# A Low-Cost Terminal Usable for Computerized Adaptive Testing

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The Technical Training Division of the Air Force Human Resources Laboratory (AFHRL/TT) at Lowry Air Force Base, Colorado, is currently involved in the development of a large computer-based instructional system, the Advanced Instructional System (AIS). The AIS is designed to handle a daily load of up to 2100 students within four Air Force technical training courses. As a computer-based system, the AIS provides primarily computer-managed instruction (CMI). In this context, computer-assisted instruction (CAI), including computerized adaptive testing, is one of the many pedagogical approaches which could be used; but due to present high terminal costs, the use of this approach is limited.

Cost, of course, is a major factor in the implementation of a computer-based instructional (CBI) system. Any CBI system, if it is to maintain cost-effectiveness, must be sensitive to the costs of courseware (instructional materials), software, and the capital investment in hardware. In terms of hardware, a CAI system is highly dependent on the cost of interactive terminals (e.g., Alpert & Bitzer, 1970). Computer costs per student for central site hardware and system software decline with an increase in students handled by the system (limited, of course, by the total capacity of the system). However, as students are added to a CAI system, total terminal costs increase dramatically, especially if each student is to be on the system for most of an instructional day.

The impact of terminal costs is reflected in the early cost projections for the PLATO IV system (Bitzer & Skaperdas, 1969). In attempting to partition total system costs between the various subsystems of PLATO, they estimated that central site hardware to support a 4,000-terminal system would be 4.5 million dollars for a cost per student contact hour of 8¢ attributable to the central site. The 4,000 terminals would cost 7.5 million dollars for a cost per student contact hour of 15¢ attributable to the terminals themselves. In this projection, terminal costs were almost twice central site costs. Actual experienced costs of PLATO IV hardware showed terminal costs to be almost five times as great as central computer facility costs (Alpert & Bitzer, 1970).

There are auxiliary support and instructional costs associated with CMI. In addition to the terminal hardware cost, there is a cost associated with the major means for communicating data through a management terminal--computerreadable forms. In the AIS these forms have been chemically treated to allow for immediate feedback of correct response to objective-type test questions. In one of the courses under the AIS, the cost of forms alone has been approximately $8,500 per year. Additionally, there may be operational costs associated with the storage, ordering, and handling of these forms. There are also the indirect costs resulting from the frustration that students experience from continuous darkening of small boxes on answer sheets to encode information.

Although the AIS is still under developement and costs have not stabilized, some indication of the relations between CMI terminal costs and the support costs associated with the terminals can be shown. An anticipated stabilized cost for one AIS management terminal in its present configuration is $18,000. The relation of capital investment costs to support costs over a five-year amortization in one of the four AIS courses is shown in Table 1.

Table 1
AIS Management Terminal and Forms Cost per Student (4,000 Students/Year)

| Terminal | |
|---|---|
| Three Terminals<br>$54,000 Capital Cost | Five-Year Amortized Cost<br>$2.70/Student |
| **Forms** | |
| One-Year Cost<br>$8,500 | Five-Year Operating Cost<br>$2.13/Student |

As can be seen, the cost of forms alone in a five-year period almost equals the cost of the terminals. Because form costs are operating costs, they will soon exceed the terminal investment. In the AIS, cost relationships are continually being analyzed. On the basis of such an evaluation, work was undertaken on the development of an electronic replacement for the paper forms--a low-cost responding device which, like a form, would be independent of the central computer system and yet easily interfaced with the management terminal of the AIS.

Analyzing the instructional environment of the AIS in relation to computer support indicated three major functional areas: (1) response handling, (2) information presentation, and (3) data collection. These three areas broadly cover the specific functional needs of a CAI terminal as reported by Martin, Stanford, Carlson, and Mann (1975). However, one should not opt for a "do everything" capability in one device unless one is ready to pay for capabilities which are not fully utilized or required. Thus, the primary philosophy behind the design of the AFHRL/TT device was to build in *only* those capabilities which were necessary in the AIS setting.

Design specifications were developed by an AFHRL/TT interdisciplinary team consisting of an electronics technician, a computer design engineer, a computer systems analyst, and educational/psychological researchers who tried to match specific instructional/testing requirements with computer hardware/software capabilities. It was seen that the type of responding device required in the AIS needed to have the interactive and dynamic response handling capabilities normally associated with CRT terminals and the low-cost and ease of use now associated with the electronic hand calculator. The device has been designated a "microterminal." The microterminal, its dynamic response handling capability combined with the cost-effective presentation of information provided by programmed tests or audiovisual materials, begins to fill the void of instructional requirements and computer usage which lie between the more traditional conceptions of CMI and CAI.

The focus of the microterminal is objective item testing, in the form of embedded or adjunct questions accompanying instruction and end of instruction achievement tests. There is a sizable body of literature represented by the work of R. C. Anderson, E. Z. Rothkopf, and L. T. Frase (to name a few major researchers) which has provided clear evidence for the instructional effectiveness of well-designed and appropriate questions. The decision was made to invest hardware development costs in the features which would have the greatest return on investment. Thus, the hardware design of the first prototype unit focused on a serial sequence of test items, with flexibility for control of feedback, response storage, and the retrieval of student response data. The initial prototype microterminal represented an interactive electronic test form.

## Microterminal Development

The heart of the AFHRL/TT microterminal is a Motorola M6800 microprocessor along with one 1,024-bit random memory chip and six 4,096-bit programmable read-only-memory chips. This microcomputer has a capacity of up to 900 test item keys which are permanently stored and a capacity of up to 250 test items for which a student's response is temporarily stored. In the prototype model of the microterminal, there are four testing algorithms which control the responding situation. The device has the option of no feedback, immediate feedback, or delayed feedback as well as an answer-until-correct option. It collects test latency data in the form of running time to complete the test and could collect item latency data with software changes. The microterminal features a 16-key keyboard, 14 display lights to allow for the indication of established directive messages, 4 hexadecimal display units to allow for answer feedback, and a sequential form of key echoing for longer response items, such as the input of a Social Security Number.

The design of this prototype microterminal was thus limited to providing response management for the effectuation of data collection. A decision was also made to handle only objective-type responses. Without the need for either extensive presentation of information or constructed responses, the display features of the microterminal could be limited. Informational presentation is left to regular programmed materials. All design goals minimized cost while attempting to satisfy high probability instructional and testing requirements in the AIS. The cost design goal for the AIS microterminal development was $500 or less per unit. Figure 1 depicts the face of the prototype microterminal, and Figure 2 shows the overall design of the first prototype terminal.

Figure 1
Microterminal Faceplate

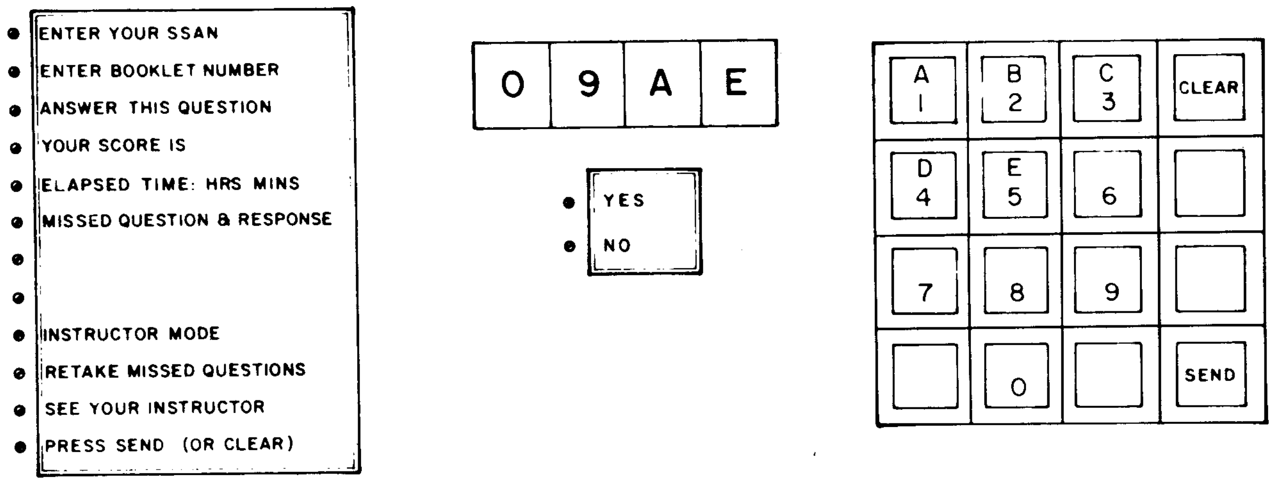
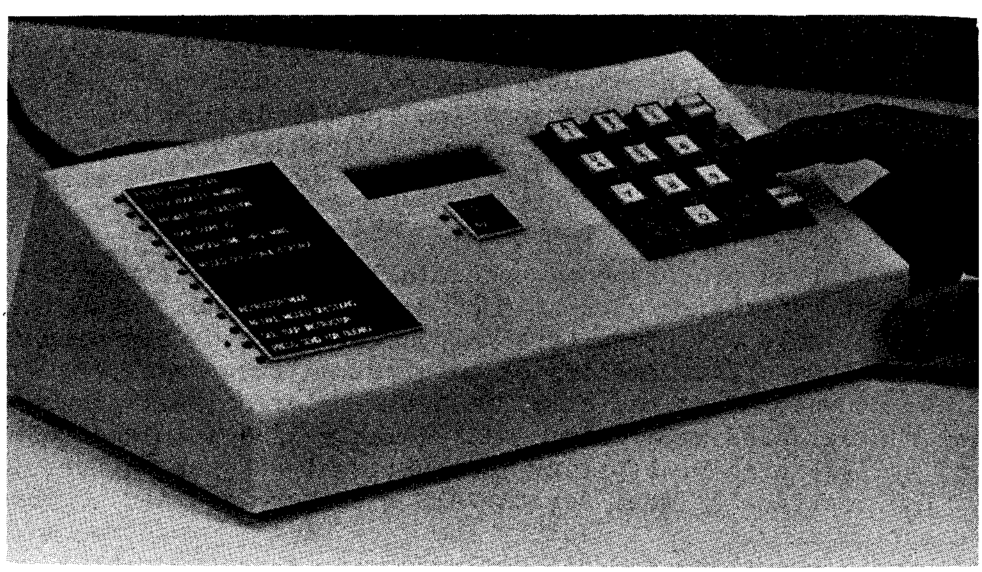



Figure 2
Microterminal



A complete technical discussion of the microterminal hardware development is provided by Kirby and Gardner (1976).

## Initial Microterminal Prototype Evaluation

A pilot study of a prototype microterminal was performed in order (1) to verify the usability and human factors of the design and (2) to attempt to gain a preliminary insight into potential instructional effects of the device. Results of the pilot study showed high user acceptance of the device, with no significant test grade differences between users and non-users. The study did indicate that students who used the microterminal accomplished lesson materials 30% faster than the control group. The time results of the pilot study are shown in Table 2. The difference in times between the groups may be due to a combination of factors such as time to fill out computer answer sheets, the effect of a computer directly monitoring the student's progress, increased attending behavior due to the direct tutorial effect (at least at the level of control over the response situations) of using the responding unit (i.e., less daydreaming), or simply a Hawthorne effect.

Table 2
Lesson Completion Times

| | Control | Microterminal |
|---|---|---|
| *N* | 12 | 12 |
| Mean | 168.08 minutes | 117.75 minutes |
| *S.D.* | 80.5 | 50.5 |

$(\overline{X}_c - \overline{X}_m) = 50.33$ minutes

$t = 1.85$, significant at $p=.05$ (one-tailed)

As part of the pilot study, an attitude questionnaire was administered to elicit student reactions to the device. The attitude questionnaire and student responses in percentages are shown in Table 3. Three items, in particular, seem important for systems design. Item 2 indicates that students preferred a device versus a form for recording their responses. Item 12 shows that a computer terminal device could be built to control the response feedback situation and to give clear directive-type information without an elaborate computer display. In other words, without having to pay for unused features such as a large display, the device satisfied an important part of the instructional situation; the information load gets carried by the programmed text or the test itself. Item 13 is of particular interest. Students subjectively reported that they "got more out of" the responder than if they used a sheet of paper to answer embedded questions. Normally, students are simply directed to record their answers on a sheet of paper, with feedback provided in the back of the programmed text. The microterminal has the advantage that the student must commit himself/herself to an answer before it is possible to receive feedback.

Table 3

Questionnaire Results of Students' Acceptance of the Microterminal (*N*=41)

| | | | |
|---|---|---|---|
| 1. | What was your opinion of the responder? | Good (86%) Indifferent (7%) | Bad (7%) |
| 2. | Which do you like better? | Responder (89%) | Form (11%) |
| | | Yes | No |
| 3. | Did you feel any type of pressure? If yes, why? | 18% | 82% |
| 4. | Did you feel nervous in using the responder? If yes, why? | 20% | 80% |
| 5. | Did you feel rushed? If yes, why? | 7% | 93% |
| 6. | Did you get frustrated? If yes, why? | 18% | 82% |
| 7. | Was someone present watching you use the responder? | 47% | 53% |
| 8. | Did this make you nervous in any way? If yes, in what way? | 7% | 93% |
| 9. | Do you feel uncomfortable about the computer grading your tests? | 5% | 95% |
| 10. | Is the device hard to use? | 0% | 100% |
| 11. | Could you understand the instructions in your lesson booklet? If not, how would you improve it? | 93% | 7% |
| 12. | Are the responder's red lights and their corresponding instructions easy to use? | 100% | 0% |
| 13. | Did you get more out of the programmed text questions using the responder rather than the usual way of answering on a sheet of paper or in you head? | 88% | 0% |
| 14. | Did you like the ability to continue responding until you received the right response for each question? | 98% | 2% |

The results of any pilot study require more extensive confirmation; however, the present results adequately represent the viability of a particular hardware solution to an identified instructional need in a computer-based instructional system. The instructional implications of the use of a microterminal,as described in this report,can be significant. In the area of testing the use of different testing strategies, test item security, and automated entry of test results for item or response analysis by a larger system become administratively feasible or easier to implement. With more adequate control over the response-feedback element, directive control conveyed by algorithmically controlled indicator lights and changeable message cards, and properly formatted materials such as programmed texts, microfiches, or audiovisual presentations, a low-cost form of computer-assisted instruction becomes available.

## Future Microterminal Development at AFHRL/TT

To further capitalize on the concept of low-cost CAI, AFHRL/TT has contracted for the development and evaluation of 10 newer prototype microterminals. The new microterminals will have several additional features, increasing the flexibility of response handling, data collection, and directive information for instructional and testing purposes. The new microterminal design still emphasizes the very limited display capabilities which resulted in significant cost reductions.

A major new feature is an insertable, self-contained memory module. The initial prototype was designed to be completely portable so that the self-contained student response data could be transferred to central site storage by having the student carry the microterminal to a CMI management terminal and plug it in for transfer of data and refreshment of the microterminal's RAM. Further examination of potential microterminal utilization revealed that although total size of the unit should be kept small to allow ease of use in student carrels, the device itself need not be carried every time transfer of data was required.

As in the original design, hardwiring of terminals was not desirable; there was a need to avoid the complexity of real-time communications between central site (i.e., polling of terminals, buffering of data) and a large number of terminals. The solution was to externalize that portion of memory which temporarily stores the students' responses, making *it* self-contained and portable. The additional benefit of this design is that the programmable hardware of the microterminal can be stabilized while the external memory unit provides a potentially expandable capability to support additional requirements. This becomes important in the context of adaptive testing,where some algorithms, such as maximum likelihood estimation and Bayesian scoring procedures, have relatively large processing and memory requirements.

Since the microterminal has limited display features, test or instructional information must be presented through more conventional media. The software of the initial microterminal was designed for serial presentation of test items. The new prototype will accommodate flexible or adaptive item presentation sequences. There are several ways in which either test or instructional materials can be presented to a student. One of the most flexible and best suited to adaptive presentation is microfiche.

The typical microfiche has 240 images, allowing for the presentation of both verbal and graphic materials. The row by column format of microfiche allows easy accessability of a particular image. The one significant problem associated with microfiche is the controlled access of an image. In the adaptive testing situation, it is most important to insure that a student look at the test item to which he/she was directed by the microterminal. To this end, the new microterminal will have an input/output port which will allow "communication" with a special electronic grid attached to a conventional microfiche projector. After a student has located the microfiche, the electronic grid will monitor and verify this location with the directed item given by the microterminal program. The microterminal and microfiche projector in combination provide a low-cost control and presentation "terminal" system.

## Projected Implementation

The use of the Air Force's microterminal and a microfiche projector for adaptive testing may be as follows: A student would report to the testing center. Upon reporting to the center monitor, he/she would receive a memory module containing refreshed memory storage for responses, adaptive test parameter information, and a test microfiche. The student would be seated at a test carrel, insert the memory module into the microterminal, and insert and index the microfiche into the projector. An indicator light would illuminate beside a standard message requesting the student to enter his/her identification information. If this were accomplished correctly, another light would come on beside a message asking the student to enter a test number; the test number activates the adaptive testing algorithm. For example, the microterminal may indicate that the student should locate and answer Item 30. Should the student incorrectly move the microfiche to the location of Item 31 in attempting to answer the test item, his/her response would not be accepted. Instead, a message light would come on, indicating that the student was at the wrong location. Correctly readjusting the microfiche location, the student would note that the correct location light was on; and the microterminal would accept the answer. Depending on feedback condition, the student may or may not be told if the response is correct. The student then would continue, complete the test, and the microterminal would indicate final score.

Taking the memory module, the student would report to the test center monitor and place the memory module in a management terminal connected to the central site computer. The student's total test data would then be transferred to permanent computer records. Immediate test analysis and results may be requested and received through the management terminal by the test monitor, if so desired.

In addition to test center activities, microterminals may be remotely located with memory modules delivered or mailed for later processing and reuse.

## Recommendations to Agencies Developing Adaptive Testing Terminals

It is recommended that other agencies or researchers interested in the development of microterminal-like devices for their own uses consider the following suggestions:

1. Begin with an extremely clear delineation of the requirements of your specific application.

2. Do not try to adapt an existing system design to another situation, unless the design requirements are compatible. For example, an agency desiring a device for adaptively testing student ability may not need a device like the AFHRL/TT microterminal, which was designed for an instructional environment; and paying for capabilities that are not utilized is unsound.

3. Use an interdisciplinary team to specify the design of the device. Infeasible goals for the device in terms of cost, size, or capability

would quickly be recognized by the computer systems designer or the financial manager.

4. Finally, keep abreast of the rapidly changing microprocessor technology. Designs are practically outmoded before they are even built. Capabilities are expanding geometrically while costs are decreasing arithmetically, yielding large increases in capability per dollar. However, it should be realized that at some point a design commitment must be made, irrespective of future technological advances.

Research and development in terminal design at AFHRL have demonstrated the feasibility of developing a low-cost testing microterminal for use in AIS instruction. Combined with other developments in the psychometrics of adaptive testing we appear to be at the edge of what Green (1970) predicted would be "the inevitable computer conquest of testing."

## References


Alpert, D., & Bitzer, D. L. Advances in computer-based education. *Science*, 1970, *167*, 1582-1590.

Bitzer, D., & Skaperdas, D. *The design of an economically viable large-scale computer-based education system* (CERL Report X-5). Champaign-Urbana, IL: University of Illinois, Computer-Based Education Laboratory, 1969.

Green, B. G., Jr. Comments on tailored testing. In W. H. Holtzman (Ed.), *Computer-assisted instruction, testing, and guidance*. New York: Harper & Row, 1970.

Kirby, P. J., & Gardner, E. M. *Microcomputer controlled, interactive testing terminal development* (AFHRL-TR-76-66). Lowry Air Force Base, CO: Air Force Human Resources Laboratory, Technical Training Division, 1976.

Martin, T. H., Stanford, M. D., Carlson, F. R., & Mann, W. C. *A policy assessment of priorities and function needs for the military computer-assisted instruction terminal* (ISI/RR-75-44). Marina del Rey, CA: University of Southern California, Information Sciences Institute, December 1975.


## Editor's Note

This paper was not formally presented at the Conference. However, since the microterminal was demonstrated during the Conference, this paper was included to properly document this important development.