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ABSTRACT

A study was undertaken to develop a microterminal for use in a computer-based instructional system. Objectives were to use new microprocessor technology to produce one terminal that is more effective and efficient than either the management terminal or the plasma type interactive terminal presently in use by the Air Force Advanced Instructional System (AIS). Four goals were identified: (1) design and develop a final configuration which takes into account stand-alone software capabilities for supporting block testing, portability (battery operation), and transfer of data to the computer site through a type B terminal; (2) refine the existing prototype for production level numbers, and produce ten prototype production units with a production cost goal of approximately $500.00 per unit in quantities of 500 or more; (3) perform a classroom study of the microterminal to determine its operational effectiveness; and (4) provide complete procurement-manufacturing documentation. Through involvement of educators, psychologists, engineers, and potential microterminal users, the human factors were defined, mechanical and electrical characteristics of the microterminal selected, and the prototype designed. The microterminal was evaluated and proved acceptable for student test taking in the AIS weapons mechanics course. Cost analysis indicated that it met the goal. Students showed a large preference for answering test items with the microterminal rather than computer test forms. Evaluation results also showed the use of the microterminal resulted in significantly better test scores. (JH)

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AIR FORCE

HUMAN RESOURCES

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DEVELOPMENT OF A LOW-COST, STAND-ALONE MICROTERMINAL FOR SUPPORT OF TESTING AND INSTRUCTION

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September 1978
Final Report for Period January 1977 – February 1978

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This technical report has been reviewed and is approved for publication.

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The development of the Air Force Human Resources Laboratory Microterminal is an effort to use the new microprocessor technology to provide a lower cost student terminal which functions in the broader scope of computer-based instruction, including both Computer Managed Instruction and Computer Assisted Instruction. The capacity of the terminal to work in conjunction with conventional media (print, filmstrip, microfiche, etc.) for presentation of information is a unique feature of its design. Another key feature is a separate memory module for storing student responses and additional program logic. The memory module is portable and removable from the microterminal. The microterminal is a stand-alone unit but interfaces with a larger Computer-Based Instruction system through the memory module. The microterminal can support various levels of testing and has already been

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successfully demonstrated supporting Block Testing in technical training. The microterminal, when used with conventionally mediated instructional materials, can provide a low level of CAI. This report reviews the background of the microterminal development, the hardware selected for the final design, classroom evaluations and a cost analysis.

SUMMARY

Problem

For a computer-based instructional system such as the Air Force Advanced Instructional System (AIS), a critical component is the computer terminal. The AIS has two major types of terminals - a management terminal and a plasma type interactive terminal. Use of the management terminal is dependent on the use of chemically treated and pencil marked, mark-sense computer forms which are consumed at a rate of approximately 1.1 million per year. The application of computer-assisted instruction (CAI) is directly limited by the cost of the terminal since for any CAI lesson there is usually a requirement of one terminal per student. Computer-managed instruction (CMI) can handle large numbers of students with fewer terminals but lacks the level of interaction provided by CAI at the lesson level and also has recurring costs associated with the use of computer forms and support materials. The development of a microterminal is an effort to use the new microprocessor technology to produce a stand-alone student terminal which functions in the broader scope of computer-based instruction providing a form of CAI in the context of CMI operations.

At the initiation of the contract, the four goals were:

1. Design and develop a final configuration which at least takes into account stand-alone software capabilities for supporting block testing, portability (battery operation), and transfer of data to the computer site through a Type B Terminal.

2. Refine the existing Air Force Human Resources Laboratory (AFHRL) prototype for production level numbers, and produce ten prototype production units with a production cost goal of approximately $500 per unit in quantities of 500 or more.

3. Perform a classroom study of the microterminal to determine its operational effectiveness.

4. Provide complete procurement-manufacturing documentation.

Approach

Through a series of meetings with AFHRL and McDonnell Douglas personnel, the controlling agency and contractor, respectively, of the Advanced Instructional System (AIS), the human factors were defined and the mechanical and electrical characteristics of the microterminal were selected. Thus, the final design benefited from the input of educators, psychologists, engineers, and potential microterminal users. A continual review of new hardware components and software needs was expected to result in a final microterminal configuration that would represent an up-to-date, low-cost terminal which would provide dynamic, objective type, response handling capabilities for support of testing and instruction.

Result

The microterminal was evaluated and proved acceptable for student test taking in the AIS Weapons Mechanics Course. Cost Analysis indicates that the microterminal can be produced at a cost of approximately $500 per unit in quantities of 500 or more. In addition, the development of a removable memory module proved to be an instructional and administrative benefit of the final design. Evaluation of the microterminal showed an almost unanimous preference by students for answering test items with a microterminal rather than a computer test form. Unexpectedly, evaluation results also showed that use of the microterminal resulted in significantly better test scores.

Conclusion

The microterminal offers an electronic solution to instructional testing and opens up avenues for further application within the Air Force. The microterminal offers a cost-effective mechanism for administering tests in a computer-based instructional environment. Further applications are seen in support of off-line individualized training materials for which the microterminal would add dynamic response handling capabilities, thus providing a low-level form of computer-assisted instruction.

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INTRODUCTION

Background

Individualized instruction which attempts to match student needs with instructional resources produces testing and administrative requirements that soon exceed the management capabilities of a traditional instructional system. Recognizing this situation, the Air Force undertook the development of a computer-based system which would take advantage of the evolving educational technology and still provide operational, cost-effective individualized instruction.

The Air Force program called the Advanced Instructional System (AIS) (Rockway & Yasutake, 1974) utilizes both computer-managed instruction (CMI) and computer-assisted instruction (CAI) to achieve this goal. Conventionally, CAI is considered to be an intensive on-line interaction between student and computer lasting over extended periods of time, while CMI provides guidance for instruction with intermittent interactions between computer and student. With a proper balance between these two, often referred to as computer-based instruction (CBI), the AIS has been able to capitalize on the advantages of each educational technique (Lamos, 1977).

Inherent within the incorporation of any two systems are the traditional problems of redundancy, duplication of efforts, and the adaptation of unnecessary features which detract from the overall performance objectives of the new product. Within CBI, this is considered to be that area where the higher costs of CAI (cost per student) make the operation of the system cost prohibitive, or when CMI limitations do not allow the CAI features to be utilized to their full potential. In terms of hardware, for example, one of the major costs in most CAI systems is the interactive terminal. With nearly a 1:1 ratio of terminals to students for CAI, the present initial capitalization of equipment cannot often be justified over traditional forms of instruction. On the other hand, if a system is designed to be entirely CMI, there are many advantages of CAI which annot be implemented within the system. Thus, the primary objective of any CBI system is to match the major benefits of both CAI and CMI without allowing one to gain precedence over the other at the cost of defeating the original objective.

In the AIS, this process of matching the trade-offs between CAI and CMI is an on-going effort. Most recently, for instance, that portion of the AIS relating to the Management of Type B terminal was investigated. This terminal is designed primarily as a means to grade student tests, relay this information to the central site, and then return a prescription to the student. It is made up of an optical mark reader (OMR), a minicomputer and a printer, and it came under scrutiny as a major equipment expense. At the same time, the test forms used in the AIS were also being investigated. In the latter case, thousands of test forms were being used each day, and at a per sheet cost of approximately 3½ cents, this also represented a major operating expense for the AIS.

Based on this information, the Air Force Human Resources Laboratory (AFHRL) Technical Training Division at Lowry AFB began to consider alternatives for portions of the Type B terminal and the paper test forms. The concept which evolved was an electronic responding device, or microterminal, which would take the place of paper tests and thereby bypass the OMR in the Type B Terminal. In 1976, a prototype was completed and successfully tested by AFHRL (Kirby & Gardner, 1976).

MICROTERMINAL HARDWARE CONFIGURATION

Original Design

The original device developed by AFHRL was referred to as a "student responder." It consisted of a keyboard, several hexadecimal display elements (0-9 and A-F), and a column of individual message display lamps all of which were interconnected directly to a central computer through an interactive terminal. Although not satisfactory as a final, usable device, this configuration was sufficient to obtain information on a favorable design and to determine the potential application of the device.

During the evaluation period, 50 students in classes at Lowry AFB (Lamos, 1977) were given a programmed instructional lesson with test. While no significant gains in performance were noted, the students covered the material in 30 percent less time. In addition, 90 percent of the students indicated that they preferred the electronic responder over the traditional computer paper-and-pencil test form.

It was also determined during this evaluation that an electronic responding device would be feasible only if the unit could operate in a "stand-alone" mode. Without this feature, the responder would require continuous interaction with a large central computer--a costly feature to implement and an undesirable situation when the central site was not operational. Likewise, it was also determined that the responder should have the interactive and dynamic response capabilities normally associated with a cathode ray tube (CRT) type computer terminal, as well as the ease of use which is associated with electronic calculators. In order to give it this capability, a complete microcomputer was incorporated into the responder. With this change the unit became known as the "microterminal."

Student Microterminal

The original AFHRL prototype microterminal utilized the Motorola M6800 microprocessor with a 1024-bit random access memory (RAM) and six 4096-bit programmable read-only memory (PROM) chips. As illustrated in Figure 1, this prototype featured a 16-key keyboard, 14 display lights to indicate directive messages, and four hexadecimal display units for answer feedback, etc. The electronics associated with the microterminal provided four test strategies with up to 900 test item keys permanently stored and a capacity of up to 250 test items for which a student's response was temporarily stored. These four test strategies could be presented in any one of the following schemes.

1. Linear progession with no response feedback.

2. Same as #1 with Yes/No response feedback.

3. Same as #2, but the student remained at the last test item until the correct response was given.

4. Same as #3, but the student could be given a retest on incorrect responses until all items were answered correctly.

Information entered by the student in the prototype microterminal was limited to manual retrieval. In the instructor mode, i.e., depressing a special sequence of keys, such information as the student's SSN, test booklet number, student score, elapsed time, and responses to each question could be retrieved.

Interface Evaluation

In 1976, the Denver Research Institute (DRI) undertook a study to determine a hardware interface which would enable the microterminal to transfer test data directly to the AIS central site (Wasmundt, Steffen, & Kargo, 1976a,b). This effort involved the investigation of hardware, software, and instructional support functions of the prototype and the interactive and Type B terminal interfaces. The recommendations from that study resulted in an interface for the microterminal between the Type B terminal and the central site.

The modifications made to the prototype to effect this change consisted of additional support circuitry, primarily input/output (I/O) buffers, and several software changes. In the latter category, the I/O format was instituted, and the calculation and display of final test scores and/or transfer of test answers to the AIS computer via the Type B terminal was made available.

An additional feature which was incorporated at this time was the provision for a redundant check digit in the test booklet number. This helped prevent the student from inadvertently entering an incorrect number. Also, the time required for the student to complete the test was measured and made available to the instructor or the Type B terminal. Figure 2 reflects the basic outline of the "initial" microterminal.

Applications Study

During the early months of 1977, under the present contract effort, DRI initiated an applications study of the microterminal. The purpose of that study was to determine a microterminal prototype design which would have the capability of meeting most of the present and projected needs of the AIS. In order to identify these objectives, a series of meetings were held with AFHRL and McDonnell Douglas personnel. A tour of the AIS courses was then conducted and possible areas of applications identified. The applications categories tentatively identified for the microterminal were as follows.

1. "Existing" microterminal applications.
2. "Extended" microterminal applications.
3. Adaptive testing.
4. Adaptive instruction.
5. Uses with external microterminal I/O control.
6. Performance training.

Under the category of "existing" microterminal applications it was recognized that the hardware and software features of the "existing" prototype placed limitations on the future applications of the device. For example, with the prototype, a typical testing scenario was limited to the following steps.

Step 1. Student enters his social security number (SSN).

Step 2. Student enters the test booklet number (containing information required for test administration, i.e., number of questions, test key, and feedback mode).

Step 3. Student answers all questions in the order requested by the microterminal.

Step 4. At the end of the test, the student takes the microterminal to his instructor or to a Type B terminal for evaluation.

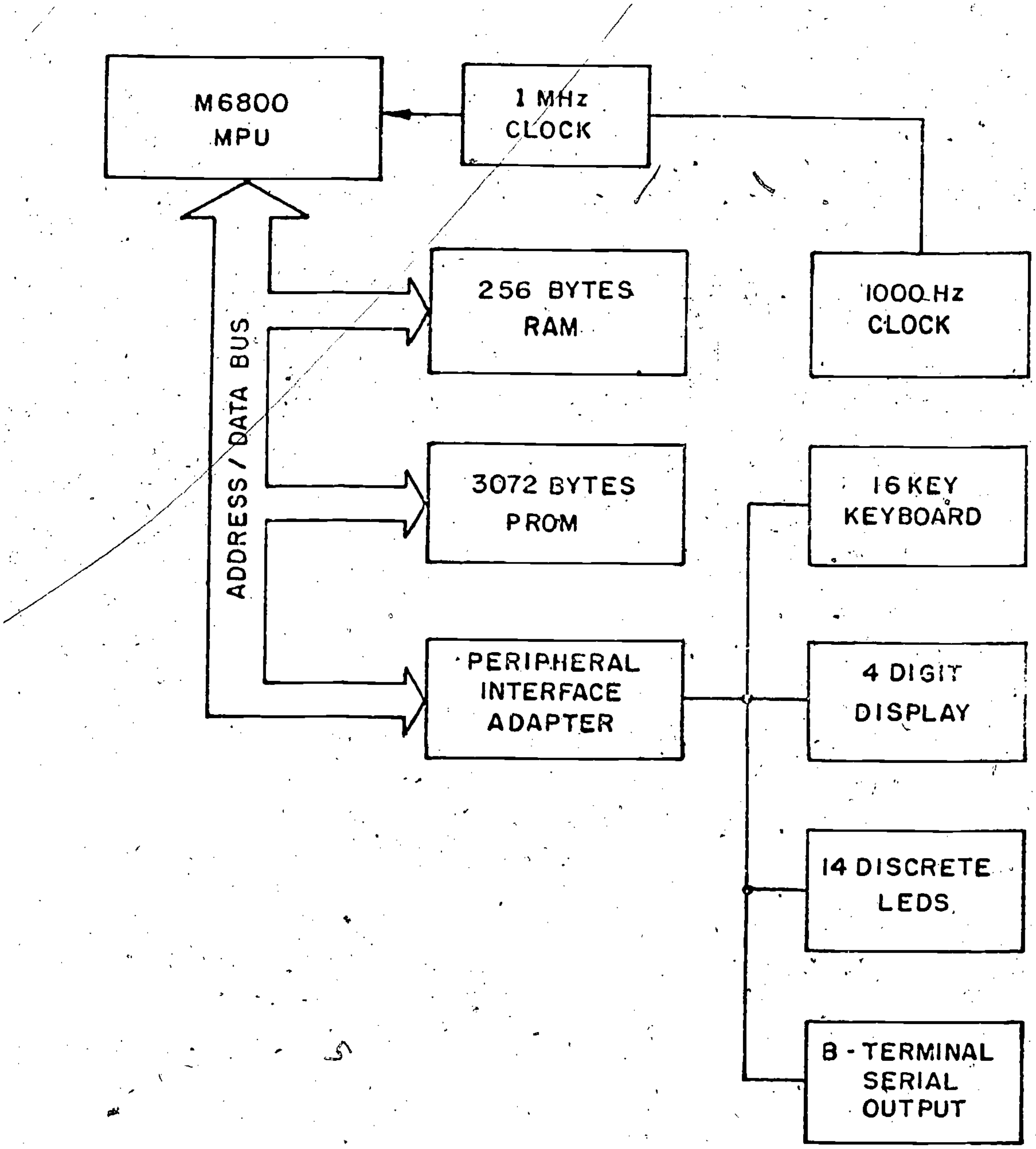

Figure 2. Microterminal block diagram

One of the objections raised by students to this scenario was that there were no provisions for altering the linear presentation of the test questions. It then followed that this could be resolved by modifying several features of the "existing" microterminal and "extending" features which would allow the student to change the order in which the questions could be answered. These modifications should, therefore, provide the following test features.

1. Non-linear progression testing, whereby the student would be able to alter the order in which questions were answered.

2. The review of answers to previous questions.

3. If feedback was not provided, the student should be provided a means to alter the answers.

In addition to these changes, which were primarily involved with the software, various hardware modifications and additions were considered at this time. These changes, which would supplement the software changes, were also considered as factors in the reduction of hardware costs. A 12-key keyboard, three hexadecimal display digits, a reduction in RAM, and a battery powered RAM were suggested as additional "extensions" of the "existing" microterminal.

Another factor considered in the applications study was that of test security. Because a large number of tests must be given in the AIS, and since students have shown great skill in deciphering test keys, it was recommended that an integral pseudo-random number generator, with a wide variety of test patterns, would be more desirable than the original test keys possible with the "existing" microterminal. This type of test generation would be structured within the AIS when the instructor first requested a test booklet number for a new test. At that time, the AIS central site would generate a number based on the type of course, block test number, and the number of questions supplied by the instructor. The capability to decipher this test booklet number and score the tests would also be a requirement for an "extended" microterminal.

The ability to administer flexilevel adaptive tests was also considered a desirable application for the "extended" microterminal. In adaptive testing, an algorithm is devised which tests the student on the fewest number of questions possible. The theory is that the adaptive test score would have a close correlation to the test score which a student would receive if all questions had been answered. In flexilevel adaptive testing, the questions are ranked according to difficulty--the first is the easiest, the last the most difficult. When issued a test, the microterminal could start the student at the middle question. For each correct answer, the student would be directed by the microterminal to a more difficult question; for incorrect responses the process would be reversed. With this capability the microterminal could provide an economy of operation that is difficult to duplicate with conventional paper-and-pencil testing.

The requirements of the microterminal for adaptive instruction do not vary greatly from those required for adaptive testing. In fact, adaptive instruction may be considered an extension of adaptive testing, but with self-explanatory questions. At the end of an instructional sequence, students answer questions regarding the material which has just been covered, and branch to material which is either more or less difficult, depending on the correctness of the response. However, since the object of such an application is to make the material conform to the student rather than to measure the student's achievement, the software demands that would be made on the microterminal for precision of measurement are greatly decreased.

The use of an external microterminal parallel I/O control could further enhance the applications of the device by providing the capability to communicate with an external device, such as a microfiche projector, an external memory, or similar devices. However, it was recommended in the applications study as impractical to simply extend the microprocessor data, address, and control bus outside of the microterminal, partly because of the number of lines involved (about 40) and partly because of the danger either of electromagnetic interference with other devices or damage to the microterminal if the bus was improperly used. It was therefore suggested that another programmable interface adapter be added to the microterminal with its external I/O lines being available only at an external connector mounted on the microterminal. This was suggested for addition to the existing hardware at little additional cost.

Performance training was briefly considered as an area for evaluating other potential uses for the microterminal. This remained largely undefined, except that it appeared that any applications beyond those already discussed would require significant additional capabilities. For example, the keyboard is limited to numeric input, plus a few function keys, so that constructed answers are not possible. Similarly, the display has limited capabilities so that any communication with the student, other than feedback verification of answers and simple instructions, must be via indexing through a conventional media, such as textual material or microfiche. Finally, such an application as performance training would probably require special programming to handle each device for which training was desired. Thus, this particular application was not recommended as immediately suitable for the microterminal.

In addition to these points, the applications study also considered a number of questions which applied to the effects of incorporating the microterminal into the AIS. Most of these questions dealt with the ability of the AIS to accept these changes with a minimum of alteration to its existing framework. For example, all applications of the microterminal require some modifications of the courseware, but it was found that these could be accomplished by treating the new portion of the courseware as an alternate module or test. Similarly, the students could be trained in the operation of the microterminal by incorporating instructions into an existing lesson module.

The support required for operation of the microterminal was also considered in the applications study. Failure in the system, for instance, would require a manual backup system. If a failure occurred in a single microterminal, then the student would be forced to start over on another microterminal, although adaptive instruction might be able to continue from some checkpoint rather than from the beginning of the test. In any case, a maintenance contract or a repair facility within the AIS would be required to deal with the problems as they arose. Other types of support would also be required, but except for the microterminal power supply, this was within the present capability of the AIS.

Cost Considerations

Three major changes to the original prototype microterminal were considered as possible advantages in the design of the "extended" microterminal. These were the inclusion of an external parallel I/O connector with the associated electronics, the addition of an external memory module which could be interfaced via the parallel I/O connector, and a power supply included within the microterminal.

The first change, that of including a parallel I/O to the microterminal, provides the possibility of interfacing the microterminal to other devices, such as a microfiche viewer or cassette tape player. This change would also make it possible to consider an external memory module which could be used to record all information that was to be transferred to the AIS central site. Therefore, if the microterminal was not physically required for the transfer of test information to the AIS, it would not have to be transported from the study carrel to the Type B terminal by the student. This would further make it possible to enlarge the microterminal enclosure to include the third change, that is, a self-contained power supply. The combinations which may result from these changes are outlined in Table 1.

Table 1. Possible microterminal changes.

	Parallel I/O Port	Self-Contained Power Source	Internal RAM	External RAM
Type 1	No	No	Yes	-
Type 2	Yes	No	Yes	-
Type 3	Yes	No	-	Yes
Type 4	Yes	Yes	-	Yes

A primary consideration in comparing the four types of microterminals was the probable cost of each. As indicated in Table 2, the range of approximately $100 between Type 1 and Type 4 was significant. On the other hand, the added features of the various types did not appreciably affect software costs as these would be a one-time development expense. As long as additional PROM requirements were held to a minimum, the added software efforts for each added feature appeared to be a worthwhile investment.

In comparing the support requirements for each type of microterminal, it was evident that there were some offsetting cost savings in return for the additional internal power supplies. In fact, the additional expense of an internal power supply for the Type 4 unit is nearly offset by the reduction in cost of supporting the other types with an external source. When also considering that the future possibilities of the microterminals could be greatly increased by not requiring the installation of external power sources and associated wiring to study carrels, the added expense of the internal power supply is insignificant.

Although not reflected in Table 2, another configuration of the microterminal was suggested. This would be the installation of a power supply and internal battery source to power the internal RAM while the student is taking the microterminal from a carrel to a Type B terminal. However, this configuration would be cumbersome in some respects, since the microterminal would not have the required portability desired for such usage--due to the added weight of the unit--and would further introduce an increased shock hazard by requiring the student to connect and disconnect the 110-volt power source.

The cost difference between Type 1 and Type 2 units versus the added capability of a Type 2 was such that it appeared well worthwhile to include the feature of I/O capability. The only remaining decision, then, was whether to include the memory module. To resolve this question, a study of maintenance and predicted life of the microterminals was performed. In making this comparison, no significant difference could be identified without also including the addition or deletion of an internal power supply. That is, without considering a memory module, an internal power supply was undesirable due to the portability requirements that would be imposed on the microterminal. Thus, a decision was made to compare the Type 2 microterminal to a Type 4 microterminal.

The resulting difference in estimated cost between these two types was $80, or, for a quantity of 500 units, approximately $40,000. The implication here was that the Type 4 microterminal would need a useful life 19% longer than the Type 2 in order to justify the cost differential, unless significant differences in support costs could be realized. It was then further estimated that the elimination of an external power source and its associated wiring to study carrels would result in a cost difference more on the order of $55 between the two types. This would then result in the requirement that the Type 4 unit have a useful life 12.8% longer than the Type 2.

The desired life of a microterminal is approximately 5 years. From this, the required life of a Type 4 unit would need to be approximately 8 months more than that of Type 2. But, since the Type 4 does not have to be carried between a student carrel and an AIS Type B terminal for the transferral of student information, it is expected that a reduction in malfunction, due to droppage and mishandling, would be realized. This cost difference of $55 would then be made up in maintenance or replacement parts expense.

By constructing the memory modules in a manner that can accept this expected abuse by students and by being able to maintain the microterminals in a stationary position, the additional expense of the Type 4 unit could be recovered over the life expectancy of the devices. When also considering that the configuration of the Type 4 lends itself to more flexible use in extended applications, the cost difference between the two types is not significant.

The selection of a Type 4 unit, with memory module, was also investigated from an instructional and administrative viewpoint. In this case, one of the most apparent advantages of a memory module unit is the ease with which it can be stored. Equivalent in size to about two cigarettes packs laid end to end, the logistics of controlling 500, or more, memory modules is less difficult than that required for 500 microterminals. Another factor in favor of the module was the cost of producing additional units. Since a surplus of modules will undoubtedly be required, especially during periods when the central site is down, the cost of doubling the number of modules, as opposed to doubling the number of microterminals, is considerably less. Downtime associated

Table 2. Comparison of unique features of four microterminal configurations.

Type 1 $404	Type 2 $429	Type 3 $469	Type 4 $509
Unique Hardware	Unique Hardware	Unique Hardware	Unique Hardware
1. Internal Battery	1. Internal Battery	1. Memory Module (External 128 Byte RAM & Battery)	1. Memory Module (External 128 Byte RAM & Battery)
2. Internal Power Converter	2. Internal Power Converter	2. Parallel I/O Control Logic and Connector	2. Parallel I/O Control Logic & Connector
3. Serial I/O Control Logic & Connector	3. Serial I/O Control Logic & Connector	3. Power Connector	3. Internal Power Supply & Line Filter
4. Portability	4. Parallel I/O Control Logic & Connector	4. Internal Power Converter	4. 128 Bytes Internal RAM
5. External Power Source	5. Portability	5. External Power Source	
6. 256 Bytes Internal	6. External Power Source	6. 128 Bytes Internal RAM	
	7. 256 Bytes Internal RAM		
Unique Support	Unique Support	Unique Support	Unique Support
1. Separate Power Source Installed in Carrels	1. Separate Power Source Installed in Carrels	1. Additional Maintenance of Memory Modules	1. Additional Maintenance of Memory Modules
2. Additional Maintenance Requirements due to Separate Power Source	2. Additional Maintenance Requirements due to Separate Power Source	2. Additional Maintenance Requirements due to Separate Power Source	2. Parallel I/O in Management Terminal for Memory Module
3. Serial I/O in Management Terminal	3. Serial I/O in Management Terminal	3. Parallel I/O in Management Terminal for Memory Module	

TABLE 2 (continued)

Unique Software	Unique Software	Unique Software	Unique Software
1. Serial Data I/O Transfer To/From AIS Management Terminal	1. Serial Data I/O Transfer To/From AIS Management Terminal	1. Parallel I/O Control For: a. Memory Module b. External Device	1. Parallel I/O Control For: a. Memory Module b. External Device
Applications/Limitations	**Applications/Limitations**	**Applications/Limitations**	**Applications/Limitations**
1. Progression testing - test presented in booklet form only	Same as Type 1 except that test can be presented by various media via I/O control	1. Progression Testing - test presented by various media via I/O control; partial retesting possible by "downloading" capability of memory module.	Same as Type 3
2. Adaptive Testing-Test presented in Booklet Form Only; Standardization of Microterminal software not possible, additional PROM may be required.		2. Adaptive Testing-Test presented by various media via I/O control; standardization of Microterminal software possible due to "downloading" capability of Memory Module.	
3. Adaptive Instruction-Test presented in booklet form only; standardization of Microterminal software not possible; additional PROM may be required; instructional sequence dictates software requirements.		3. Adaptive Instruction-Test presented by various media via I/O control; standardization of Microterminal software possible due to "downloading" capability of Memory Module with additional PROM which controls instruction sequence.	

with the central site also made the memory module more appealing and practical, because the student could continue with a test. When completed, the instructor could "manually" score the memory module on an instructor microterminal, make the next assignment, and then save the module for processing when the central site was back on line.

A final point in favor of the memory module is related to the extended application of the microterminal. In this case, if the microterminal proved satisfactory as a testing device, it could also be extended for use in correspondence courses and on-the-job training (OJT). With a microterminal on hand at each installation, or accessible to field units, memory modules could be mailed back and forth to central locations as an alternate to direct communication links with remote terminals and when time is not a factor.

As stated earlier, one of the original objectives of this project was to develop a microterminal whose per unit cost would be $500, or less, in quantities of 500 or more, and the Type 4 unit fulfills this objective. This cost goal had been previously determined from an analysis of the present costs of the AIS paper-and-pencil test forms which the microterminal would replace. In an earlier study, the cost of paper forms was determined to be approximately $367,500 over a 5-year period (based on 40 forms/student/week over 50 weeks, an average enrollment of 1400 students, and a cost of 3.5 cents per paper form) (Gray, Steffen, & Wasmundt, 1977). Extended over the same period, 500 microterminals at $500 each would result in a net initial expenditure of some $100,000 less. By further considering the capability of the microterminals to administer adaptive testing, it was also believed that further savings could be achieved by reducing test time and the normal administrative requirements of processing the test data. Therefore, it was agreed that the final design configuration of the microterminal should be one which has the characteristics of the Type 4 unit.

Final Configuration

During the final design stage, the selection of hardware and the structure of software were modified due to technological advances which took place during the development period and because of considerations given to human factors in the use of the microterminal. In the latter case, the final configuration, as reflected in Figure 3, was selected with the goal of producing an "electronic test form" which duplicated as many of the inherent features of a paper test form as was possible. In this regard, student use and acceptance of the device would be improved if answers could be skipped, reviewed, and changed. In order to limit student confusion and frustration, every attempt was also made to design the microterminal so that each action by a student would result in a recognizable reaction by the microterminal. Such responses as erroneous

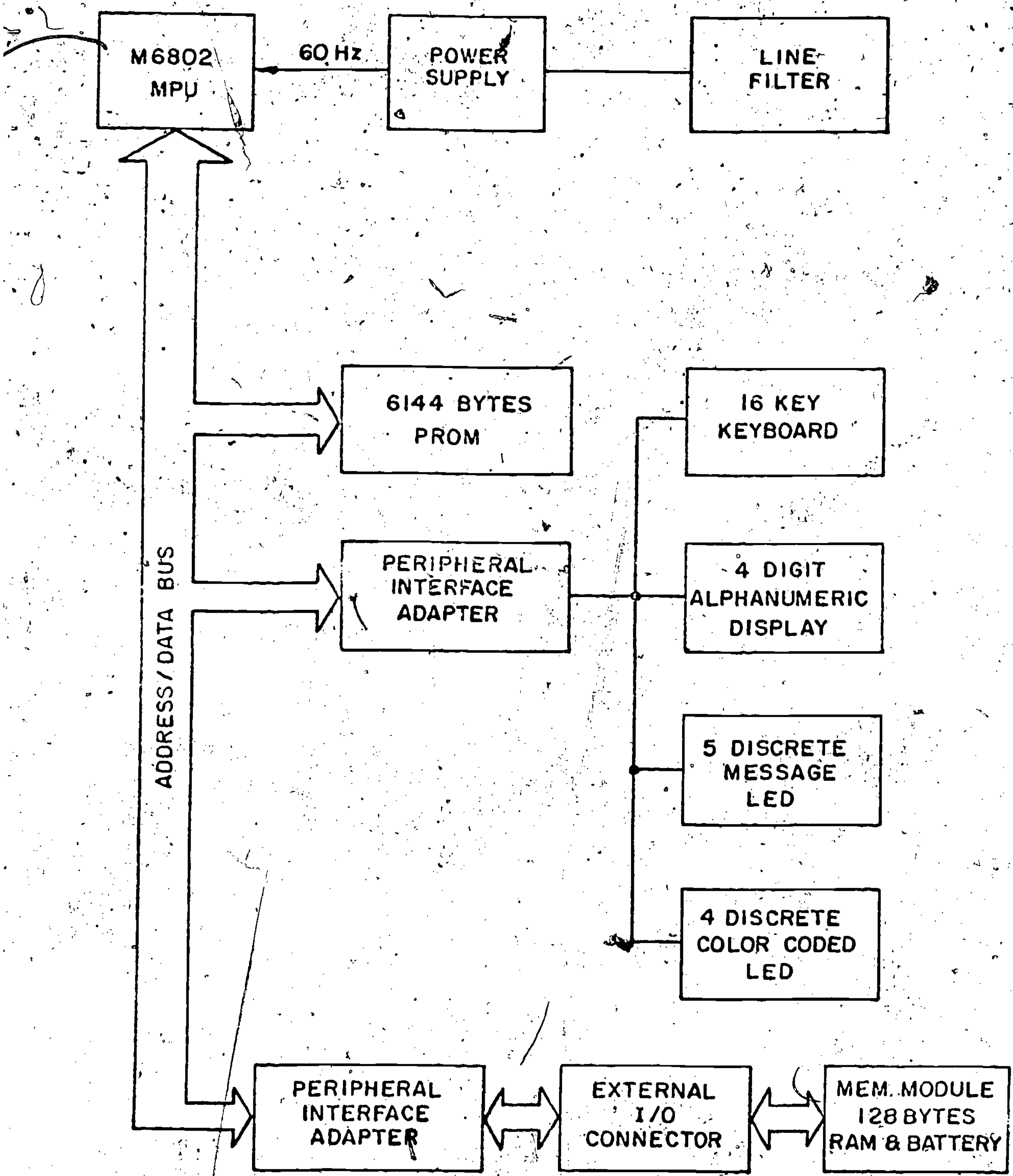

Figure 3. Final Microterminal block diagram

key depressions (answering a question with "8" rather than "B") would cause the display to flash a question mark; or, the depression of any combination of keys would not cause the microterminal to become non-functional. Similarly, the student is required to confirm each answer by depressing either ENTER (to validate) or CLEAR (to void).

The location of indicator lights, the microterminal enclosure, and tactile buttons for the keyboard were also selected with student use in mind. Several layouts were discussed on these subjects and agreement reached before proceeding further.

In the case of hardware, new products were substituted for original selections when it was found that their substitution would improve performance, cost, or both. For example, a four-digit, low power alphanumeric display became available during the contract period. By substituting this for the four-digit light emitting diode display, short messages, such as "Yes," or "No," could be presented to the student. Furthermore, the 64-character ASCII set, as well as punctuation symbols, could also be adapted for various messages. With this extended capability, it was possible to reduce the LED message lights from 16 to five and to add four additional color-coded LEDs for possible adaptive instruction applications.

Prior to the final design, Motorola also introduced the M6802 microprocessor unit (MPU) which contains 128 8-bit words of internal memory and an oscillator. This modification reduced both the component count and the power requirements. Also, a PROM became available which contains 2048 8-bit words, but required no more power nor space than did the original 512 8-bit word PROM. Thus, with a provision for three of these units, a capacity of 6144 8-bit words of memory was achieved.

With the addition of an internal power supply, it was also possible to develop a 1-Hz clock for timing purposes from the 60-Hz AC line. This resulted in a significant reduction in the existing timing circuit which had previously used a 1-MHz oscillator.

Considerable effort was also expended on the design of the memory module. Enclosed within a ruggedized high impact plastic (Figure 4), is a complimentary metal oxide semiconductor (CMOS) random access memory (RAM), which is powered by a miniature 50-milliamp-hour nickel-cadmium battery. When the microterminal power supply is on, the battery is recharged; when removed from the microterminal, the module battery is capable of powering the memory for sufficient periods of time without losing stored data (up to 20 weeks with a full charge).

The final configuration of the microterminal, with memory module in place, is illustrated in Figure 5. A close-up of the display panel

Figure 4. Memory Module

Figure 5. Microterminal & Memory Module in place

(Figure 6) demonstrates that it was designed so that the legends could be changed on both the commands and keyboard for other applications. Figure 7 is the microterminal with the top case tilted forward for ease of maintenance and repair.

Classroom Evaluation

From 16 January to 3 February 1978, the microterminals were operated in support of Block 4 testing in the Weapons Mechanic Course at Lowry AFB. This block test consisted of 15 multiple-choice items, with two alternative tests available, and was supervised by AFHRL personnel.

The primary purpose of the evaluation was to determine the reliability, ease of use, and acceptance of the microterminal in a functioning classroom situation. Students who used a microterminal followed a typical testing procedure. Upon entering the test center, each received a standard test booklet, plus a two-page set of operating instructions on the microterminal. Individual assistance was given only if the student requested such assistance. Following the written directions, along with the displayed directions on the microterminal, the student responded to test questions via the microterminal. When the student completed the test, the memory module was then taken to the Type B terminal in the same manner required for computer test forms.

During the evaluation period, 123 students used the microterminal, and there was only one significant malfunction. This was caused by an unusual powerline fluctuation, which was corrected by unplugging and replugging the microterminal into the wall receptacle with no effect on the status of data in the memory.

To assess the reaction of students to the use of the microterminal, the questionnaire in Figure 8 was administered. The percentages reflect how the 91 students who had only written directions on how to use the microterminal reacted to the microterminal. As can be seen, a large percentage preferred the unit to a generalized computer test form and found it quite easy to use. Item 10 was used to elicit open-ended comments from students. Forty-nine percent (n=46) responded with some comment. Of those, 20 expressed a general liking for the device, seven felt that the microterminal was faster to use, 12 believed it was easier to use or allowed better concentration on the test, and seven registered a minor complaint. Of these last seven, six had indicated a good opinion of the microterminal on Item 1.

Following up on some of the comments made about the microterminal, two additional groups of students were evaluated. Students as they came to the testing room for taking a Block 4 test were alternately assigned to responding on a computer form (Group 1) or to responding on the microterminal (Group 2). Those in the latter category were given pre-

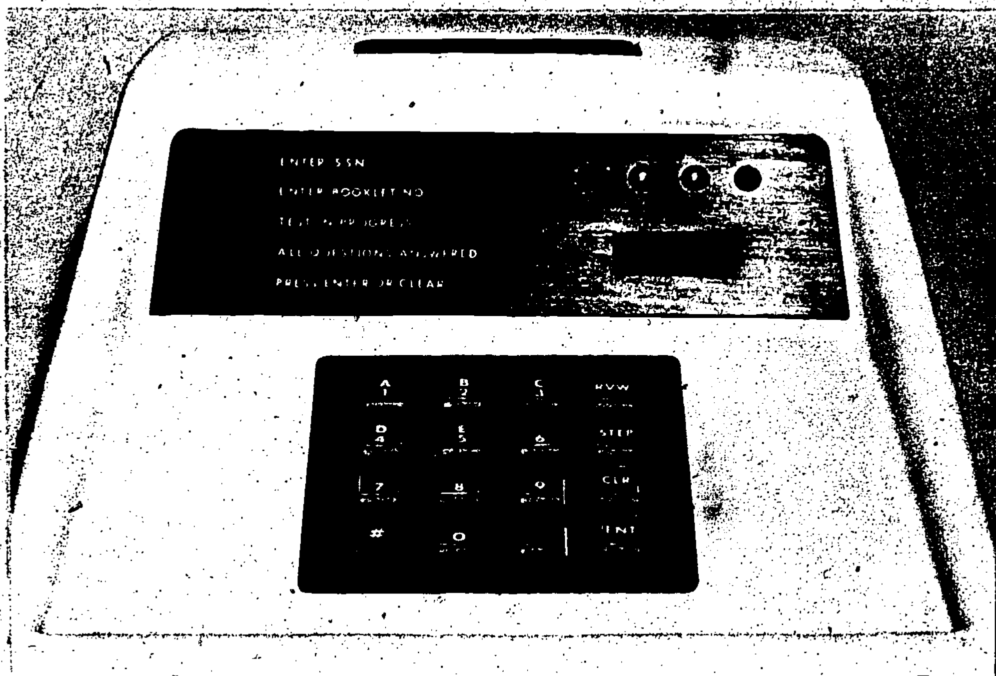

Figure 6. Microterminal front panel

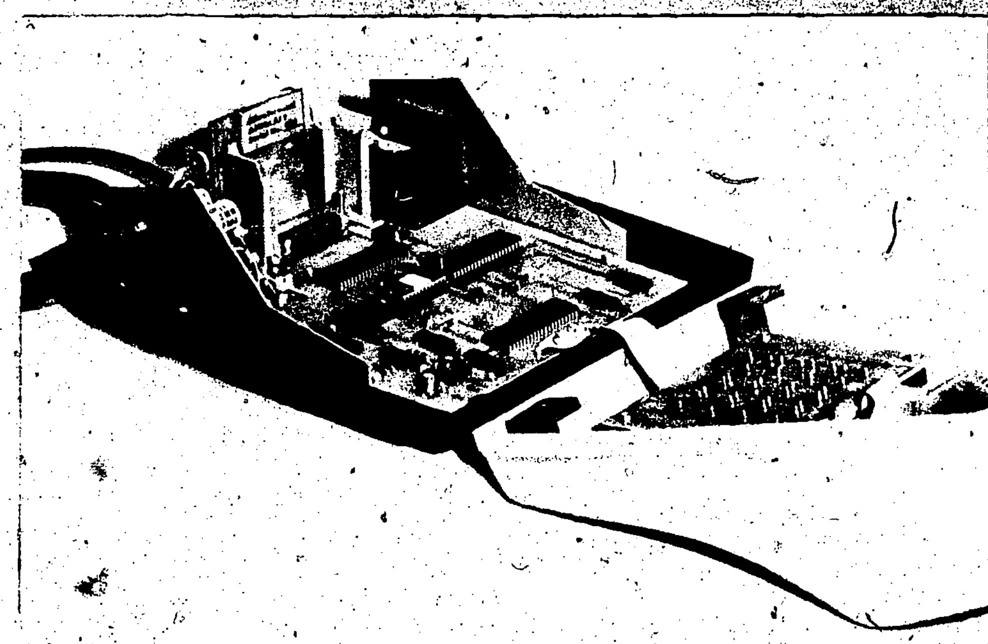

Figure 7. Microterminal hardware placement

Figure 8
STUDENT QUESTIONNAIRE

Microterminal Use
(N = 91, Students Read Instructions)

1. What is your opinion of the microterminal?

   91% Good ____ Bad 9% Indifferent

2. Which would you rather use for answering test questions throughout the rest of the course?

   91% Microterminal 9% Computer Test Form

3. Did you feel nervous using the microterminal? 11% Yes 89% No

4. Was the microterminal difficult to use? 1% Yes 99% No

5. Did you feel that you were restricted by the microterminal, as compared to a test form, in the way you could answer test questions? 5% Yes 95% No

6. Over the length of the course do you think that you would have less problems using the microterminal and its memory module than computer test forms? 65% Yes 9% No 26% No Difference

7. Were the directions indicated by the lighted messages on the microterminal hard to follow? 1% Yes 98% No 1% Marginal

8. Was the display area of the microterminal easy to read? 99% Yes 1% No

9. Was using the memory module at the management terminal as easy as using a test form? 96% Yes 4% No

10. In the space below, please indicate any other comments or suggestions you may have about the microterminal.

instruction on the use of the unit in order to eliminate any "learning curve" time element. Comparing time and score data between the two groups produced the results shown in Table 3. Group 2, the pre-instructed microterminal users, averaged a faster test completion time (9.7 minutes vs. 11.3 minutes) than Group 1, the computer form users. This difference was statistically non-significant. The microterminal users had a higher test score average (92% vs. 85%) than the computer form users, and this difference was statistically significant.

An expanded questionnaire was then given to the second group of microterminal users. The results are reflected in Figure 9. Of this second group, 100% had a good opinion of the device, and 97% preferred its use over a computer test form. Twenty-four students responded to either of two open-ended questions. Their general comments were as follows:

- 14 (44%) expressed a general liking of the device.
- 6 (19%) specifically stated that the unit was faster to use.
- 18 (56%) specifically stated that the microterminal was easier to use or allowed better concentration.
- 4 (13%) expressed a minor complaint.

Figure 10 is a selected sample of student comments.

To eliminate the possibility that the better performance of the microterminal users was due to better general aptitude, in spite of the apparently random assignments, both a discrimination analysis and an analysis of covariance (ANCOVA) were performed. The discrimination analysis was used to ascertain whether or not the form users or micro-terminal users differed on any of five preassessment variables which are used as measures of general ability. Only one variable, reading comprehension, significantly discriminated between the groups. When this preassessment variable was used as a covariate, the ANCOVA showed that a significant main effect ($P < .05$) still existed between microterminal user scores and computer form user scores. The results of this analysis are tabulated in Table 4.

With respect to the initial purpose of the evaluation, to determine whether or not students would accept the use of the microterminal and whether or not the microterminal was easy to use, the data gathered definitely show that students prefer the microterminal over computer test forms. Time and score data further indicate that there is merit to several student comments that the unit is a faster way to respond to

Table 3. T-Test Results for complete form users (G1) vs. microterminal users (G2)

TIME	N	MEAN	S.D.	T VALUE	D.F.	PROB (1-Tail)
Group 1	44	11.3	6.7	1.31	70.3	.10
Group 2	32	9.7	3.8			
SCORE						
Group 1	44	.85	.16	-2.40	70.3	.01
Group 2	32	.92	.09			

Table 4. Analysis of covariance.

Source of Variation	Sum of Squares	DF	Mean Square	F	Prob.
Covariates	.001	1	.001	.055	.815
Read S2	.001	1	.001	.055	.815
Main Effects	.069	1	.069	4.769	.032
Cond.	.069	1	.069	4.769	.032
Explained	.069	2	.035	2.412	.097
Residual	1.006	70	.014		
	1.075	72	.015		

Figure 9
STUDENT QUESTIONNAIRE

Microterminal Use
(N = 32, Students Pre-Instructed)

1. What is your opinion of the microterminal?

   100% Good ____ Bad ____ Indifferent

2. Which would you rather use for answering test questions throughout the rest of the course?

   97% Microterminal 3% Computer Test Form

3. Did you feel nervous using the microterminal? 9% Yes 91% No

4. Was the microterminal difficult to use? 3% Yes 97% No

5. Did you feel that you were restricted by the microterminal, as compared to a test form, in the way you could answer test questions? ____ Yes 100% No

6. Over the length of the course do you think that you would have less problems using the microterminal and its memory module than computer test forms? 88% Yes ____ No
   12% No Difference

7. Were the directions indicated by the lighted messages on the microterminal hard to follow? ____ Yes 100% No
   ____ Marginal

8. Was the display area of the microterminal easy to read?
   100% Yes ____ No

9. Was using the memory module at the management terminal as easy as using a test form? 91% Yes 6% No

10. In the space below, please indicate any other comments or suggestions you may have about the microterminal.

11. Did the microterminal make block testing seem easier to you?

91% Yes 9% No

12. By using the microterminal instead of a computer test form, for recording your test answers, did you feel that you were better able to concentrate on answering the test items?

81% Yes 19% No

13. What is the single thing about the microterminal which you either liked or disliked the most? Please answer below.

Figure 10.
Selected student comments

"It was better than filling out test forms and a lot easier to use."

"I like it better because you can make changes easier and (it) doesn't leave pencil and erase marks."

"It was a lot better than test forms because you can change the answers easier."

"It's faster. You don't mark the wrong letters by mistake as easily (sic).

"Not having to worry about mistakes."

"With the computer test form one can show proof when the computer messes up, (which isn't too often but it does happen). How can the microterminal be proven wrong when and if there is a malfunction?"

multiple-choice items and that the microterminal allows better concentration on taking the test without concern for making recording errors. This latter point is important because the recording of data (SSN, test identifier; item responses, etc.) requires the careful darkening of many little boxes on a computer test form. A mistake in filling in the boxes could result in form rejection and/or erroneous test results, all of which seem to be a worry to students. It would thus seem reasonable to conclude that the significantly better test scores of the microterminal users would be due to better concentration; however, the rival hypothesis that there are novelty effects cannot be discounted until a more extensive longitudinal study is conducted.

Cost Analysis

The parts costs for a microterminal with memory module are itemized in Table 5. The prices shown were current when the microterminals were being constructed in late 1977 and are subject to change. However, it is anticipated that the effect of the price changes which are likely to occur over the period of a year will tend to reduce the total parts cost. The reason for this is the general trend that now exists in price reduction for such items as the M6802 microprocessor and the TMS 2716 EROMS. It is also noted here that this total price includes only one EROM for each microterminal.

The actual fabrication costs for the various structural components of the microterminal are itemized in Table 6. In many instances, a major portion of an item cost was for the fabrication of a template or other mechanical aid. These, of course, were one-time charges and, therefore, distort the production costs of an item. For example, the cost of the spring for the memory module shutter is unusually high. The costs of the memory module case and microterminal case modifications were also quite high. It is expected that for a quantity of 500 or more units, it would be feasible to pay the setup charge for a tape-controlled milling machine, which would greatly reduce the cost per model While it is difficult to determine the exact cost reduction from such action, it is estimated that the final fabrication figures would be approximately 25% of the figures shown.

The unit cost for assembly and checkout, including the EROM programming, was approximately $330. However, for the last few prototypes, after the technicians became familiar with the units, the assembly and checkout required less than 12 hours (approximately $144) per unit. It could be expected that on a production line this figure might be cut in half. In any case, a unit cost of $509 appears realistic for quantities over 500.

TABLE 5. Components and material cost

Part	Unit Quantity	1-25 Unit Price	25-100 Unit Price	100-500 Unit Price
M6802P (Microprocessor) Motorola	1	$25.00	$22.00	$22.00
M6820P (PIA) Motorola	2	9.75	8.25	6.60
*6561 (CMOS RAM) Intersil/Harris	1	8.25	8.25	8.25
DL1416 (Display) Litronix	1	40.00	35.00	30.00
CD4050AE (CMOS-Hex Buffer) RCA	2	.74	.74	.62
LM339 (Comparators) Natl. Semi.	1	.80	.60	.52
RL4484 (Red LED) Litronix	6	.29	.19	.19
YL4484 (Yellow LED) Litronix	1	.71	.71	.52
OL31 (Orange LED) Litronix	1	.47	.47	.31
GL4484 (Green LED) Litronix	1	.71	.71	.52
74LS174 (Hex-D Type Flip Flops)	2	.98	.80	.68
74LS139 (Decoders)	1	1.73	1.38	1.10
TMS2716 (EROM) TI	1	32.00	32.00	29.95
74L20 (NAND Gates)	1	.64	.52	.45
74L04 (Hex Inverters)	1	.68	.56	.48
7404 (Hex Inverters)	1	.34	.29	.26
82-601-817)	2	6.80	6.80	4.25
82-301-61) (Keyboard) Grayhill	1	3.65	3.65	2.25
82-101-71)	1	1.55	1.55	1.00
1B1 (Line Filter) Corcom	1	7.00	7.00	5.00
357001 (Fuse Holder)	1	.30	.30	.25
17236 (Power Cord)	1	1.45	1.45	1.20
*B50T (Ni-Cad Batteries) Eveready	3	1.86	1.86	1.20
6P-11 (Strain Relief)	1	.06	.06	.06
CY15C103M (.01 uF)	1	.16	.16	.12
196D186X9020KA1 (18 uF)	2	.25	.25	.20
DM15-180J (18 pF)	1	.15	.15	.10
CK058X104K (.1 uF)	2	.78	.78	.50
2CZ5V224X0050C4 (.22 uF)	1	.25	.25	.15
*DB-25PY) (Connectors)-ITT Cannon	1	5.44	5.44	5.00
*DBP-25SAA) (Connectors)-ITT Cannon	1	4.10	4.10	3.75
RC07CB (¼ watt, 5% resistors)	28	.12	.09	.07
#433260 (4 MHz Crystal)	1	5.95	5.95	5.95
C93-24-02 (I.C. Sockets)	3	.63	.56	.56
C93-40-02 (I.C. Socket)	1	.99	.91	.91
ICMP (Power Supply) Alpha Power	1	39.95	36.75	33.55
MC-4.9H-BE-BK (Console Case) Techmar	1	37.70	35.82	32.05
55-120-G-2 (Socket Strip)	1	1.65	1.65	1.55
P.C. Boards (4 required)	-	40.00	40.00	30.00
Miscellaneous Hardware & Materials	-	50.00	40.00	30.00
Total		$364.45	$335.44	$282.53

*Memory Module

The items listed here are those actually used but other similar components and materials would have been equally suitable. This listing does not imply endorsement of these products or manufacturers by the U.S. Government.

TABLE 6. Microterminal fabrication costs

Part	Dwg. No.	Unit Quantity	Average Charge Per Terminal
Shutter	EA-13225	1	$ 6.88
Spring	EA-13266	1	11.01
Hinge	EA-13224	1	16.51
Hinge Plate	EA-13305	1	2.75
Indicator Panel	EB-13216	1	16.51
Window, Display	EA-13264	1	5.50
Memory Module Case	EB-13236, EB-13237	1	48.15
Support Block	EB-13220	2	27.52
Spacer	EA-13233	2	11.01
Guide Pin	EA-13228	2	11.01
Guide	EB-13221	2	20.64
Filter Bracket	EB-12686	1	4.13
Chassis	ED-13215	1	27.52
Console Case, Modification	ED-13219	1	77.05
Mounting Spacer	EA-13309	2	11.01
Display Panel Block	EA-13270	1	5.50
Keyboard Block	EA-13271	2	16.51
Keyboard Bezel	EB-13273	1	19.26
		Total	$338.47

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Conclusion

The microterminal described in this report fulfilled the objectives, and reached the goals that were intended at the initialization of the contract. As an "electronic testing device" the microterminal gave students greater confidence in answering questions, while also improving scores. The final cost figures also indicate that the use of the microterminal is an economically viable alternative to the standard computer paper-and-pencil test forms presently in use.

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