core for program execution, only data must be written out of core and saved between program executions. Referring again to Figure 13, it can be seen that the core of the main processor is so divided that there are two user partitions. The operating system allocates time between the two partitions so that while one partition is loading the programs for one student, the other partition is loading the programs and data for yet another student. The timing chart for this cycle is shown in Figure 14. To make the simultaneous loading of programs and data possible, two disk channels are used so that the load operations do not interfere with one another. Whenever possible, each program informs the operating system which program module will be used to process the next student input. This means that less time is taken from the execution cycle to find a new program module or to change program modules.

The organization of the control programs in the main processor is illustrated in Figure 15. The main control program is the heart of the operating system. It passes control to the scheduler which accepts student input messages and forms a task queue. The main control program next uses the loader to bring the programs and data areas into core for the next task in line. While the loading operation is going on, the execution of the previously loaded module in the other partition. When execution is complete, the data area is swapped out.

The movement of program modules into processor storage and of student data records in and out of processor storage is the major job of the main processor operating system. This operating system also supports input/output operations by the courseware modules (e.g., output to the log tape, input/output to the student terminals via the terminal processor) and handles errors in the courseware programs.

An instrumentation package has been designed into the main processor operating system from the very beginning (see Figure 16) because a capability to record all inputs and outputs on magnetic tape can provide a valuable debugging tool to test the proper functioning of the operating system and the courseware. The operating system itself uses an instrumentation program, which can be made to operate between all other programs. This allows for system traces, system timing, and selective looks at critical system parameters. In addition, the courseware programs themselves can do internal data recording and place information on magnetic tape.

As stated before, the terminal processor handles the detailed hardware interactions. As the student types an input (1 to N characters), the terminal processor displays the characters on the students' TV (this is called "key echoing"). The terminal processor also examines each character to see if it is an end-of-message. When an end-of-message is received, the complete message is code-converted as necessary, edited, and then passed as a complete unit to the main processor for courseware processing. After processing, the main processor sends the reply to the terminal processor. Text messages are formatted and the proper hardware control information is added. If a graph or other nontext information is to be output to the student, a graphics program in the terminal processor converts the pictorial description into the proper vector end-points for presentation to the vector

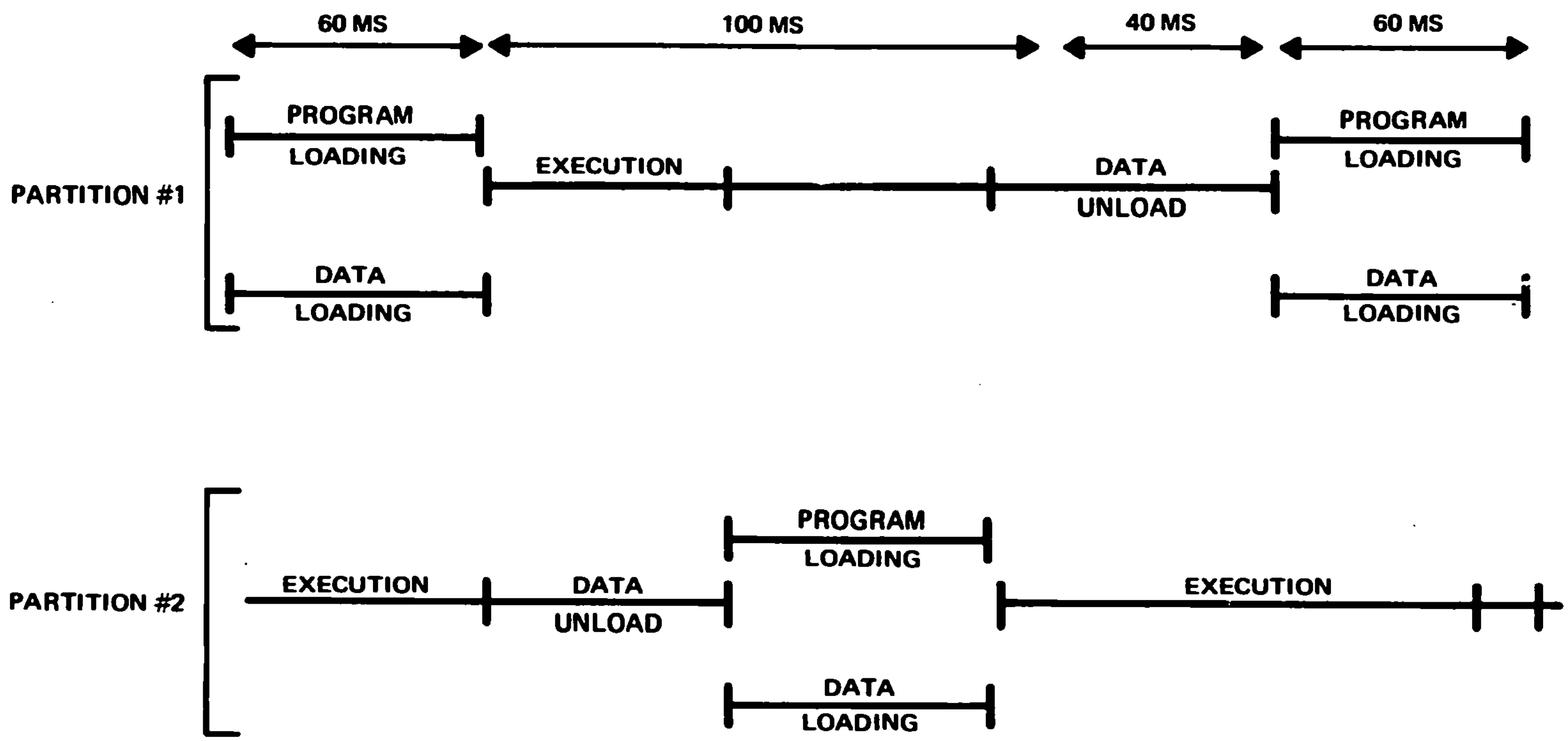

FIGURE 14
PARTITION EXECUTION CYCLE

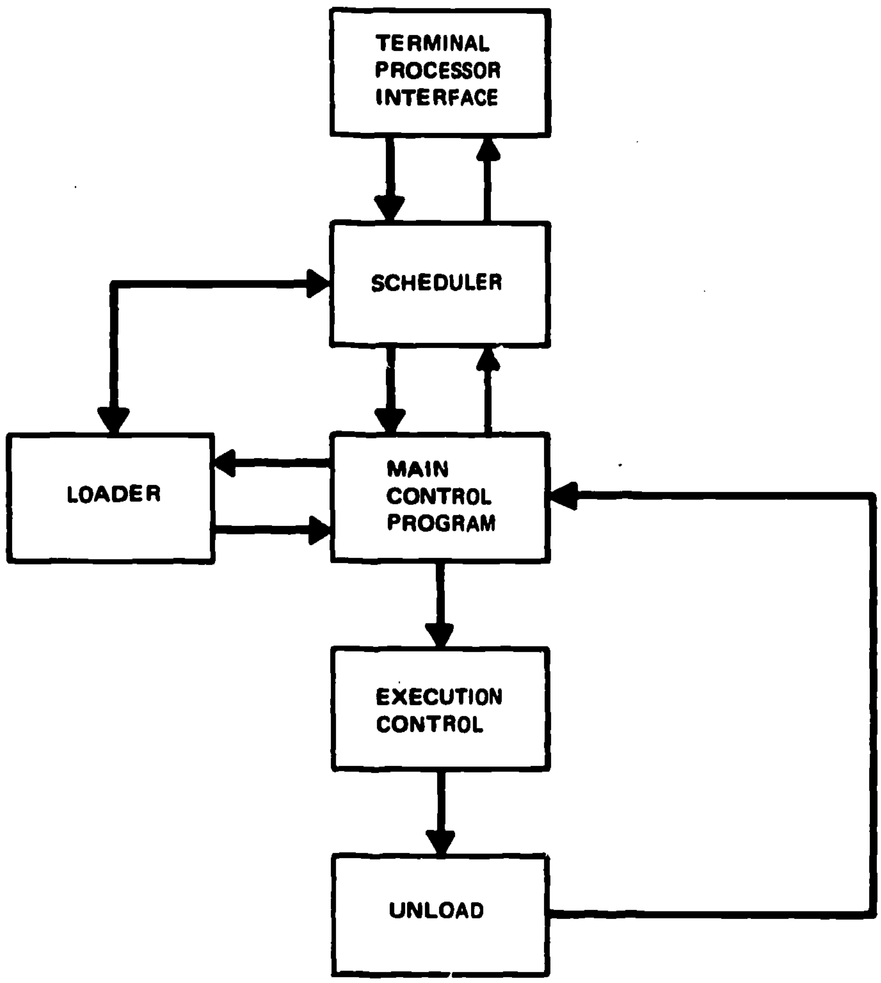

FIGURE 15
MAIN PROCESSOR PROGRAM ORGANIZATION

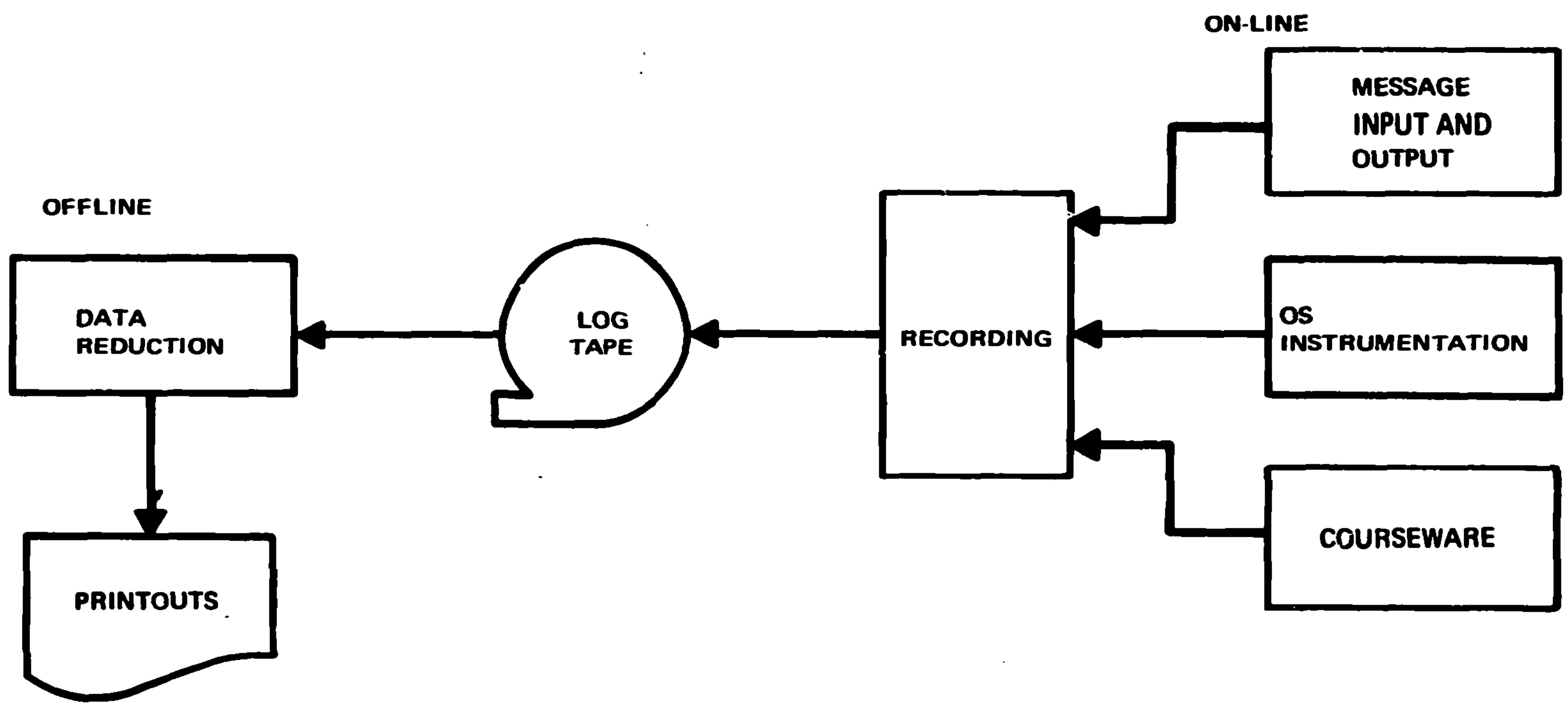

FIGURE 16
MAIN PROCESSOR INSTRUMENTATION

generator. Audio messages to the student require little manipulation by the terminal processor. However, close control of output is required so that textual, graphics, and audio output reach each student in exactly the sequence desired by the authors of the courseware. The terminal processor supplies both preprocessing and post processing functions for all messages that enter and leave the TICCIT computer.

TICCIT System Analysis

The parameters that are most important to system responsiveness and system throughput have been studied both by design analysis and the computer simulation. Both methods indicate that expected levels of performance are reasonable and will be attained.

Design analysis approach uses the current system design and calculates the processing time available for courseware.

The basic program execution cycle in the TICCIT system is 100 milliseconds (ms). This cycle is arrived at by using the following assumptions:

There are 128 active terminals,

There is one input per terminal every 13 seconds,

Each input is 10 characters long,

An average of 20 characters per input is placed on the system logging tape, and

Each input to a student averaged 100 characters. 100 students log on and log off the system per hour.

Based upon information gathered from other CAI systems, these assumptions are conservative. In many cases the average time for a student to respond will be 20 to 25 seconds. Using the current design of the TICCIT delivery system and in particular the design of the operating system of the main processor an analysis of throughput of the system has been done. In the 100 ms. program execution cycle there are 125,000 machine cycles. Of this total 14,000 machine cycles are used for input and output. This includes all information transferred to disc, to tape and to the other processor.

Input-output represents 11 percent of the machine cycles. Currently the operating system executes 3000 instructions per 100 ms. cycle. To allow for the addition of new features this figure should be doubled to 6000. Since each instruction requires an average of two machine cycles, the operating system uses 12,000 machine cycles or 10 percent of the machine cycles. The addition of the input-output and operating system figures gives the total system overhead of 21 percent. This leaves 79% of the time available for courseware execution. In this time 49,000 instructions can be executed. The experience of other CAI systems indicates that this is more than enough time to do traditional CAI functions. In fact non-traditional functions of TICCIT such as computer aided grading of english compositions and providing individualized advice to the student for learning strategies can be accommodated. The TICCIT design analysis indicates that significant processing per input can be accomplished for each student.

The computer simulation was done by creating a model of both processors in the TICCIT delivery system. This model simulates the actions in each processor and the many interactions involved in handling each student. The data from each student are represented as the characters received when the student types on his keyboard, as the resultant message for processing by the courseware and as the new display produced by the courseware.

The major measures of interest are:

- The delay between the time a student types a key on his keyboard and the time the character is displayed on his terminal screen (the key echo time), and
- The delay between the time a student completes typing a message and the time he receives a response from the courseware.

The model, as shown in Figure 17, estimated the key echo time at less than 1/4 second, and the courseware response time at about 1/2 second with a full load of students. This rapid responsiveness should meet the student's needs with a considerable margin of safety.

The model itself is a sizable computer program. IBM's General Purpose System Simulator (GPSS) was used to develop the model. Each character typed by each student is handled separately in the terminal processor section of the model. The rate at which students type is varied with some randomness to reflect the differences experienced with actual students at the University of Texas. The number of characters in each message also has random variation representation of the anticipated characteristics of the courseware.

Throughout the model, the student's data passes through the same steps (and delays) that it will encounter in the actual system. The accumulation of times in these steps and delays for many students' messages provides the statistical base for estimating the performance of the system.

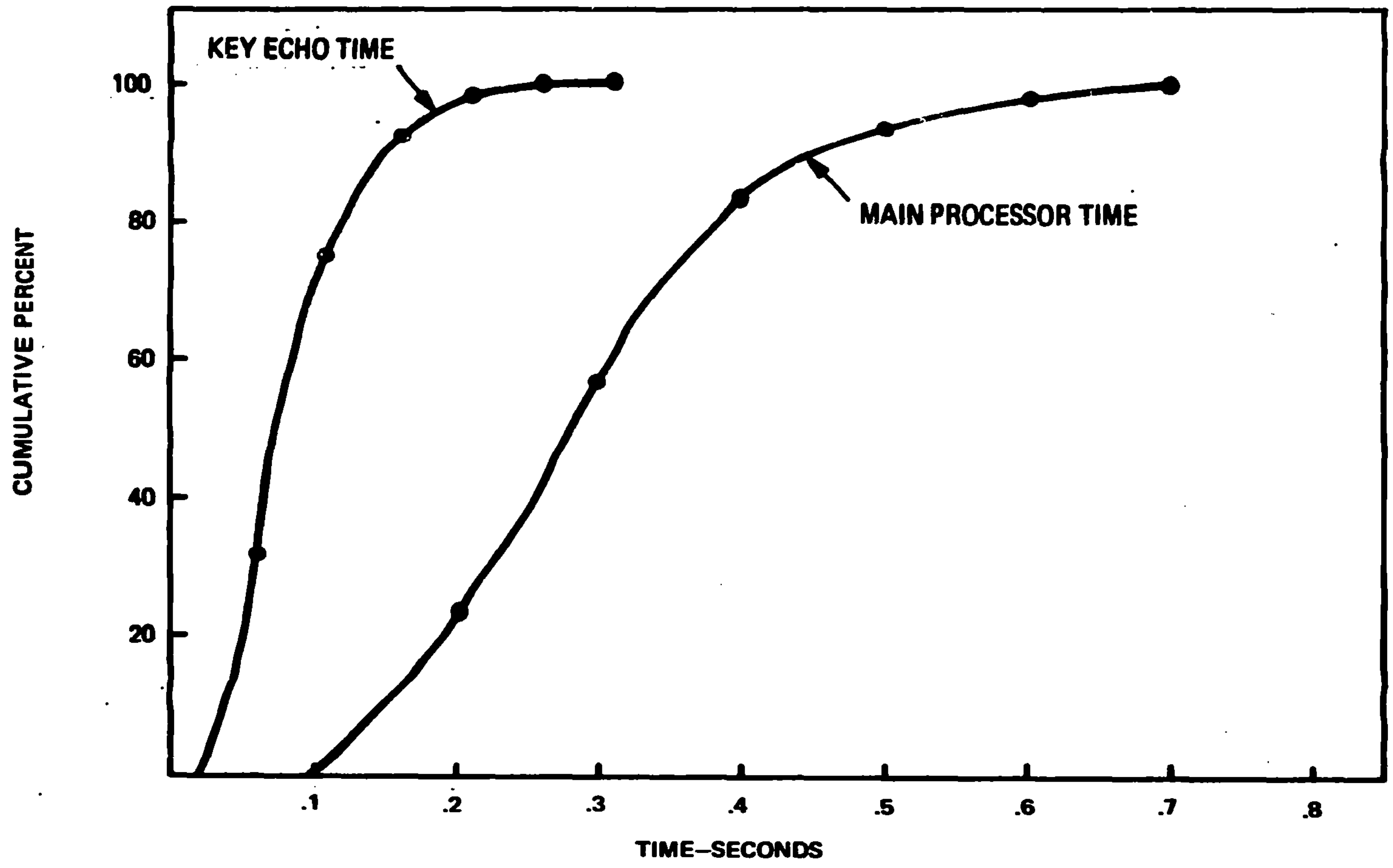

FIGURE 17
SIMULATION MODEL RESULTS
128 STUDENT LOAD

VI. HOME DELIVERY OF INSTRUCTION AND OTHER SOCIAL SERVICES VIA INTERACTIVE TELEVISION

As noted in the previous discussion of Computer-to-Terminal Communication, a standard cable television system laid throughout an urban area would support the delivery of CAI into each cable subscriber's home, using the system presented in the preceding sections of this paper.

A cable system is basically a network of coaxial cable, strung out in "tree-fashion" from a central source of transmission, called the headend, through the streets of a given city or community, and into individual homes. Cable systems were originally invented for the limited purpose of bringing more broadcast TV signals, and a clearer picture, to areas where over-the-air TV reception is relatively poor.

In a typical cable system, a large main antenna is erected on a hill or some other spot chosen for good reception. The antenna feeds signals into the system's headend--a small control station where they are tuned, amplified, and sometimes rechanneled. They are then passed into the cable. Amplifiers are placed on the cable at regular intervals to keep the signals strong. A "drop-line" itself a length of coaxial cable, leads from the cable in the street to the subscriber's home. Subscribers usually pay about $5.00 a month to be hooked up to the service.

At the heart of the great interest that cable television has aroused among technicians and laymen alike lie certain inherent characteristics of the cable itself. Despite the limited uses to which it is presently being put in cable TV systems, coaxial cable is an electronic signal carrier of tremendous capacity. With existing technology, a single cable can carry at least 30 channels of TV, or equivalent spectrum amounts of non-visual transmissions; dual cable systems now being constructed in many urban centers will double this capacity. In addition, cable is capable of two-way transmission, enabling individual subscribers to transmit electronic signals, voice, or even video pictures back to the source of programming or transmission. As cable moves into urban centers, these capabilities will come increasingly into play. In urban settings, the uses of cable can be expanded greatly and applied to CAI as well as to important but yet unmet communications needs of our cities and out society.

The Potential of Interactive Television

Television, until now a one-way form of communications, will become an interactive communications form as the technology reported herein is married to the cable systems. There is increasing concern among urban planners, social scientists, and historians that one-way TV communications may in some ways be adding to, rather than ameliorating, basic problems of our society.

At the same time, it is increasingly recognized that new forms and imaginative uses of telecommunications can make contributions of fundamental importance to meeting and solving nearly every major problem of urban society and urban life. This view emerges clearly from the Report recently issued by the Committee on Telecommunications of the National Academy of Engineering, whose membership was widely representative of United States government, industry, and national civic groups:

> "Our cities have many problems in urgent need of solutions. City governments have a requirement for closer communications with their citizens and readier response to citizen needs. City schools are less than satisfactory in providing quality education to the nation's youth. Medical care is inadequate for the cities' poorer and older citizens. Individualized transportation is clogging the streets and polluting the air. Public transportation is often inefficient and unattractive to its users. Law enforcement agencies have difficulty in coping with a growing crime rate."
>
> "The Committee believes that modern communications technology, thoughtfully applied can help in relieving many of these problems and in upgrading the level of city life. This conviction has been further confirmed as a result of the Committee's in-depth study of city operations, and a continuing exchange of ideas with officials in a cross-section of U.S. cities."

A second source of increasing interest in interactive TV stems from its potential for performing functions and delivering services that cannot be provided in the context of any form of one-way communications, and that offer great promise for dealing with problems of increasing urbanization. These include: wider and better access to education; wider and better dissemination of health care; direct access to a wide range of information through computer hookups; delivery of specialized visual material to the home when the subscriber wishes to see it; facsimile printing of material in the home; and greater participation of urban populations in civic life through polling and direct interaction with political leaders.

Interactive television, built on the existing highly refined television technology, in which American citizens have already invested over 20 billion dollars, has just been developed to the point of public demonstration. By coupling home television sets on cable systems to computers, interactive television is ready for studies, experiments, and demonstrations leading to the fulfillment of its potential.

The Nature of Interactive Television

Telephone, radio and television were all breakthroughs in communication. History shows the impact and dissemination speed of each was greater than its predecessor. We believe that interactive television will be the next, and in some ways the most dramatic, in "great leaps forward" of media technology. Since its potential for public services transcends those of its predecessors, we feel confident in predicting that it will have an even greater social impact and spread even more quickly than any of these earlier forms of communications. One of the better categorized lists of potential services (made by the Department of Communications, Government of Canada) is shown in Table III.

As shown in Figure 18, The MITRE Corporation's pioneer interactive television system (TICCIT) has a keyboard associated with each TV receiver as a computer entry device. The computer is programmed to interpret viewer key pushes in the context of what the viewer is watching. A key push may be interpreted in the context of a public meeting straw vote as a yea or nay; in a search for a new apartment as the number of bedrooms desired; in a course on repairs as a part of the answer to a question; etc. The keyboard is the viewer's means of interacting with the system. The TV receiver displays information the computer generates in response to the user's key pushing.

The potential uses and their importance follow from certain technical qualities.

(1) Interactive television is individualized. It responds "instantly" to the demands of each viewer, permitting him to receive detailed information economically and privately.

(2) It is computerized, offering search and calculation of information that might otherwise be difficult to obtain.

(3) It provides unlimited points of entry and delivery of information (similar to the advantages of the telephone and the mail); but, in addition, it offers controlled storage, access, and unparalleled speed and convenience of retrieval.

(4) It is multimedia, providing sight, sound, and computer assistance all within one system, and offering the potential of a common carrier between people (i.e., two-way videophone "snapshots").

<u>The Uses of Interactive Television</u>

All surveys of this field reviewed by us conclude that computer-assisted instruction, in theory, could be one of the services having greatest importance to the subscribers. If it is popular, practical, and affordable, it would thus seem a reasonable further assumption that CAI will possibly consume more hours of utilization of interactive television than many or all of the other services combined. A further speculation is that the impact on adult education may be more significant (due to its present inconvenience and unavailability) than use by people of "typical" student age. The frequently cited important

TABLE III
LIST OF SERVICES

Business – Work at Home

- Secretarial assistance
- Person-to-person communications
- Computer-assisted meetings
- Electronic mail
- Adding machine functions
- Access to company files
- Message recording

Business – Commerce

- Shopping transactions
- Grocery price list (information and orders)
- "Cashless society" transactions
- Dedicated newspaper
- Banking
- Answering services
- Real estate listings
- Better Business Bureau
- Special sale information
- Budget preparation and monitoring

Political

- Council meetings, other local meetings
- Voter views and participation
- Nationwide voting surveys and voting
- Debates on local issues
- Free political channel for candidates
- Access to elected officials

Social Services – State and Federal Governments

- Social Security
- Immigration and naturalization
- Taxes
- Weather Bureau Information
- Courts
- Index of Social Services
- General Postal Information
- Welfare

TABLE III (continued)

Vocational counseling
Employment service
Disaster warnings and evacuation control
Marriage counseling

Health

Remote diagnosis
Emergency medical information
Drugs
Health insurance
Medicare claim processing
Prescription communication (doctor-to-pharmacy.)
Dietetic meal planning and scheduling
Ambulance/doctor/hospital coordination
Outpatient services
Medical and dental appointments and reminders.
Advice on simple problems
Doctor directory
Immunization information
Mental Health center (psychiatric consultation)
Suicide prevention center
Alcoholics Anonymous

Household

Water,electric, and gas meter reading
Alarm systems
Operate household services (turn lights on, light up furnace, etc.)
Recipe file
Telegrams
Mail and messages
Daily Calendar (reminders about appointments).
Address book
Equipment maintenance reminders
Christmas lists
Generate shopping lists, weekly menu.
Cleaning information
Food storage information
Keeping track of food supply, household items.

TABLE III (continued)

Agriculture

- Soil conditions
- Fertilizers
- Insecticides
- Gardening
- Seasonal crops

Education

- Correspondence schools
- Computer tutor
- Computer-aided instruction
- School-related communications
- College catalog and related information
- Adult courses, evening courses
- Seminars
- Consultation with teachers, professors

Transportation – Travel

- Department of Motor Vehicles
- Road conditions
- Travel advice
- Traffic conditions
- Vehicle maintenance reminders
- Taxi service
- Bus route scheduling, flight and train schedules
- Maps
- Travel accommodations
- Fares and ticket reservation
- Tour information
- Travel and car insurance
- Passports

Recreation

- Skiing (snow conditions)
- Camping (areas, facilities)
- Tennis (courts, partners)
- Golfing (courts, partners)
- Golfing (courses, etc.)
- Picnic Areas (facilities available)
- Flying (lessons, airports)
- Fishing (season, permit, etc.)
- Hunting (season, permit, etc.)
- Boating

TABLE III (continued)

Recreation (continued)

- Hobbies
- Games (Chess, bridge)

Entertainment

- Current cultural events
- Local plays, movies
- Ticket reservations
- Restaurant reservations
- Computer dating

Information – General

- Index of all services available
- Library
- Dictionaries
- Encyclopedias
- Expanded yellow page service
- Stock market information
- Newspapers
- Magazines
- Recent book publications (lists and abstracts).
- Telephone area codes.

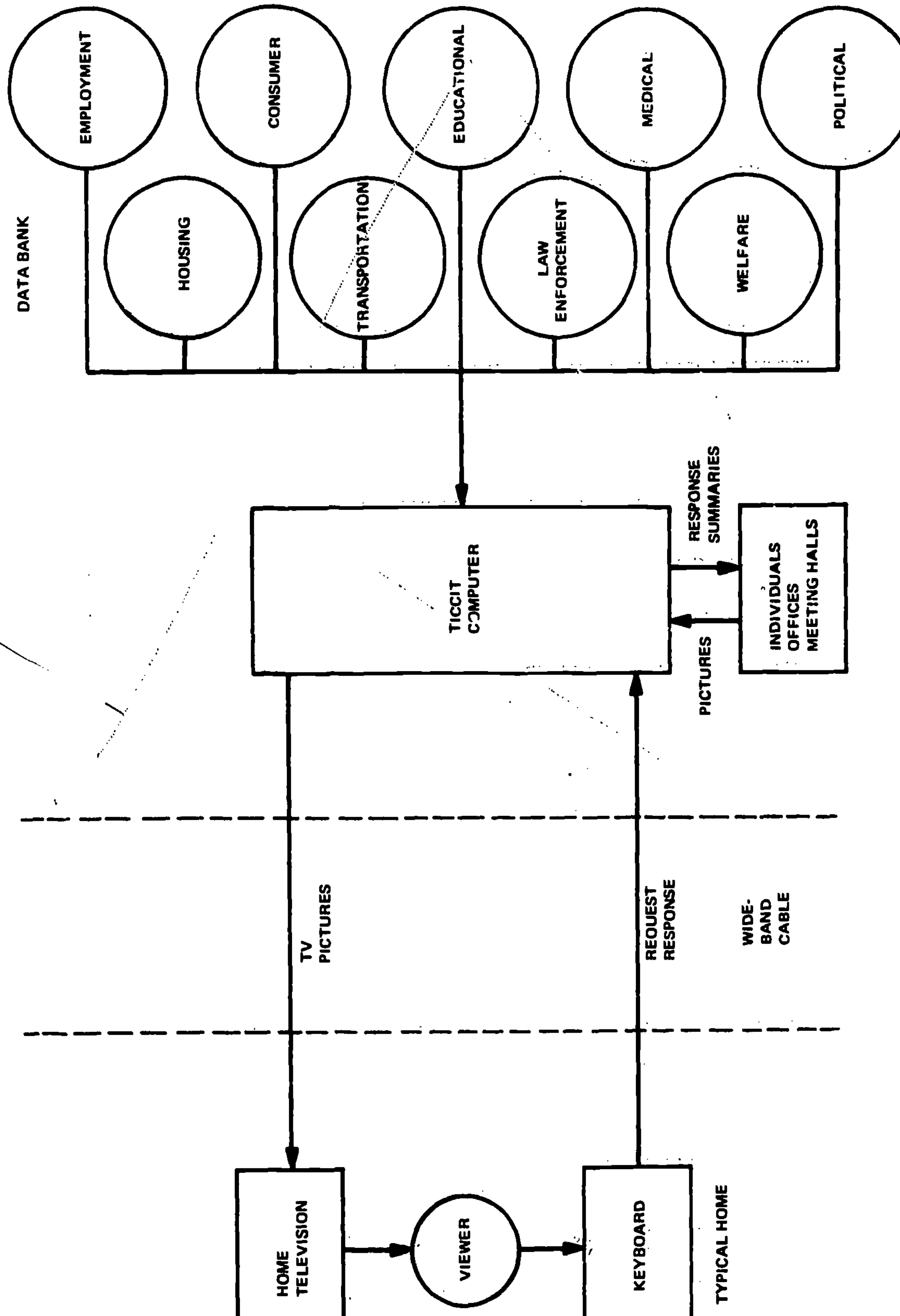

FIGURE 18
INTERACTIVE TV SYSTEM

innovation in Britain called the "open university," wherein ordinary television supplements correspondence school type materials is a relevant example of response to a need in this area.

For interactive television to be of social utility, it is not necessary to think only in terms of programs and courses which instruct or inform. There are functional characteristics of the system which in themselves offer classes of communication which are unique and of great potential social significance. The open or "public" data base offers a forum to which the subscriber may access with anonymity (subject to controls similar to those governing anonymous letters to a newspaper). In this manner, people experiencing any of the alarming range of fears that modern living exercises over us; that believe their particular problems are unique and hence that they are isolated in their need to solve these problems; that they are old and may die alone; or young and the first to ever feel this way: may lose their uniqueness and find a community.

Another example in which the subscribers themselves will provide the program concerns the situations in which a community infrastructure has evolved to deal with a local political or social problem but is stalled in its influence and effectiveness because of the considerable volunteer energies required to expand the information transmittal and response collection systems to the necessary level. Interactive television will optimize the time the subscriber wishes to spend on community affairs, allowing participation and contribution from his home.

The following brief descriptions indicate a range of services in both the programmed and "unprogrammed" categories:

(1) Sit in on a meeting of the city council and not only watch the proceedings, but also directly participate while the meeting is in session.

(2) Participate in a preference pool providing feedback not only regarding government policies and services, but also TV programming.

(3) Express views on any topic and have access to the opinions and expressions of other individuals or groups.

(4) Review candidates' positions and records immediately before going to the polls at election time.

(5) Receive information on available social services.

(6) Prepare income tax forms interactively with programs written by experts, or learn how to fill out an application for welfare.

(7) Feel a greater sense of security and protection because of new crime prevention and detection services.

(8) Distribute employment information that is clear and well-defined including job descriptions, locations, accessibility by public transportation, as well as how to apply for the job using interactive, personalized information retrieval techniques.

(9) Raise the level of education in order to improve chances for employment or make leisure time more stimulating. Skill training, literacy courses, high school equivalency programs, and college courses can all be available.

(10) Establish a sense of local, regional and national identity through a sharing of services. Local community information, meetings of civic groups, new books in the library, adult education programs, recreational facilities will be available to outlying areas. The pooling of local recipes, folk crafts, language courses and social activities can encourage more intermingling between areas while also preserving a sense of community identity and pride.

(11) Establish closer relationships between neighbors, and shut-ins using games via the computer, closed circuit TV, visits via the video screen.

(12) Create ties within special interest groups. Share hobby tips on gardening, fishing, knitting.

(13) Have available up-to-date information on the public transportation system, including public transportation schedules, automatically calculated routes and fares, and current traffic conditions.

(14) Use of secretaries in homes to support offices via cable.

Interactive Television System Concept

For more than a year, MITRE has been experimenting with and publicly demonstrating an interactive television system in Reston, Virginia, in conjunction with the Reston Transmission Company (the cable TV operation in Reston). Many of the services (including CAI) discussed in the previous section have been implemented in various degrees and shown to thousands of visitors.

The interactive television system in Reston is similar to the junior college TICCIT system in so far as still TV displays are concerned. The interactive television system's computer is interfaced to a character generator that sends single pictures, in a 60th of a second, to refresh memories associated with each TV display. In Reston, the refresh memories, though, are located in the viewer's home adjacent to the home TV, and the communication link between the character generator and the refresh memory is a standard channel on the Reston Cable TV System. A digital address is imbedded in each TV picture the character generator outputs, specifying which home refresh device is to receive and hold it. Because the Reston cable system does not have a two-way capability, communication back to the computer is via a standard 12-key touchtone telephone.

MITRE is now designing an interactive television system that will deliver CAI and other socially beneficial services to more than 1000 households. While final decisions have not been made, it is planned that the system will be very similar to the junior college TICCIT configuration. The computer system will be nearly identical and about 75% of the system software needed will be directly transferrable from the junior college program: Many of the peripherals will be the same or only slightly modified. Distribution of the system signals from the computer to the home, though, will be done exclusively by cable television and the home terminal will consist of the home owner's unmodified TV receiver and a keyboard; a 16-button-type for the casual user or a full typewriter-style keyboard for the serious user, i.e., one taking CAI courses, for instance). Keyboard signals will be transferred back to the computer via the same cable that brings the TV signals into the home.

A major impediment to the operational implementation of a system such as has been demonstrated in Reston has been the cost of the refresh memory needed in each home utilizing interactive television. Remotely operated refresh memory electronics cost more than $1,000 in moderate quantities. In Reston, a video tape recorder is used as a refresh memory (in its stop-frame mode) so that the home owner not only has a refresh memory, but also a video recorder/player. But, even with its multiple uses, the refresh memory costs a disproportionate amount relative to the cable television system.

To overcome this problem, a new approach is being investigated. We project that the average household will use interactive television services that require a computer-generated display (and, hence, a refresh memory) about 30 minutes each day. Assuming a ten-hour day, this means that one refresh memory could serve up to 20 households with interactive television services. The advantage of sharing refresh memories is obvious—the cost per refresh can be spread over many users. The central location of the refresh memories creates a need for a communication channel between the shared refresh memories and the home television receivers. MITRE is analyzing a new approach to providing this capability within the bounds of standard cable television hardware. As shown in Figure 19, the cable system is divided into cells of about 200 subscribers. Each cell is connected with its own trunk cable to a hub, and each hub services about ten trunk lines (i.e., 2000 subscribers per hub). The hub, in turn, is connected to a common program source (head-end). About ten channels on the cable system are dedicated to interactive television. Most

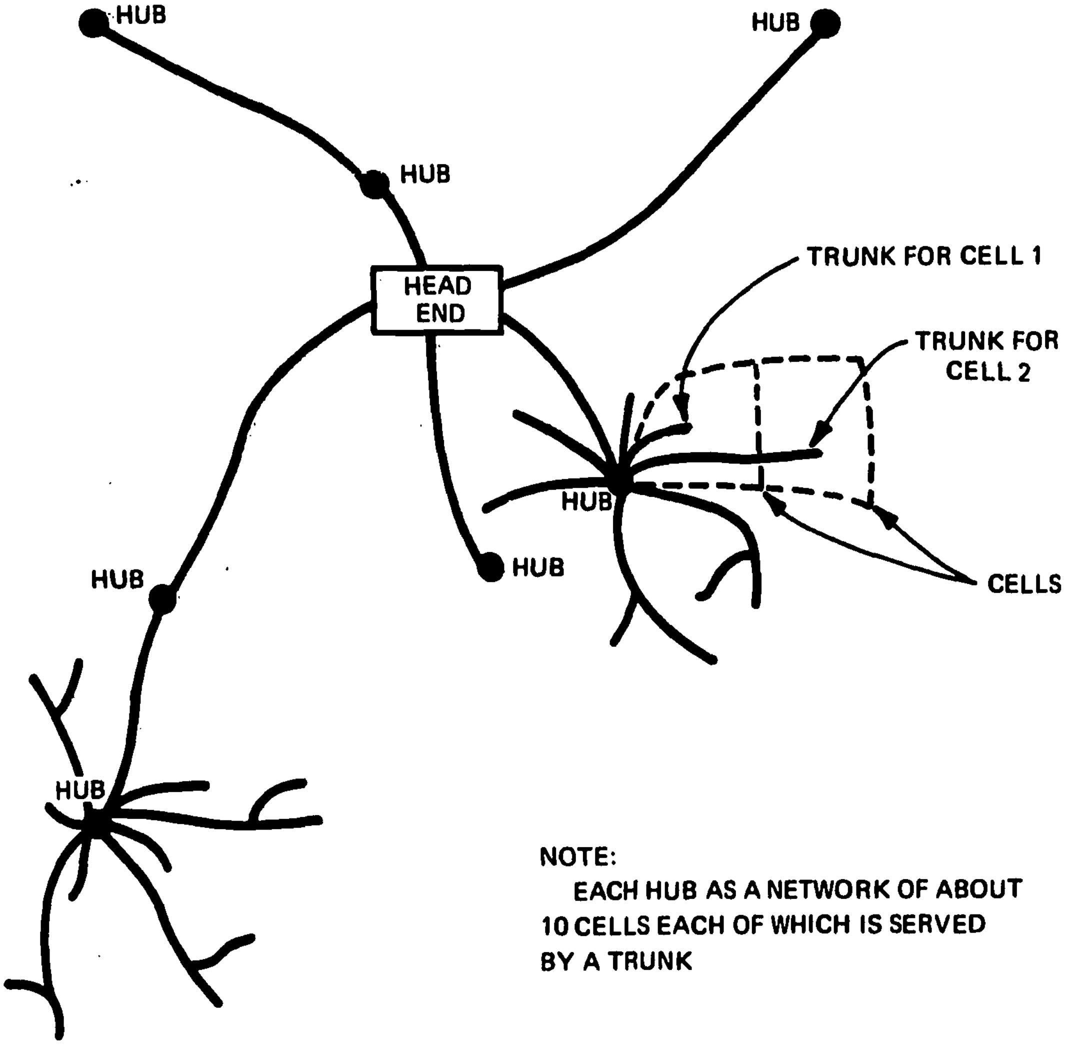

FIGURE 19
HUB CATV SYSTEM WITH TRUNKING
TO INDIVIDUAL CELLS

new systems can have more than this number of "spare" channels with the addition of set-top converters. Broadcast television is transmitted through the system from the headend to the hub to the trunk and into the homes in each cell. The interactive television channels, though, flow only from refresh memories in each hub to the homes in each hub's cells via the individual trunk lines. Each trunk line in this example has ten refresh memories (one for each interactive channel) associated with it. The users in each cell, therefore, have access to ten refresh memories by turning to the ten interactive television channels. Located in each hub is equipment to place the broadcast television signals on each of its ten trunks along with the outputs of the 100 refresh memories. The hub may also contain either the computer to provide interactive television services, or equipment to allow a remote computer to serve it. Communication from the home keyboard (and other devices such as meter readers, burglar alarms, etc.) to the hub is accomplished with a separate, relatively narrow-band digital communication links to the trunk that carry TV signals to the home.

Initial analysis, based on a city like Washington, D.C. shows that this form of cable layout is about 20% more expensive for the distribution plant than a conventional two-way cable system (i.e., for new construction, the system will cost about $11 more per household to install). Other expenses associated with interactive television include; the shared refresh devices and appropriate switching and multiplexing electronics prorated at $100 per subscriber, the keyboard at $100 per subscriber, and the TICCIT computer, pro-rated at $125 per subscriber, for a total terminal cost of $347 per subscriber, if 50% penetration is assumed. In addition, to provide privacy, a picture scrambler, similar to the type now available for pay TV, may be added at about $50 per subscriber. Each picture generated by the computer would then be viewable only in the home that requested it.

Considering these costs, it would appear possible for a cable operator to lease the required hardware for around $9.00 per subscriber per month. In addition to these costs, the interactive television viewers will also have to buy channel space (in our example, ten television channels) assuming costs similar to what cable operators are quoting users who wish to purchase channel-time. The cost pro-rated across all interactive viewers for the channel space amounts to only $3.00 per month. In other words, the total cost of interactive television—about $12.00 per month, not including the cost of programming—is very similar to that of the telephone. We recognize that this new approach to providing interactive television services can probably only be effected economically on new systems. The approximate 2800 existing cable systems—most of which are quite small in rural areas—may not need this concept to foster interactive television's development. Further, as interactive television develops and market pressures come to bear, new technologies (such as low-cost refresh memories) will influence and no doubt alter the overall design of interactive television systems.

Plans to Implement Interactive Television

The National Science Foundation has funded MITRE, under a separate grant, to select a set of services and to develop specifications and recommendations for terminal hardware, the configuration of systems, and criteria for the selection of a site or sites for conducting meaningful tests and demonstrations. A range of possible services to be tested has been developed. Economic data that will illuminate the trade-offs involved, the costs of various combinations of services and functions, the impact of various levels of service and subscriber fees on system configuration requirements, and the relatively profitability of these combinations is now being developed. In subsequent phases of this program, we hope to implement an interactive television system and demonstrate its social utility on a meaningful scale in a typical urban area.

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