MDS—A unique project in computer-assisted mathematics

by ROLFE H. NEWTON and PAUL W. VONHOF
Rochester Institute of Technology
Rochester, New York

INTRODUCTION—A MATHEMATICS DIAGNOSTIC SYSTEM?!!!

In the education of the deaf, are there problems so special that their solution justifies the use of a computer? And if there are such problems, how can the computer best be used to solve them? Early in the history of the National Technical Institute for the Deaf, its administrators voted “Yes” on the first question and “Let’s find out” on the second. As a result of these decisions, an IBM 1500 Instructional System was included in the Institute’s original home on the campus of the Rochester Institute of Technology.

The National Technical Institute for the Deaf (NTID), is the only institution devoted exclusively to education of the deaf in technical and scientific studies beyond the secondary level. The NTID is a division of the Rochester Institute of Technology, and NTID students studying at the degree-level attend classes that are predominately populated by “hearing” students, students without an aural impairment. RIT is justly proud of its status as the only conventional “hearing” campus in the nation to educate large numbers of deaf students.

There are, of course, special problems associated with providing the means by which the deaf student can adapt to the environment of the conventional classroom. The instructor’s lectures, inaudible to the deaf student, must be made meaningful by the use of interpreters and tutoring. The instructor must receive training in the consideration of the special needs of the deaf. Hearing students volunteer to make their lecture-notes available to the deaf by means of special self-duplicating notebooks. These are some of the devices that work toward placing the deaf degree-candidate on an equal basis with his hearing colleague.

But it is in preparing the NTID student for participation in regular RIT classes that the most interesting problems occur. The problem most directly related to pedagogy is inadequacy of educational background. The educational backgrounds of incoming NTID students generally contain serious deficits in the information, skills, and attitudes necessary to success in degree programs at RIT. It is the responsibility of NTID to rectify such instructional shortcomings before the deaf student is exposed to the RIT classroom. The responsibility for filling gaps in the student’s secondary education falls to the NTID Vestibule Program. The project described in this article was done by the Computer Assisted Instruction Section of NTID in support of the Vestibule Program.

But how did the remediation of instructional deficiencies become a project in computer-assisted instruction? What special characteristics of the needs of NTID students make them susceptible to fulfillment by computer-assisted instruction? What special attributes does the computer have that justifies its use in the diagnosis and treatment of ailing educational backgrounds?

Initially, the answers to these questions will be given in general terms. First let us say that the remediation of instructional deficiencies became a CAI project because (1) the nature of the problem seemed appropriate to solution by computer, and (2) money had been included in the budget for such an activity.

If the solution of an educational problem is to be appropriate to the computer, the problem should be complex enough that its solution requires the computer’s capacity for easily manipulating large blocks of data. In particular, the problem should need to apply the computer’s almost infinite capability for conditional branching—the ability to sift, winnow, and select output data—that depend on the nature of the input. (For example, the computer can pre-
scribe appropriate instruction if the student’s answer to a question indicated the need for such instruction. A different response to the same question might “branch” the student to a different remedial sequence on the same topic or to a new topic, depending on the correctness of the response.) It is, however, inappropriate to use the computer unless the computer is needed.

The implication of this stipulation that the computer’s data-handling capability be *needed* is that it is usually not appropriate to use CAI unless there is great need for the program to adapt itself to a highly disparate set of individual needs. A situation appropriate to use of CAI might be one in which the subject area is inordinately broad and/or the educational backgrounds of students are extremely diverse.

Such a set of conditions exists among students entering the NTID. Probably the most prevalent instructional deficiencies are within the subject-area of pre-college mathematics. Many students display serious shortcomings in this area of study so vitally important to success in scientific and technical subjects. But, in any large group of students, the defects generally appear over the entire range of the subject from arithmetic to analytic geometry, with no means of predicting what deficiencies any individual will display. When the range of potential deficiency encompasses the entire mathematics curriculum from grades 8 through 12, the problem of ferreting out specific lacks in the mathematical background of any individual student is formidable. General review of topic-areas over a range as broad as the secondary mathematics curriculum is too time-consuming and inefficient to be practical. Therefore, the diagnosis of problem-areas must pin-point all the specific bottlenecks in the mathematics behavior of each individual student. The objective of such a precise diagnosis is that the resulting remedial instruction will encourage the student to acquire all the missing learning behaviors and only those behaviors that are truly missing from his behavioral repertoire. The result of such a program is that the student works full-time in areas of deficiency and is never exposed to material in which he has demonstrated proficiency.

Achieving this goal under the conditions described in preceding paragraphs is a task that is peculiarly appropriate to the unique capabilities of a computer-based education system. So the first task assigned to the CAI Section of NTID was to design an instructional system that would diagnose and remediate defects in the mathematical backgrounds of incoming and prospective NTID students. The instructional program by which we are pinpointing defects in the skills that comprise secondary mathematics has been named a Mathematics Diagnostic System (MDS).

This article not only describes the rationale, design, and structure of the MDS, but also provides some insight into its historical and philosophical aspects. The article also contains evaluative information and conclusions resulting from the first field tests.

The next few paragraphs very briefly describe the events that led to the creation and utilization of our Mathematics Diagnostic System (MDS).

**HISTORY**

With the passage of Public Law 89-36 in 1965, the National Technical Institute for the Deaf came into being. By 1968 the Rochester Institute of Technology had been chosen as its home, and a small cadre of key faculty-staff personnel became the organizational nucleus. The Applied Science Building was designated the location for NTID until permanent housing could be completed. June, 1968, brought the appointment of a director for the as yet nonexistent CAI Section of the NTID. In July, 1968, IBM representatives installed the IBM 1500 Instructional System. Between July and September of 1968, technically-oriented people joined the section, and by October, 1968, there were, in addition to the director, an operations manager, a systems programmer, a computer operator, and a keypunch operator.

By November of 1968, RIT and NTID faculty members were trying their hands at writing instructional programs for CAI, and student-assistants were translating these programs into a computer language called Coursewriter II. Lacking mediation by trained CAI course development personnel, this method of producing CAI materials proved to be not entirely satisfactory. As yet there were no CAI course development people on board.

Meanwhile, in July, at about the same time the 1500 System was being installed, steps were being taken that would eventuate in the Mathematics Diagnostic System (MDS). Once secondary mathematics was identified as an area of study appropriate to the computer, Dr. Robert L. Gering, then director of the CAI project, was apprised of the need to upgrade the mathematical backgrounds of NTID students ultimately to be registered in RIT’s Calculus 75-101. Though he did not at that time know what the exact solution to such a monumental problem would be, Dr. Gering exhibited the educational acumen for which he is justly respected; he decided that, before a solution was attempted, the problem should be defined. He decided that before trying to provide
students with skills prerequisite to learning the calculus, these prerequisite skills had to be defined in detail and in behavioral terms.

This approach to producing a diagnostic-remedial instrument resulted in the Summer Mathematics Workshop in July, 1968. The Workshop was charged with defining the skills necessary to the study of Calculus 75–101 and therefore consisted of members of the RIT mathematics faculty as well as members of the NTID faculty and staff. The efforts of this group were reasonably successful; it identified 23 subject-matter areas required for success in studying the calculus, pointed to some of the skills required, and indicated the emphasis to be placed on the various topics. As might have been expected, this activity did not produce a detailed statement of terminal behaviors; what resulted was a fairly comprehensive statement of projected course content.

Until December, 1968, the Summer Mathematics Workshop was the last activity that led directly to the development of the MDS.

In December, 1968, I was fortunate (I think), to be appointed CAI Course Development Leader at the NTID. Before coming to the NTID, I had spent six years at Friden, Inc. (a division of the Singer Company), applying educational technology to the problems of training service technicians. Although the position at Friden had required the creation and implementation of multi-media instructional systems, use of CAI had not yet been made available to us. When the Eastman Kodak Company offered the opportunity to extend the scope of the job to include using the computer in education, I joined that company as an education communications specialist. While at Kodak, I developed some of the CAI techniques that later were to facilitate the creation of the MDS.

Although no signs of the existence of an MDS were to become visible for several months, during the next eight months every working hour was devoted to some aspect of the MDS. There were questions of rationale and instructional strategy to be decided. Objectives (terminal behaviors) and subobjectives (enabling behaviors) had to be decided upon. And above all, when problems of strategy, rationale, and purpose had been resolved, there remained the overriding urgent question, “Who will do the enormous amount of rather specialized work that is required by this project?”

For, contrary to the somewhat naive expectations of the NTID administrators, this was not a job to be done by one lone CAI course development specialist. Even with the cooperation of a few subject-matter experts, if this task were to be completed in time to have maximum effect, it would require a substantial number of trained instructional programmers working overtime. Getting additional people was a sticky problem, for the table of organization provided for but a limited number of full-time CAI personnel; and most of these were allocated to technical support of course development activities. And if authorization to expand the course development staff could be obtained, where would we find competent CAI instructional programmers who were available and who would fit into a limited budget? People capable of this kind of work are rare, usually they are already employed, and they are expensive. It was obvious that if instructional programmers were to be added to the staff, they would have to be “home grown”—trained at the NTID. A time-consuming process and not conducive to producing a Mathematics Diagnostic System.

But what if development of the MDS and the training of personnel could be done simultaneously? Why not a sort of “Learn as you earn” operation in which the steps in developing the MDS coincided with the acquisition of expertise in educational technology? In fact, could the production of the MDS be organized in such a way that it could be fragmented; so that it could be done by a large group of non-specialists having backgrounds appropriate to learning the rudiments of instructional programming? We decided that this approach was possible, and acted accordingly. By March, 1969, we had employed a group of ten people having scientific and/or mathematical backgrounds and had them working under the supervision of Mr. Alex Andres, an educational consultant from the University of Pittsburgh. The term of their employment was to end June 30, 1969. Because all but one member of the group were female, the group became known as the “Distaff Practicum”.

By July 1, the Distaff Practicum had, within the constraint of a predetermined logic, produced the first draft of the diagnostic portion of the MDS. In addition, they had produced first drafts of objectives and subobjectives. Enough training had occurred that, by excellence of performance and by expressed inclination, three members of the Practicum were considered to be usable on a full-time basis. So when the term of the Distaff Practicum ended, it had not only achieved its goals but had also provided the CAI section of NTID with an organizational nucleus of three excellent people. In addition, one member of the Practicum, a chemist, was retained by NTID’s Division of Instructional Affairs.

Previous paragraphs have presented the Distaff Practicum’s work as being not only design and production but also as a sort of boot-strap training activity; the members were on a “learn as you earn” basis.
Most of this training was of informal nature. It is, however, worth mentioning at this point that some formal training occurred when 8 to 10 days of the group’s time was spent in going through the Instructional Technology Workshop (ITW) produced by General Programmed Teaching. Bill Deterline, president of GPT, was the guiding spirit behind producing the ITW workshop.

Besides ITW, the only other formal training instruments made available to CAI instructional programmers at NTID have been standard texts by Skinner, Lysaught and Williams, Mager, Bloom, Markle, and others. One text, not so well known as the others, is this manual The Creation of Remedial Courses for CAI, written at NTID between January and June of 1969. While written primarily as a training instrument, it functions equally well as documentation of the principles, policies, and procedures used by CAI-NTID to ensure effective instruction by means of the computer.

We don’t make any extravagant claims for this little manual—it is just a “how to” book on causing the computer to be a tutor. Perhaps this much should be said on the subject of manuals that deal with the “nuts and bolts” of CAI instructional programming: They are scarce. The scarcity of such materials probably accounts for most of the interest shown on our manual. For example, I was surprised and flattered when Dr. Gabriel Ofiesh, Director of the Center for Educational Technology of Catholic University, requested multiple copies for use in graduate courses in educational technology. IBM has requested permission to use the manual in some of its training activities. If you have an interest in, or a use for, such a handbook, it will be sent to you on request.

Using the manual to set the ground-rules for completing the first rough approximation of the MDS, the months of July through September, 1969, were spent in revising and polishing existing diagnostic test items, formalizing remedial prescriptions, and translating the diagnostic portion of the MDS into computer language, Coursewriter II. (In the first version of MDS, remedial prescriptions were administered by an instructor-proctor.)

By the last week in September, the writing and programming of the MDS was sufficiently advanced that we were ready to work with our first group of test subjects; we were ready to begin the initial field test. On September 22, 1969, eight deaf students and one hearing student sat down at the computer terminals and began item 1 of segment 1 of the Mathematics Diagnostic System (MDS). Three months later, six of the nine were considered well-prepared for entry into Calculus 75-101. Because they have been in calculus for a short time, it is too early to report positive results, but the prognosis seems favorable.

While the students were working through the MDS during the fall quarter of the school year, they were producing performance records that would be the basis for revising, improving, and extending the MDS. The winter quarter of 1970 was spent in updating the MDS from the original version, now known as MDS-V1, to the more effective, more reliable, more completely computerized version designated MDS-V2. No new students were accepted during the winter quarter so that this major operation, the production of MDS-V2, could be as complete as possible by the time the next group of students arrived in March of 1970.

When RIT’s spring quarter began on March 23, there were 20 NTID students on-line with the first segments of the MDS-V2. For a number of reasons, among the best of which was that our computerated classroom has but 10 student-positions, the group was divided into two classes, each containing 10 students. Because MDS-V2 eliminates much of the administrative and clerical activity that had wasted the instructor’s time in MDS-V1, it was thought that the ratio of students to instructor could be raised from 4 to 1 in MDS-V1 to 10 to 1 in MDS-V2. Another significant difference in the administration of MDS-V2 was that, while remediation in MDS-V1 had been tutored by the course authors, the instructors for MDS-V2 would be members of the RIT and NTID mathematics faculties.

At this point in our narrative perhaps some mention must be made of the role of the instructor-proctor in the effective presentation of MDS-V2. As “proctor,” he keeps the mechanical and technical aspect of the course going smoothly; he sees that each student is having no difficulty with operating the terminals; he cooperates with the technical staff in operating the equipment; he evaluates records of student progress. These are the more mundane and mechanical features of the job that require some technical ability but do not evoke much creative effort.

But as “instructor” his knowledge of mathematics and his tutorial effectiveness may well be strained to the limit. This demand on the tutorial skill of the instructor-proctor results from the fact that the nature of the MDS produces a mode of instruction demanding that the full-time job of the teacher is to teach—not to present instructional materials. The computer presents diagnostic materials, prescribes remediation, and tests to see whether or not the desired learning behaviors have occurred. Because there is no such thing as a perfect program, some of the program must fail with some of the students. When
the program fails to produce the desired results, the student is directed by the program to consult the instructor. There is another, happier way that can produce tutorial activity; the program may have so stimulated a student's imagination and enthusiasm for the topic that he requires more information than has been provided. When this happens, the student may voluntarily seek the guidance of his instructor in going beyond the limits of his program. Whatever the reasons for the demands placed on his teaching skills, the instructor who operates in this setting is faced with an intense, varied, and—I should think—rewarding experience.

While the combined activities of human and machine are working to produce the most effective preparation for calculus that is within their power, records are being produced that will permit the effectiveness of the course to be evaluated. The results of MDS-V1, considered by its authors to be a first rough approximation, have been empirically evaluated and revised on the basis of student performance records. Further evaluation of MDS-V1 will be possible when it becomes clear how many of the difficulties experienced in calculus by MDS-V1 students may be related to lack of preparation—to failure of the MDS-V1. Such crudity of method was thought to be not only adequate to the circumstances of MDS-V1 but necessary if MDS-V2 were to appear on schedule.

Because MDS-V2 is considered to be reasonably close to a finished product, evaluation of this instrument will be carried out by the NTID's Research and Training staff. It is hoped that applying the talents of this group to determine factors of reliability and validity will produce data that are useful in improving subsequent versions of the MDS. Data for this project being gathered now during the spring quarter should produce usable results before the opening of the fall quarter in September, 1970. By the winter quarter (1970–1971), it is expected that the MDS will have reached a point of stabilization; that subsequent versions will be extensions and additions to MDS rather than revisions.

While determining the effectiveness of the MDS in educating deaf students is of first priority, there is reason to believe that it could be equally effective in performing its function for hearing students who anticipate entering first year calculus at RIT. To test this belief, during the 1970 summer quarter the MDS will be given to two groups of regular RIT students who would otherwise have been enrolled in pre-calculus math courses. If this experiment proves to be successful, it will lend a universality to the application of the MDS that will greatly enhance its economic feasibility—always an important factor in determining the practicality of any project in computerated education.

Practicality? Well, we here at the NTID think that the MDS, if not immediately justifiable on purely economic grounds, points the way to innovations in education of the deaf that will someday make CAI projects feasible from all points of view, educational as well as economical. Although it is much too early to label the MDS an unqualified success, its existence and apparent effectiveness are stimulating RIT and NTID faculty members to cooperate in similar projects. Several such projects are already under way; courses in thermodynamics and circuit design are being produced by the combined efforts of RIT faculty and the CAI Course Development that could herald RIT's emergence as a front-runner in the field of educational technology as well as in the education of the deaf. That is what we hope, and that is the goal toward which we shall continue to work.

What I have told you thus far has been a history and description of the first major project undertaken by the CAI Section of the National Technical Institute for the Deaf. The information you have is but part of a complete report on the MDS that includes a description of the underlying philosophy of course-design, the rationale and design-principle, and a report on initial field-tests. If any of those present are interested in these details, please leave your name and address and you will be sent a copy of the complete report.

Also included in the final report are details of the computing system by which the MDS is administered. This part of the report was prepared by Mr. Paul Vonhof, Technical Support Leader for NTID's CAI Section.

THE IBM 1500 INSTRUCTIONAL SYSTEM

The IBM 1500 Instructional System consists of two major elements: a "hardware" element and a "software" element. All the items of equipment—mechanical, electro-mechanical, electrical, and electronic—make up the hardware element of the 1500 System. The software element consists of the various computer programs that instruct the hardware in what it must do to achieve the results desired from the 1500 System. Both elements must be present if the system is to work; the hardware is just expensive junk without the software, and the software in meaningless symbology without the hardware. It takes both elements working together as a complete system to produce the instructional magic of which the System is capable.
For there is an element of magic about a machine-based instructional system that adapts itself to the specific needs of individual students; that makes allowances for individual differences in learning rates, entrance behaviors, and intellectual capacities; that can perform this service for as many as thirty-two students, not all of whom are working on the same course; that records and reproduces data on course-performance and student performance; that, in short, provides educational services the quality of which is limited only by the capability and imagination of the course-designer.

A machine such as we have been describing is, however, only a machine. In the final analysis, it is no better than the people who use it. Its effectiveness depends very much on the interaction between the people who consume its output, the people who control its operation, and the people who design and implement its input. These are the three general categories of users served by the System: the student, the instructor-proctor, and the course-author.

Of these three users, the student comes first, for he is the ultimate consumer, the reason for the existence of the System. The System prescribes or presents the instructional materials that uniquely fulfill the needs of the individual student. Instructions may reach the student as text on the CRT (cathode-ray tube) display. Or, the CRT may contain graphic information with which the student must interact. Student interaction with the CRT may require the use of the keyboard or the light-pen. The material presented to the student usually is contingent upon the nature of the preceding student response. It should be apparent, therefore, that input and output are each a part of a total continuum in which each determines the other. This characteristic of the System allows us to design courses having a high degree of adaptiveness to individual student-needs; it is the characteristic of the System that ensures the ability to provide instruction that is truly individualized.

To enhance the interactive nature of the CAI program, the System provides for student comments at any time. It also permits the student to request help from the instructor-proctor at any time the student thinks he needs it.

While the student interacts with the System, the instructor-proctor controls it. The duties of the instructor-proctor are covered in a fair amount of detail within the body of the text of this article. All that needs to be added is that, because students and course-authors may simultaneously be using the System, the proctor exerts control over the activities of both students and course-authors. The term "course-author" includes both the instructional programmer and the Coursewriter programmer. The System provides the author with services that are essential to him. It "assembles" his courses in a storage device—-assembles Coursewriter II into a format that can be interpreted by the machine. During the execution, it "interprets" his courses—implements machine-language instructions. It presents his courses as specified by the logic of his program. It analyzes progress. The author can make changes, additions, and deletions that are based on information received from the System itself.

All the activities and services to author, proctor, and student depend on human interaction with the hardware/software complex that is the IBM 1500 Instructional System. Having given some indication of what the System does, the remainder of this sup-

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Figure 1—Interrelationship of hardware components
plement describes its hardware and software components.

Hardware

It is the hardware of the System that is visible to the consumer or observer. He becomes familiar with the keyboards, the light-pen, the CRT display, and the film-strip projector—all of the facilities to be found in the computerized classroom. If he is a special friend of the operations manager, the observer may be allowed into the machine room, where he sees the devices by which course materials are stored—the magnetic disk drives and the magnetic tape units. He sees the card reader/punch by which course materials and computer software are created, assembled, and entered into the system. Also located in the machine room are the central processor and the station control unit, which directs the flow of course materials from the central processor to the appropriate terminals. A printer prepares performance recordings and other lists required in operating the System. (See Figure 1—a pictorial representation of how the various units relate to one another.)

Software

The 1500 software, expressed more formally as the 1500 Programming Systems, supports the 1500 hardware. It supervises and expedites all operations performed by the IBM 1500 Instructional System. In addition to the Coursewriter II System described in Appendix B, it includes six major programs that cooperate to keep the 1500 System operating efficiently. These programs are:

1. Main Control Programs.
2. Station Command Processing Programs.
3. CAI Processing Programs.
4. CAI Support Programs.
5. CAI Utility Programs.

The Main Control Programs are supervisory programs and form the basic operating system. These programs provide scheduling service to each instructional station that demands individualized service in handling inquiries and responses. They accumulate performance records and, when necessary, provide the user with diagnostic information about the operation. The operating system routinely stores and maintains all data needed by the programs executed under its control.

Station Command Processing Programs provide the language link between the system user and the computer. It facilitates all communications between the student terminal and the computer.

The CAI Processing Program is the major CAI application program, Coursewriter II. This program contains the Coursewriter II interpreter, which executes the user's assembled course and interacts with the students at the terminals. The CAI Processing Program can present textual material on the typewriter or display screen, present problems, process student responses, and operate the image projector. It performs arithmetic and logical operations. The CAI Processing Program also can be called upon to set and to interrogate a response timer, a device for recording the speed with which students respond to questions.

The Coursewriter II assembler translates Coursewriter II language statements into a form acceptable to the interpreter. The assembler is an important program within the CAI Support Programs section of the programming systems. Material can be inputted by means of either keyboard entry or card input. CAI Support Programs also allow for modifications to courses.

The CAI Utility Programs allow certain special background jobs to be done; these jobs support the operations for organizing courses on magnetic disk.

The System Utility Programs provide the functions necessary to preparing and maintaining systems package.

All of the software briefly described in the preceding paragraphs are necessary to control the multitude of operations demanded of the hardware. Students taking courses, authors entering Coursewriter statements, proctors sending supervisory commands, and operations people scheduling background jobs—each makes demands on the programs included in the 1500 Programming Systems.

SUMMARY

The combined facilities of the 1500 hardware and software present a versatile tool for instructional techniques. Thirty-two students, each working independently on a different problem or program, can time-share the system. Textual material, full-color film, and audio messages can be presented to the instructional stations under computer control. The computer automatically provides file maintenance to course and user's records. Course and student information is

From the collection of the Computer History Museum (www.computerhistory.org)
stored and retrieved as required by each station when it is serviced by the computer.

The operating system controls all interaction between the students and the course material being presented. The answer analysis of each problem and the infinite branching through the course is automatically performed by the CAI processing programs. The system allows for a standard dictionary of 128 characters, three special 128-character dictionaries, and three graphic sets of 64 symbols each. Course writer allows the system to display alternate dictionaries or graphics during course presentation. The interactive graphic capability allows the student to point at a position on the CRT and have the system determine the co-ordinates of the pen response. Finally, the system is flexible in its software capabilities and allows the user to make additions or extensions to it.

But, above all, the IBM 1500 Instructional System provides the course development specialist with a means of presenting the student with a course the effectiveness of which is limited only by human ingenuity. The potential of the System has only just been scratched; CAI itself is but an infant-giant.