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ABSTRACT

Costs and production requirements for developing "mainline," as distinguished from "adjunct" computer-assisted instruction (CAI), are discussed. "Mainline" programs are complete systems which teach an entire course, while "adjunct" programs supplement a regular course. Mainline CAI programs are expensive. A course equivalent to a three-credit semester course usually takes a year to write and another year to evaluate. Present costs range from at least $5,000 to $10,000 per student hour, and at best, they might be reduced to $3,000 an hour assuming the existence of languages, systems, and authoring techniques which are still under development. However, one possible individualized instruction environment which could accommodate the logistics of CAI is described and illustrated. It makes extensive use of program design and supplementary help by teaching assistants. This model, which uses as an example a course in college freshman mathematics, has been shown to be reasonably effective and to be more economical than traditional instruction. (JK)

JUSTIFYING CAI IN MAINLINE INSTRUCTION

TECHNICAL MEMO NO. 4

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Paper Presented at the NSF-Sponsored Conference on Computers in the Undergraduate Curricula

The University of Iowa

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By the way of a definition of terms, this paper involves justification which implies costs and benefits. It involves CAI which I define broadly to include problem solving and simulation as well as drill, tutorial and expository instruction. Finally, it involves something called "mainline instruction" which needs a detailed discussion. Few of the computer applications to the undergraduate curriculum presented at this conference represent what I mean by the term "mainline". The principal reason is that they are adjunct to, or supportive of, traditionally constituted classes and not supplantive of personnel or facilities in these courses. There is in reality a continuum between an adjunct computer application and what I choose to designate a "mainline" application. The two extremes differ generally in ease and cost of developing the program, system requirements, and economic potential to education.

In an earlier paper (Bunderson, 1969), two classes of CAI application were distinguished, which represent the extremes of this continuum. It is useful here to elaborate on the distinction between these two classes.

The first class of computer application, not considered as "mainline", is adjunct to, or supportive of, regular classroom or laboratory instruction. It is used for illustration of quantitative relationships, simple simulation, quickly generated drill, practice, or testing. Often it is a form of homework. Seldom does it deal with content which has not been introduced in class, but when new content is introduced, it is usually by a discovery approach which places a great deal of the instructional burden on the student rather than by a carefully designed tutorial or expository sequence.

Computer applications in this category are relatively quickly and easily generated by a faculty member. Alternately, they simply use available computer languages known by the student for problem solving or exploration of a set of examples or problems prepared by the instructor.

Systems requirements for these applications are not strict. Many of them are suitably accomplished with batch processing systems. When interactive systems are used, teletypes or selectric typewriters are usually suitable except when a simulation or illustration using computer graphics is employed. Languages like APL, BASIC, or standard compiler languages are most commonly used.

Programs which would be categorized in the second class supplant some or all of the usual teaching staff and classroom or laboratory facilities. This class of programs teaches new concepts and information, ideally in a highly effective and efficient manner. Students work at their own pace in an individualized manner. The computer may act as an evaluator, manager, tutor, simulator and drill-master, as well as a tool in problem solving.

The development of programs of this class is expensive and time consuming. It is most analogous to the development of a good textbook for mass dissemination, but there are additional complications in the development process due to instructional design and computer systems technologies.

System requirements imply a facility with multiple terminals in time sharing mode, providing system response time following each student entry in the order of .5 seconds. Cathode ray tube terminals, rather than teletypes, are highly desirable because of noise and speed considerations.

Applications in this second category have the potential of helping to solve major economic and logistic problems facing higher education which the adjunct use of the computer, representing an add-on cost, does not have.

There is no wish to downgrade the value of the first class of computer applications, indeed, applications all along the continuum between these two classes should be encouraged, for from the ferment in a creative teacher's mind as he mixes the disciplines of computer programming and modeling with an analysis of the structure of his discipline may come new ways to teach and new ways to comprehend his subject matter. Because of the important economic and educational consequences of the use of CAI in mainline instruction, however, the remainder of this paper will be concerned only with this type of application.

Producing CAI Programs for Mainline Instruction

The implementation of CAI in mainline instruction has proved to be a task of major magnitude. It requires the solution to a number of new problems, the mixture of several technologies, and a rethinking of the ways in which instruction is managed. It is costly. The first problem to be solved is how to design and develop high quality instructional programs that can carry an important instructional burden and can be disseminated. This has been a major emphasis of The University of Texas Computer-Assisted Instruction Laboratory. In 1965, we acquired a 1401 computer with four 1050 typewriter terminals driven by the Coursewriter I language. We attempted to implement tutorial programs in statistics, German, and mathematics, and simulation and drill programs in chemistry.

None of the tutorial efforts were successful. College instructors, given instruction in a supposedly simple tutorial language and a goal to produce usable CAI materials, were unable to produce satisfactory materials. We found that a research-based technology of instructional design was necessary and have developed a management and quality control model for CAI program development (Bunderson, 1970). We found that better terminals were necessary and acquired an IBM 1500 system. We also found that the author should not be burdened with, nor constrained by, the programming language and developed a team concept for curriculum development which consists of an author, an instructional designer, and a programmer. With more advanced CAI author languages having modular design and advanced instructional logics, we see that the programmer's role will lessen or disappear. Some instructional design know-how can also be "built into" the logics of an advanced author language, but instructional design expertise will always be necessary.

Despite expected improvements in instructional design and development systems and techniques, CAI course development will remain costly and time consuming. A fairly extensive CAI program (equivalent to a major portion of a 3 semester hour course) cannot be developed in much less than a year, and often takes longer. Evaluation and revision takes another year. Cost estimates for the production of high quality CAI programs vary widely. For example, in a study conducted for the Committee on Economic Development by Booz-Allen & Hamilton (1968), estimates of $30,000 per hour of tutorial instruction and $5,000 per hour of drill and practice were used as the basis for projections. These estimates were obtained from early experience in CAI at Stanford University.

They are quite high according to the experience of other CAI laboratories and probably include research and development costs. Based on the development of a CAI and multimedia physics course, Hansen, Dick & Lippert (1968) at Florida State University estimate $5,280 per hour of tutorial CAI with multimedia adjuncts and $2,860 per hour for revision. At The University of Texas we have tended to use more elaborate programming and answer-processing techniques, and have used the image projector extensively, while Florida State has restricted its development to CRT and teletype displays. Our expenses are consequently higher. For a program in mathematics prerequisite to freshman science, we estimate about $10,000 per student hour. This does not include extensive evaluation. Our most economical large-scale development effort was a program in English punctuation and usage. By starting with an existing programmed textbook, the costs were about $4,700 per hour and included a small-scale evaluation.

Based on the experience gained on these and other projects, we have learned how some costly aspects of development could be reduced by the application of better management, design, and production techniques and better CAI languages and systems. There are certain irreducible human costs for management, authoring, and evaluation-revision which cannot be automated, however, and for which there appear to be no dramatic shortcuts. The analogy to the writing and production of a first-rate textbook should be borne in mind when some computer salesman is trying to convince you that a CAI language will solve your curriculum development problems.

At best, we could now produce good tutorial CAI programs for somewhere in the neighborhood of $3,000 per hour. This assumes the existence of languages, systems, and authoring techniques that are still in the development stages.

There are a number of reasons why estimates for the production of CAI programs vary so widely. One is that a comparison may be made between what I have described above as a quickly prepared adjunct to regular instruction, rather than a "mainline" program. A carefully designed program to teach new concepts and principles may include several additional hours of material for every hour the average student takes because of branching and remedial options. More generally, the mix of drill versus simulation versus tutorial logics and the sophistication of the branching and answer analysis programming is an important source of variation. Programming costs for CAI language or utility programs may be included in some cost estimates and not in others. Rental rates for computer time used may vary widely, as may the amount of time used during development. Personnel and computer costs for evaluation studies may or may not be included. These can be major costs. Estimates also vary depending on the mix of media used in the instructional systems design. CAI may only be one component, reduced in some cases to testing and management. To my knowledge, no acceptable cost analysis of CAI curriculum development has been published which takes into account all of these variables.

The justification for the time and expense required to develop high quality programs in CAI comes from the potential for greatly increased effectiveness and the economics of mass distribution. CAI evaluation studies have shown that students usually do at least as well under CAI as under traditional methods. One should not expect to be able to measure striking improvements in the performance of the better college students by means of CAI. "A" students will work until they get "A"s, "B" students, "B"s, and other students until they reach their level of aspiration. It is difficult to measure the time and effort they spend outside of class or outside of

CAI to accomplish this. The most striking finding in CAI evaluation studies has been that students are able to achieve educational objectives in much less time. Savings of 40% or more are not uncommon (Ford & Slough, 1970; Homeyer, 1970; Hollen, Bunderson & Dunham, 1968). As discussed later in this paper, this increased efficiency has important economic implications for education. Another important finding is that lower ability students are able to achieve important performance gains by means of CAI, often approaching the same levels as the higher ability students.

The sources of increased efficiency and effectiveness of a good CAI program probably reside in two classes of variables. The first class is related to the systematic design procedure used in the development and refinement of mainline CAI programs, and the second in the dynamic communication between student and subject matter provided by the CAI interface.

The increased effectiveness related to the dynamic interface seems to be rooted in such fundamental variables as the requirement for active response, the opportunity for immediate feedback, the use of appropriate media and method for each objective. In addition, increased motivation on the part of the student has been observed, due perhaps to the moving, dynamic aspects of the interchange, and the use of simulation, on-line problem solving, graphics, and other unique contributions of the computer. The opportunity for true individualization, on the model of one tutor for each student, is also a source of increased effectiveness. Individualization occurs not only in the pace and schedule a student may follow, but through adaptive branching on the basis of achievement differences, predictable errors, and potentially even on the basis of learning styles.

These advantages cannot fully be exploited without the application of a systematic, research-based design procedure to curriculum development, testing, and revision. It is beyond the scope of this paper to describe the activities and products of such a systematic design approach in detail. It is so fundamental to the "Justification of Mainline CAI", however, that a quick overview must be provided. This can be accomplished by reference to Table I, which lists the "products" of each stage of instructional design. These products become the public documents and manuals which describe the program in order to assist decision making about acquisition of the program and to facilitate the actual use of the program. The products also lead to the final program materials.

Table I lists these products, classified into five categories. These categories roughly define the different "audiences" for which instructional design products and documentation are intended.

The first category, brochure and/or proposal information, is intended for a funding agency when the program has not yet been developed, and for potential users when the program is complete. It features a discussion of the institutional needs which generate problems which a carefully engineered CAI program or system can potentially solve. The societal needs surrounding this problem may also be discussed in a proposal to some socially conscious funding source. The goals are defined by presenting an analysis of the subject matter to be programmed and a description of the "model" for student mastery which will be the "output" of the program. The "input" is roughly defined by describing the target population and the prerequisites. A general description of the approach selected to achieve the instructional goal follows, with a justification for the choice of CAI over other alternatives.

TABLE I

Documentation and Other Products of Instructional Design

I. Brochure and proposal information

Societal needs

Institutional needs

Goals: subject matter analysis and description of the model for student mastery

General description of approach and justification for CAI vs. other alternatives

Some evaluative data

II. Design architecture and rationale

Performance objectives

Analysis of objectives and learning hierarchy

Synthesis of course structure and restrictions

Individualizing mechanisms (flowcharts)

Tests to measure objectives

Specification of display and response conventions for each subordinate objective, also constraints adapted to accommodate system limitations

Technical evaluation and research reports

III. Manuscript or author's draft

Program steps and step formats; subroutines with associated curriculum text files

IV. Technical documentation of final program components

Program documentation for systems programmers

Documentation for operations:

Operator and proctor guides

Student manuals

V. Production management plans for the production of all products listed above

The justification for CAI program development features an analysis of potential benefits and potential costs. The benefits derive from the increased effectiveness due to the interactive interface as described above and to the advantages which can be gained by systematic analysis and design. The analysis of subject matter and goal specification clarifies what we mean by the subject matter, and helps eliminate the irrelevant. The writing of performance objectives and the behavioral analysis further specifies the instructional goals and makes them operational, and hence makes the instruction testable and improvable. It is primarily through the application of this systematic, empirical, interactive design process that education can achieve dramatic gains. Such a technology of instruction and design, coupled with the hardware and software tools to implement it, can enable education to make the enormous leap from the labor intensive, low yield field it now represents, similar in many respects to agriculture 200 years ago, to a system of greatly increased productivity and throughput. Human values dear to us all can be maintained and enhanced by appropriate design and by definition of the roles of the new breed of teacher in the system.

Improvability, made possible by continual cycles of evaluation and revision based on computer-maintained records of student achievement of program objectives, is another source of increased effectiveness. For college students, increased effectiveness will usually translate into substantially reduced time to learn objectives, although it will often increase measured performance as well (Ford & Slough, 1970). In the cost analysis which will form the part of a good justification, reduced learning time becomes one of the most important parameters. This paper concludes with an illustrative cost analysis.

The second category in Table I, "Design Architecture and Rationale", represents the heart of the instructional designer's task. Documentation is maintained of the performance objectives, behavioral analysis, flowcharts to describe individualizing mechanisms, and decisions as to the specification of display and response conditions for each objective. These documents, along with research data from evaluation and research studies using the developed program, are intended for the author's or instructional designer's professional colleagues, for his design might represent a useful clarification or contribution to understanding the structure of some part of his discipline and its pedagogy. This information is also of great relevance to the more sophisticated potential user.

The manuscript or author's draft, category III on Table I, is intended for the author and the production personnel with whom he must communicate. These include media specialists, programmers, and perhaps typists if a part of the final program is printed. The author's draft is also the minimum documentation needed to transplant the program to a CAI system other than the one for which it was originally designed.

The technical documentation of final program components is designed for programmers and operators at a user institution. A CAI program designed for mainline instruction is a large and complex operating system, and its maintenance and updating is no small matter any less than the maintenance and updating of the latest version of FORTRAN at an institution is a small matter. Improvements in CAI languages and operating systems and efforts at standardization will ameliorate this problem.

Documentation under category V in Table I is not seen by any outside audience except perhaps the funding agency. A production management plan is essential however. CAI program development projects have a habit of going beyond their deadlines and their budgets.

At this point you are probably saying to yourselves that the magnitude of the development task outlined above goes well beyond your available time and resources. You may not be sure that development for mass dissemination of this sort is even an appropriate role for colleges and universities, but rather should be accomplished by publishers or by major government-sponsored consortia. The development patterns for this type of curricula which will ultimately emerge are not yet clear. A study currently being conducted by the RAND Corporation has addressed itself to this matter and may shed important light on it when published later this year.

For those of you who have the confidence to undertake a major CAI development project, let me encourage you to investigate and use such of the instructional design procedures and techniques implied by Table I which you feel are appropriate to your situation. Also let me mention a less expensive and reasonably effective alternate procedure which has been moderately successful at The University of Texas and elsewhere. This is the "highly motivated graduate student method". A number of graduate students in science and language education and chemistry have developed and in some cases evaluated CAI programs as a part of their Ph.D. dissertations (Abboud, 1970; Castleberry, 1969; Culp, 1969; Homeyer, 1970). In no case were these projects completed courses, however. Nevertheless, give a good graduate student a little training in instructional design, and allow him to "bootleg" computer time, staff consultant time, and supplies. Give him appropriate faculty guidance. Under these circumstances, students with good intuitions about student needs, gained through teaching experience, can produce effective CAI programs (though perhaps their programs will not be efficient nor ready to disseminate). Without genuine released time, without the sacrifice of home life, faculty members cannot so perform, and should concern themselves with adjunct rather than mainline efforts. With improvements in our understanding of the systems organization of courses, author systems to implement easier course production, and free access to good CAI hardware, faculty authors who have gained a knowledge of instructional design may be able to produce CAI programs on the publisher and royalty model now effective for textbook production.

Organizational and Facilities Problems in the Implementation of Mainline CAI

While the primary goal of The University of Texas CAI Lab has been research with and about CAI and instructional design, a secondary goal has been development and implementation. I will discuss two CAI programs in high need areas which we have explored, give reasons why we have not yet succeeded in achieving operational CAI in these areas, and project requirements for successful mass implementation of CAI in mainline instruction.

The problem which generated two of our major curriculum development efforts was the wide background deficiencies among freshman students in mathematics and English. Freshman students in chemistry, physics, and other science courses fail or have difficulty because they are deficient in algorithmic skills related to exponential and scientific notation, logarithms, unit conversions, and other skills. English students are deficient in a variety of composition skills, among them being basic skills in punctuation and usage. Not unlike other universities, our College of Arts and Sciences would like to regard these deficiences as the responsibility of the student and his high school, and not give credit instruction for them. This stance does not make the problem go away, so large numbers of teaching assistants and a few professors are employed in large freshman sections to provide instruction of varying degrees of quality covering varying subsets of these and other topics which interest them.

Observing this problem a few years ago, we undertook to develop tutorial CAI courses which would diagnose a student's deficiencies and instruct him individually until he had corrected each diagnosed deficiency. Because of the enormous variation in patterns of deficiency we had observed in our pretesting, such a diagnostic, individualized system seemed very advantageous. The Preskills Mathematics program was developed in cooperation with Science Research Associates, and the Punctuation and Usage Course with McGraw-Hill Book Company. The philosophy at that time was to develop individualized systems which could be assigned by faculty members in a manner analogous to laboratory or home work. Thus the materials were designed as major adjuncts to regular courses.

It has been exceptionally difficult to evaluate these programs. Due to their adjunct and experimental nature, faculty members have been adverse to require them of their students, and repeatedly have put it on a voluntary basis with no credit and no penalty attached. CAI can never succeed if it does not have at least the status of a term paper. Students will spend their time meeting those deadlines and demands which have the best chance of paying off for them in the context of their immediate course requirements. Despite these problems, we have had enough cooperation from enough faculty members to have obtained extensive evaluation data based on over 1,200 students for the mathematics course, and over 100 for the English course. Except among engineering students for the math course, there was a strong pattern of deficiencies among the students who took the program. The program was well suited to the Arts & Sciences student population at The University of Texas, a large state university.

Students are able to progress rapidly in learning those skills in which they are diagnosed as being deficient. Students at all levels of ability, except the highest, showed gain from pre-test to post-test, with the more deficient students showing the most gain. Attitude toward the experience varied widely, with most students being favorably disposed. We have some evidence that the more negative attitudes were found among the poorer students, whose adjustment to any kind of concentrated study has not been good.

Despite the demonstrated need for these programs, and their demonstrated effectiveness and efficiency, there are serious obstacles standing in the way of their implementation. The most obvious problem is the lack of a large, multiple terminal CAI facility sufficient to handle the thousands of students in Arts and Sciences who need basic instruction in math and English. Our IBM 1500 system is a small 12 terminal configuration dedicated to research and development. A service-oriented system with clusters of terminals located conveniently for the science and English students is necessary. Despite early problems in getting students to take the math course on other than a voluntary basis, we now have enough interest and support from science faculty members that many hundreds of students would be assigned to use the programs if terminal time were available. There are other more subtle problems to be overcome, however, before these or any similar CAI programs could be implemented in mainline instruction.

First of all, there is no clear place for the Preskills mathematics program in the science courses at The University of Texas. The commitment of faculty members in these fields is to the concepts related to their own field of study. They recognize the deficiencies in mathematics which their students possess; however, they do not always feel that it is their job to take their time and the students' time to refresh the weaker students on these skills. Ideally, these should be taught in the Mathematics Department, but faculty in this department may regard these fundamental skills as not too interesting because of their desire to teach the conceptual foundations for upper division mathematics. The facility with notation and manipulation required by the student in his other university work is regarded with a certain amount of distaste by professors and teaching assistants (TAs) whose interests and opportunities for advancement are centered in the advanced concepts of graduate mathematics. A similar problem was found in our attempts to evaluate the English skills program. While we could demonstrate the serious deficiencies in punctuation and usage skills among freshmen and show the beneficial gains due to the use of our program, the faculty members and TAs are interested in graduate work in literature, or in the more creative aspects of composition, and not in the foundation skills. I do not wish to be critical of teachers in these departments. They are certainly right in wanting to teach university rather than high school topics. They have a difficult problem.

Summarzing the organizational and facilities obstacles to implementation, we find three principal barriers:

1. The lack of a cost effective, service-oriented terminal facility.
2. The problem of "grafting on" an individualized, adjunct course to the lock-step, tightly scheduled course structure of universities.
3. The lack of fundamental interest and incentive of teaching assistants and other faculty in meeting the remedial needs of freshman students.

The function of freshman courses as a source of training and financial support for graduate students is the heart of this third problem. Since four year colleges and junior colleges are not faced with this problem, they may possess the best environment for early implementation of mainline CAI in topics like preskills math and English.

There are a number of proposed solutions to the facilities problem. Alpert and Bitzer (1970) have proposed a 4000 terminal system at the University of Illinois, requiring a capital investment in the order of $12,000,000, but providing CAI service for from $.34 to $.68 per student hour. Because of the time and costs involved in curriculum development to keep such a monster system busy, and because I am skeptical about very complex systems working reliably, I prefer the notion of a small computer driving a cluster of 30 to 100 CRT terminals, and requiring a capital investment of around $200,000. Given a sizable market, such systems are within the state of the art today. Such a system could be completely justified for the administration of a small number of courses, which are feasible to develop soon, and would cost somewhere between $.40 to $1.20 per student hour. CRTs are necessary because of their greater display speed, and their display capabilities which reduce the need for communication by character strings. These capabilities translate into shorter mean time to complete the program. I believe that the so-called inexpensive teletype will soon be revealed to be a costly, as well as noisy and inelegant, terminal for CAI. Since with CRTs and good design, one hour of CAI may produce results equivalent to two or more classroom hours, $.40 to $1.20 per hour becomes highly competitive under an appropriate organizational model for instruction

An Organizational Model for Implementing Mainline CAI

Individualized or individually prescribed instruction cannot coexist with the lock-step, tightly scheduled semester or trimester organization in use by most institutions of higher education. The smallest unit within which individualization can be managed without severe logistics difficulties is the course. Thus, to be successful, our Math and English CAI materials must either be expanded into complete courses or be incorporated into a modular, self-paced system for teaching those courses, with a heavier mix of other media and teachers where CAI is inappropriate or undeveloped.

The concept of what constitutes a "course", however, must undergo some important changes. The most fundamental change is that the course must be redefined in terms of output instead of input. It must be defined by what the student is able to do at the end, that is, in terms of measurable performance objectives instead of in terms of how much time he spends or in terms of what the teacher tries to cover. Computerized testing, in particular through the use of simulation, can help counter the criticism that behavioral or performance objectives often turn out to measure trivial aspects of what a teacher regards as important. Performances requiring subjective judgments on the part of the teacher, quantified by rating scales, can also be used.

A modular, self-paced system of instructional activities using some form of CAI for some or all modules can be put on a pass-fail basis, with the successful demonstration of competence on some set of objectives determining whether or not a student passes. Alternately, a minimum set of objectives achieved would lead to a "C", a larger set a "B", and the larger set plus a project or paper an"A".

In the CAI applications in freshman math and English described above, we would not deem it desirable to have no human teachers in the system. If we were to develop a course in precalculus mathematics, for example, using our current Preskills course as a part of the system, we would want mathematics teaching assistants to play an important role, though in a much reduced teacher-student ratio.

Consider for example a 5 credit hour course in precalculus mathematics. The equivalent course in traditional form would deal with a 3 hour lecture introduction to the concepts of set, relation and function, and conceptual development of elementary polynomial, logarithmic, exponential, and trigonometric functions. A 2 hour laboratory would deal with the manipulative skills related to the elementary functions, and would relate itself to future science courses in which the student will need these skills. A professor might present the lectures, and a TA the laboratory.

In the CAI version, one professor could manage an entire system for teaching one or two thousand students. He would be able to do this by concerning himself with the evaluation of the system for possible improvements, and with the direction of a small corps of from 4 to 7 TAs. Instruction would be accomplished in a single large terminal and study room equipped with 30 to 40 CAI terminals, waiting-study areas, and 2 or 3 cubicles for small conferences between a TA and a few students.

The TAs would know the CAI curriculum material well, and be able to trouble-shoot and help students with mechanical and conceptual problems. They could also schedule small conferences with students where difficulties or advanced needs were found. This close work with students would enable the TAs, meeting on a regular basis with the professor, to communicate weaknesses in the system to him for improvement on the next revision of the course. Detailed computer analysis of student responses and achievement records would also help him define improvements to the system. He would also instruct the TAs in the use of the system and in their own mathematical understanding.

Self-paced instruction courses, using student proctors in this manner but not often using CAI, have been developed successfully at a number of universities here and abroad.

A Cost-Comparison Between CAI and a Traditional Course

It is possible to compare the costs of implementing a traditionally administered course in precalculus mathematics with the modular, self-paced, TA monitored CAI system described above. While such an analysis will not generalize to all educational institutions, the parameters and logic of the analysis are general, and perhaps can serve as a model for costing other well-defined CAI applicaltions.

Consider first the cost of traditionally administered instruction (TAI). Assume a section of 30 students wherein a professor lectures for 3 hours and a TA provides 2 hours of lab work on applications of elementary functions. This model has built-in effectiveness assumptions in the use of an assistant professor (@ $12,000 for 9 months), and the use of a small class size. At The University of Texas there is no 2 hour lab, the lecture is handled by a TA, section sizes approximate 50, and there is only 3 hours of credit. The students pay for any reduction in effectiveness. At a college, the course would more often be 5 hours and there is no cheap TA labor. The assumptions for costing this mode of instruction are summarized as follows:

Costs for one Mathematics Section, Traditionally Administered

5 credit hours, one semester in duration

3 lecture, assistant professor @ $2,000 (9 hr./semester load)

2 lab, teaching assistant @ $500 (12 hrs./semester load)

Overhead, assume 40% of personnel costs

Effectiveness Assumptions

Use professors rather than TAs exclusively

Use sections of 30 students

The overhead item listed above may vary widely from one institution to another. It is hard to identify through normal University accounting procedures. The 40% was chosen as a conservative estimate of the fluctuating rate applied to grants by the University of Texas. This overhead is accounted primarily to maintenance, operations, and usage related to buildings and equipment (55% of the 40%), general and administration, including departmental administration (27%), benefits (11%), and library and student services (7%). In discussions with personnel from our Auditor's office, I was informed that the overhead for classroom instruction was probably higher than the research overhead, and that the overhead for the CAI operation would probably be lower. The 40%, therefore, is a conservative estimate in all respects.

Consider next the cost for a self-paced, TA monitored system of CAI programs to teach this same 5 hour course. Assume that 1500 students will be serviced per two-semester period. The assumptions are as follows:

Costs for 1500 Math Students, TA Monitored CAI

Personnel

1 assistant professor, 1/2 time, 2 semesters - $6,000

teaching assistants

(assume each can monitor 15 students/hour; assume students can schedule 3 hours/week)

2.5 full-time equivalents, 2 semesters - $15,000

Overhead @ 40% of wages and salaries

CAI costs

1500 students x 30 hours

Assume $2 per student hour

There are certain logistic assumptions listed above which have relevance to the costs of CAI. Recall that the roles of the personnel are quite different from their TAI counterparts. The professor is primarily a manager, although he may serve an instructional design and evaluation function. The TAs are trouble shooters, tutors, and students in their own right as they learn on the job and in the weekly seminar with the professor about the method and the mathematics it teaches. That a TA can monitor 15 students per hour is a function of the quality of the course and of the students. A well debugged, tested, and revised course guides the student with little outside assistance. Lower ability students need more help from the TAs, and should not be scheduled all at once. That a student can schedule 3 hours per week is a function of the number of terminals and the number of courses being serviced each week.

These logistic assumptions lead to the conclusion that 2.5 TAs @ 40 hours per week can monitor 1500 student hours per week. If each student schedules 3 hours, 500 students can be serviced per week. If students complete the course in 30 terminal hours, 500 students, on the average, will finish in 10 weeks. In 30 weeks, or two semesters, 1500 could finish with no additional personnel requirements for monitoring, grading, and other functions.

The assumption that the mean time to complete the CAI course will be 30 hours is an estimate based on our experience with the Preskills math program. This parameter is at any rate under control of the designer. He can move toward computer-managed instruction by pushing more work home with the student rather than onto the terminal. He can use an analysis of student records of progress through the course to locate time consuming parts and redesign them. Even though 30 hours is less than half of the 75 or 80 hours of classroom instruction required by TAI, I feel very confident in stating that, through good instructional design, the course could be taught by the model described in an average of 30 terminal hours without loss in effectiveness.

The figure of $2 per student hour can be achieved today using a stripped down IBM 1500 system with 32 terminals if each terminal were scheduled 2,000 hours per year. It is thus a very conservative estimate. The state of the art in the design of small systems having similar capabilities can greatly reduce this figure. For example, TICCET system developed by MITRE Corporation (Stetten, 1970) can probably provide service for less than $1 per student hour. (They claim 20¢ to 40¢.)

A comparison between the costs of CAI and TAI modes of instruction based on these assumptions is provided in Table II. The calculations are straightforward and speak for themselves.

The lower portion of Table II speaks to the relative costs after 5 years, assuming salary increases of 8% per year. Bowen (1970) projects a 4% increase per year for teaching personnel in higher education assuming no inflation. Four percent inflation per year is also assumed in the 8% figure used in Table II. The CAI equipment, if amortized over 5 years, will be paid off. Maintenance would increase, as would salaries for operators, but even if maintenance quadruples and operations staff salaries double, the cost per student hour would still be reduced to 10¢ per hour.

Note that the analysis does not include costs for CAI course development. If the 30 hour CAI course could be developed for $3,000 per hour, development would cost $90,000. With widespread dissemination so that the course could be used by 10,000 students per year, in 3 years the costs would be recovered if a profit of only $3 per student were sought. Production and distribution costs added to this might leave the charge for the student about the same as for a textbook. The institution might be charged an additional sum by a private or non-profit distributor for installation of the program, training, user documentation, and update services.

The analysis reported here does not include equipping and maintaining the CAI terminal room, but neither does it consider the cost of 25 classrooms for TAI.

TABLE II

Costs of CAI vs. TAI

for 1500 Mathematics Students in 2 Semesters

TAI		CAI	
Personnel	$2,500	Personnel	$21,000
Overhead @ 40%	1,000	Overhead @ 40%	8,400
	$3,500		$29,400
For 50 Sections of 30 Students	x50	1500 Students, 30 Terminal Hours @ $2.00/hour	90,000
	$175,000		$119,400

5 Year Projections
8% Increase in Personnel Costs
Equipment Depreciation

TAI		CAI	
Personnel	$3,673	Personnel	$30,856
Overhead @ 40%	1,469	Overhead @ 40%	12,342
	$5,142		$43,198
50 Sections	x50	Maintenance and Operations @ 10¢/hour 1500 x 30 x .10	4,500
	$257,100		$47,698

In reflecting on the implications of Table II, it is not probable that personnel at universities will truly be supplanted. Most TAs may be supplanted from their roles as classroom teachers in lower-division mathematics, but can be used in higher-level courses or paid to develop materials as a member of an authoring team. They can also be given fellowships. What is really being supplanted is an inefficient mode of instruction. The net effect will most often be a reduction in the expansion of faculty in the face of mounting enrollments, rather than the loss of jobs. At junior colleges it is possible that personnel, and certainly classroom space, would be supplanted, although new jobs would be created, including those of instructional manager and instructional designer.

Summary

In this paper some of the costs and production requirements for developing mainline, as distinguished from adjunct, CAI programs were discussed. A possible individualized instructional environment which could accommodate the logistics of CAI was described and illustrated. The economic advantages of such a model were illustrated by reference to an example in freshman mathematics.

It is hoped that the production models and cost analysis models presented in this paper will facilitate planning for the implementation of mainline CAI.

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