Educational requirements for a student-subject matter interface

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INTRODUCTION

The problem of communicating knowledge, skills, and attitudes to students has concerned educators for centuries. Earlier debates centered around the use of lecture versus discussion methods, the use of the textbook, workbooks, etc. In general, these earlier "media" of instruction were passive display devices requiring relatively little response involvement on the part of the learner. Recent advances in communications technology have revived interest in the question of the media of instruction and have broadened the avenues through which the learner may come into contact with his subject. In general, the newer instructional display and response devices are "active" as opposed to earlier more passive media. They provide for the adaptation of the instructional materials to the characteristics of the individual learner as contrasted with earlier "static" display devices, and require active response involvement by the learner in the process of instruction. These devices allow the learner to interact overtly with his subject.

Paralleling the recent technological developments in the area of computers and communications systems, there has been an emerging technology of learning and instruction. A new breed of educational psychologist has emerged which is dedicated to the proposition that education can and should be a science and not an art. Armed with the tools of behaviorism and operationalism, he critically analyzes complex subject matters, behaviorally defines and evaluates instructional objectives, systematically arranges instructional experiences to optimize learning, and applies theoretical models to the process of instruction. It is not surprising that these investigators should also address themselves to the problem of the optimization of the modes of communication used in instruction.

In computer-assisted instruction (CAI) the term "student-subject matter interface" describes the devices such as two-way typewriter, cathode ray tube, slide projector, tape recorder, etc., through which the student interacts with the subject matter. The two major dimensions of the interface are its stimulus display capabilities and its response processing capabilities.* Stimulus display capability refers to the varieties of ways that a subject matter can be displayed to a learner through the interface. Response processing refers to the variety of student responses which can be detected by the interface and processed by a computer. The present paper will examine several classes of educational variables which determine the characteristics of an effective interface. The four categories of educational variables which must be considered in the design of the interface are the characteristics of the subject matter, the characteristics of the learner, the nature of the instructional process, and the objectives of instruction.

Subject matter characteristics

Perhaps one of the more obvious factors affecting the capabilities which must be available in an interface is the subject to be taught. Different subjects require different interface characteristics. The most extensive study of the relationships between subject matter characteristics and interface requirements

*The stimulus display and response processing capabilities of a CAI system are not solely dependent on the interface device. These capabilities are usually a joint function of both the interface, the computer, and the software. The lack of an important display or response processing feature may be due to a limitation in the interface device, the computer, the software, or some combination of several of these factors. Regardless of the source of the deficiency the net effect on students is the same. The lack of an audio capability may be just as serious whether it results from an inadequate recording and playback system, a limitation of the central computer, or a lack of available software. The purpose of this paper is not to analyze how the various display and response processing capabilities may be implemented technologically. This would be a task for the engineer and computer scientist. The present paper will be concerned with the educational variables which must be considered in establishing specifications for a student-subject matter interface.
has been made by Glaser, Ramage, and Lipson. These investigators conducted an extensive analysis of the behaviors involved in learning three subjects: elementary mathematics, elementary reading, and elementary science. The analysis was based on an actual survey of instructional programs and curricula used in the schools. From this task analysis Glaser and his associates were able to draw up a set of specifications for an instructional environment to teach each of the subjects. A summary of their findings is shown in Table 1. The table shows the wide variety of interface requirements for elementary mathematics, reading, and science subjects. Science appears to provide the greatest challenge to the development of an instructional environment. For example, science instruction often requires the visual display of natural phenomena and simulation pictures. One can't help but note the obvious advantages of a closed circuit television capability as part of the interface for displaying scientific phenomena. Science instruction also appears to place rather sizable demands on the interface in the area of response processing, thus, there are times when the learner may need to manipulate controls, construct graphs and figures, etc.

Some of the requirements listed in Table I are easier to implement than others. For example, our experience at the Penn State CAI Laboratory indicates that it is a relatively simple matter to provide various types of manipulanda for the student at the

<table>
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*Instructional functions which probably can be implemented in a CAI system within the foreseeable future.
One conclusion seems evident from an examination of Table I. Existing interface capabilities cannot accommodate all of the requirements of these subject matters as they are presently taught in the schools. Furthermore, it is doubtful whether some of these capabilities (voice detection for example) will be feasible in the near future. This observation is not surprising in view of the fact that most classroom instruction provides a wide variety of experiences for the learner. It must be remembered that Glaser’s analysis represents the total spectrum of instructional experiences and few investigators expect CAI to reproduce all aspects of these experiences. The rather marked discrepancies between the requirements of Table I, and current interface capabilities reemphasizes the widely held view that CAI must be supplementary to existing instructional techniques. Mitzel has pointed out that one of the most important problems to be solved in the development of CAI is the determination of the appropriate “mix” between computer-mediated instruction and components of instruction which are mediated by the teacher or by still other means such as educational television. It is likely that the nature of the “mix” will be determined in part by the kinds of instructional experiences which can be efficiently and effectively provided by the CAI interface. Those experiences which cannot be implemented via CAI must be provided by the teacher or by some other means.

Mathematics frequently involves the display of relatively complex equations and symbolic configurations containing subscripts and superscripts. The typewriter is not efficient in dealing with such materials, and may actually interfere with learning when the student is confronted with the complex task of inputting symbolic material. The cathode ray tube display may alleviate this problem to some extent, but the problem of inputting symbolic material through a keyboard still remains. It is noteworthy that even the most experienced typists have difficulty in reproducing material containing many symbols and equations. IBM attempted to solve this problem by developing a mathematics typehead and a keyboard mask to aid the student in identifying the new character set. Our experience with this device at Penn State suggests that it is satisfactory for relatively short responses, but that it does not greatly simplify the inputting task for longer symbolic responses. IBM’s discontinuation of the mathematics typehead for its 1050 communications system suggests that they may have had similar misgivings concerning this procedure.

Mathematics is not the only subject matter which presents special problems for the CAI interface. Several studies conducted at Penn State (Wodtke and Gilman, Wodtke, Gilman, and Logan), demonstrate that the typewriter is an inefficient interface for highly verbal subjects at the college level. When identical instructional programs were administered on-terminal and off-terminal there was an increase in instructional time of 25 per cent in the on-terminal group with no commensurate increase in learning. In a second study employing a still more highly verbal program, the increase in instructional time was 75 per cent for the on-terminal group with no significant difference in learning when compared to the off-terminal group. The largest portion of this time decrement is undoubtedly due to the slow type-out rate of the typewriter (approximately 120 words per minute).
which is substantially slower than the normal reading speed of the typical high school or college student.

In an area of research where variations in instruction typically produce only small gains in student achievement, a time loss of 25 per cent represents a substantial decrement. The time could be used to give students more practice, instruction on new material, or practice on transfer problems. In addition to the gains in student learning which might accrue from a more efficient use of instructional time, there are also economic considerations in the cost of computer time, tie-lines, and other "hidden" costs involved in the preparation of courses. All other things being equal, by employing an interface which would decrease instructional time by 25 per cent without reducing the amount learned, four students could be taught for every three taught by means of a typewriter interface.

From the college student's point of view, learning at a typewriter terminal is not self-paced instruction since he must slow down his normal rate of work. Pacing instruction below a student's optimal rate could produce boredom, negativism, and avoidance of CAI as an aid to learning. This is not an uncommon finding when the pace of classroom instruction by the lecture method is too slow for the brighter students. The advent of the cathode ray tube display device should speed up substantially the display of verbal information to students.

The results obtained with the typewriter interface at Penn State are not consistent with the results reported in several other studies. Grubb and Selfridge compared the performance of college students taught descriptive statistics via CAI, conventional lectures, and programmed text. Those students taught via CAI took one-tenth as long and achieved twice as well on the final posttest as did the other two groups! These results are so spectacular that they demand replication by other investigators. Schurda found that students who learned Fortran programming via CAI saved 10 per cent in instructional time, and performed 10 per cent better than students using a standard text or a programmed text. These somewhat more modest results conform more to expectations than the phenomenal results reported by Grubb and Selfridge.

The nature of the subject matter is also an important determinant of the response processing requirements of an interface device. Relatively simple drill programs may not require very extensive response processing since most student responses are of the short answer variety. College-level tutorial and problem-simulation programs will ordinarily require a CAI system with partial-answer processing capability.

Partial answer processing refers to the capability of the computer to search a student's response for the essential elements of the correct answer: to disregard minor character mismatches, spelling, and typing errors, to regard or disregard word order in a student's response depending on the nature of the problem; etc. In one preliminary study, Wodtke examined the relationship between student performance in a CAI mathematics course, and the number of times a student entered a correct answer at the terminal which was regarded as incorrect by the computer because of a minor character mismatch. The correlation between student achievement in the course, and the number of mismatched correct answers was -.80! Thus, it is quite clear that inadequacies in the computer's ability to detect correct answers seriously interferes with student learning. It should be noted that detection of incorrect responses is not solely an interface problem, but is also a software problem. The partial answer processing capability in the IBM CAI system is provided in the Coursewriter author language.

Learner characteristics

The second class of variables which must be considered in the design of an effective student-subject matter interface are individual differences among the students. The effects of some individual difference variables on the interface are obvious, for example, different interface capabilities are required for young children as compared to college students or adults. Whereas auditory stimulus display capability may be "supplementary" at the adult level, it is absolutely essential in instruction with very young children who are still nonreaders. Auditory communication would be the primary means of communication with nonreading youngsters. Glaser, Ramage, and Lipson point out that auditory response detection would also be an essential requirement for an interface in teaching young students some aspects of mathematics, reading, and science. For example, in reviewing an elementary reading curriculum, Glaser and his associates point out that the student must acquire the following competencies involving an oral response: (1) In learning sound-symbol correspondence, the student is asked to pronounce the sounds of individual letters when written on the board or to circle or write the appropriate letter when its sound is presented, and (2) At all stages the student is asked to read aloud stories using the words he has learned. It is probable that some instructional functions such as oral reading which require oral response detection will have to be delegated to the teacher, with CAI incorporating those functions which are feasible within the present technology.
Object manipulation is likely to be another important instructional experience for very young pupils, and for older students in some subject matters such as science. According to Piaget's stage theory of human development, children pass through several stages of development. Early developmental stages are characterized by sensorimotor development and the manipulation of concrete objects. Later stages are characterized by the ability to operate in more abstract terms. According to this view, the manipulation of concrete objects would be an indispensable part of instruction for elementary school children.

Although there may be mechanical methods for providing experience in the manipulation of concrete objects (Glaser, Ramage, and Lipson have described an electronic manipulation board which would be capable of detecting the identity and placement of objects located on its surface), within the present stage of technology, it would seem more efficient to delegate this function to the teacher.

The CAI interface must provide a maximum of flexibility in adapting display and response modes to differences in student aptitude and past achievement. An author should have the capability of speeding up or slowing down the flow of information to a student depending on the student's aptitude or progress through the course. The variation in the rate of presentation of instruction requires a time-out feature (now available on most CAI systems) which enables the author to regain control of the terminal in the case of a student whose response latencies are excessively long. Without this terminal control, it is difficult for an author working through his computer program to alter the pace of instruction.

The need for the interface to provide graphics and auditory display capabilities also depends on the past experiences and backgrounds of the students. The typical college undergraduate has high verbal ability. CAI for college students can rely heavily on communication by means of verbal material displayed via a typewriter or cathode ray tube. However, if one considers instruction for culturally disadvantaged students or students in vocational and technical education programs, much more reliance must be placed on relatively nonverbal media of instruction. Such students will probably require more graphic displays in the form of pictures, diagrams, and drawings depicting the concepts of the course. These students may have difficulty thinking in abstract verbal terms and may require much more actual manipulation of the objects of instruction. In addition, the relatively nonverbal student might show considerable improvement in learning when verbal instruction is supplemented with auditory communication. The problem of how to communicate concepts to learners who are handicapped in verbal communication skills is an important problem for research with direct implications for the design of CAI display devices.

One learner characteristic which has important implications for the determination of the appropriate "mix" between computer-mediated and teacher-mediated instruction is the student's need for affection, nurturance, and personal contact with a teacher. This variable would be particularly important during the early stages of learning with young children. It is well known that children vary considerably in their need for affection and contact with a teacher. The need seems to be particularly acute in less mature youngsters when they are initially confronted with the complexities of a difficult learning task. Increased teacher support and nurturance may be required during the early stages of the development of a complex skill such as learning to read. Children should be tested prior to instruction so that some decision can be made concerning their need for support and contact with a teacher. The instructional system must then provide the additional personal contact required by a given child.

The branching and decision-making capabilities of the computer are the most unique and potentially important characteristics of a CAI system. To the writer's knowledge, all current CAI systems provide the ability to store information concerning the student's learning history, and the ability to make decisions to branch the student to instructional material which is appropriately suited to the particular learning history. The decision-making capability of most CAI systems is one technological capability which far exceeds our present knowledge of the process of learning and instruction. Unfortunately, psychologists are hard put to know which characteristics of the learner (immediate response history, pattern of aptitudes, response latencies, etc.) are optimum for branching decisions, and until we discover the instructional experiences which are optimal for a student with a particular learning history, the full power of CAI for individualizing instruction will not be realized.

Characteristics of the instructional process

The nature of the instructional process must also be considered in the design of a student-subject matter interface. It will not be possible in the present paper to consider all of the instructional variables which may effect the efficiency of an interface; however, some of the variables which may have special relevance to interface design will be considered.

It is a commonly accepted principle in all theories of learning, that there must be contiguity of stimulus
and response for learning to occur. In common parlance, the principle of contiguity simply means that in order for a response to be associated with a stimulus, the response must occur either implicitly or explicitly in the presence of the stimulus. If a student is to learn the English equivalent of a German word, he must reproduce the English word (explicitly or implicitly) while attending to the German word. Hence, attention to the stimulus word or instructional display is a critical factor in instruction. It is therefore important to determine the characteristics of displays which produce a high degree of attention on the part of students. Perhaps the most relevant research on this question has been conducted by Berlyne. Berlyne found that attention to a stimulus is heightened by the element of surprise, change, or novelty of the stimulus. When the same stimuli are presented in the same format over repeated presentations, attention to the task wanes, and motivation declines. The effects of novelty on behavior can be observed in any student working at a CAI terminal for the first time. The novelty of working with a machine which “talks back” has high attention holding value, at least during the early stages of instruction. The interface must be capable of providing enough variety of stimulation and novelty to sustain attention over an extended period of time. An interface which because of limited display and response processing capability provides for only very simple display and short answer response formats such as the multiple choice frame will soon lose interest for the learner.

Travers and his colleagues have recently conducted an extensive review and research on various aspects of audiovisual information transmission. Travers' studies and those of Glaser, Ramage and Lipson must be considered among the primary references in the field of interface design. Travers has re-examined the traditional view that the primary advantage of audiovisual presentations is in the realism they provide. Contrary to this traditional view Travers argues that increased realism may actually interfere with learning by providing too many irrelevant cues, thus, a simple line drawing may be more effective in communicating essential concepts to learners than a more realistic picture. Travers concludes:

First, the evidence points to the conclusion that simplification results in improved learning. This seems to be generally true regardless of the nature of the presentation—whether it is pictorial or verbal. This raises interesting problems, for the simplification of audiovisual materials is that they provide a degree of pictorial content will generally result in a less realistic presentation than a presentation which is close to the life situation. The argument which is commonly given in favor of realism which other procedures do not. The realism provided may not be entirely an advantage and may interfere with the transmittal of information. The problem of simplifying realistic situations so that the situations retain information essential for permitting the learner to respond effectively at some later time to other realistic situations, is an important one (pp.2.110-2.111).

The limited capacity of a cathode ray tube for displaying a high degree of realism may not be such a deficiency after all.

A more recent experiment suggests that the above generalization may have to be qualified in several respects. Although simplified displays may facilitate transmission of information they do not appear to facilitate transfer or application of what has been learned as well as more realistic displays. Overing and Travers found that students who were taught the principle of refraction of light in water by means of realistic demonstrations were better able to apply the principle in attempting to hit an underwater target than students who were taught by means of simplified line drawings. This study suggests that the primary advantage of realistic displays may be in helping the student to apply what he has learned later on in realistic problem solving situations.

Travers and Van Mondfrans and Travers have also conducted research on the relative efficiency of information transmission through the auditory or visual senses, or some combination of the two senses. In general, their results suggest that instruction involving the visual modality is superior to auditory instruction when the auditory presentation produces some ambiguity in the information transmitted. Thus, the auditory modality was distinctly inferior to all other modality combinations in the learning of a list of nonsense syllables, but no differences between modalities were obtained when meaningful materials were learned. The auditory transmission of a nonsense term produces considerably more ambiguity of interpretation than the auditory transmission of a meaningful word. These results suggest that the use of the visual modality will be particularly effective when the task is to learn new associations such as in learning a foreign language.

Another relevant consideration in interface design is the capacity of the human being for processing information. Travers favors a single channel theory of information processing. According to this view,
the human receiver is capable of processing information through only one sensory channel at a time, although the theory postulates a rapid switching mechanism through which the receiver can switch from one channel to another. Accordingly, it is possible to overload the human information processing system by sending messages through multiple sensory channels simultaneously. This condition might result in a loss of information processed by the multi-media CAI interface should be capable of keeping the multiple modalities distinct. This problem is also of concern to the CAI course author who in preparing his graphic and auditory displays must give attention to the information processing limitations of his student.

Another stream of research in psychology has been concerned with the problem of imitation or observational learning. Bandura and Walters\textsuperscript{18} have demonstrated that much learning results from the child's observation of the behavior of peers or adult models. Undoubtedly, much classroom learning results from the students' observation and imitation of the behavior of other students and the teacher who serve as effective models. Bandura and Walters have also demonstrated that observational learning occurs as readily from film-mediated models as from live models. These results strongly suggest that an effective instructional environment should provide opportunities for students to observe and imitate the performance of models. To provide adequate opportunities for imitative learning, a CAI interface would have to provide a video tape, closed circuit television, or film projection capability. Provisions for observational learning would seem to be most valuable in science instruction. In learning to use various pieces of scientific apparatus or measuring instruments, the student could watch a video taped demonstration by the teacher and then practice imitating the teacher's behavior. Ideally, such a system should have a playback feature so that students who require more than one demonstration can have the demonstration repeated. Slow motion and stop action would also be of value in breaking down the components of a complex demonstration so that the student can observe the subtleties of the performance.

Another important aspect of the instructional process is that of guidance or prompting of the desired response. The interface must be capable of providing hints or cues to the student when an unusually long response latency indicates that the student is confused, or when the student makes an overt error. Hints may consist of highlighting the correct response in a display by increasing its brightness or size relative to the other words in the display. IBM's Coursewriter provides a feedback function which enables an author to provide cues in the form of some of the letters in the correct response. Thus, a student who was unable to name the capital city of New York State could be prompted with the display: A----y. If the student is still unable to produce the correct response after the first prompt, he could be given still more information in the second prompt, such as: A-b-ny. In addition to the guidance provided by prompting, it is also essential that the system provide for the gradual withdrawal of guidance or the "fading of prompts." A prompt should be gradually eliminated over a series of practice trials as the student becomes more certain of the correct response.

Finally, the interface should be capable of providing various forms of positive reinforcement or "rewards" to students as they progress through the course. Reinforcement may often take the form of information to the student concerning his progress through the program. Reinforcement has the effect of sustaining motivation and consequently performance on instructional tasks. Perhaps the most potentially powerful source of reinforcement in CAI is the degree of control which the student can exercise over the course of instruction, the extent to which the student can select his own menu of instruction, and the extent to which the student can query the computer for information. Recent research on problem simulation and economic games programmed for computer presentation (Feurzeig\textsuperscript{19} and Wing\textsuperscript{20}) suggest that instruction involving conversational interaction and inquiry are highly reinforcing to students. Although these interactive programs place no unusual demands on the stimulus display requirements of the interface, they do extend considerably the requirements for response processing. The interface must be capable of accepting rather lengthy verbal inputs, and the computer must be able to detect key words in a wide variety of verbal responses.

Instructional objectives

Instructional objectives play an important role in determining the interface characteristics required in instruction. It is no great surprise that one of the most successful early CAI projects involved instruction in arithmetic drill (Suppes, Jerman, and Groen\textsuperscript{21}). Arithmetic drill provides a relatively delimited class of instructional stimuli and responses. The presentation of arithmetic problems via the interface presents few serious display problems, and the responses are such that little complex response processing is required. As Suppes has demonstrated, elementary arithmetic skills can be easily taught by a relatively simple teletype interface, which pro-
vides an important adjunct to regular classroom instruction. As one begins to include other instructional objectives such as diagnosis, remediation, application, transfer, problem solving skill, attitude formation and change, etc., one finds that the interface facilities must be broadened considerably to provide the enriched variety of experiences needed to accomplish these objectives.

SUMMARY
The primary purpose of this paper was to illustrate the effects of different subjects, different students, different learning objectives, and instructional processes on the functional requirements of the student-subject matter interface. Although there is much diversity in the experiences which an instructional environment must provide to students, these experiences also have much in common. The question arises as to whether a single general purpose instructional interface can be developed to teach a wide variety of different subject areas. In general, there seems to be some consensus that the next generation up-to-date operational CAI system will have the following capabilities:

(1) Keyboard for response input
(2) Cathode ray tube display with light pen response capability
(3) Video tape or closed circuit television capability built into the CRT unit
(4) Random access image projector with positive address (may be unnecessary if the system provides video tape capability)
(5) Random access audio communication device with positive address.

A CAI system with the above capabilities would be able to provide many of the educational experiences outlined in Table I.

In analyzing elementary mathematics, reading, and science, Glaser, Ramage, and Lipson have outlined some of the major deficiencies of the general purpose interface. These special educational functions may require special purpose interface devices which will be feasible only in experimental CAI systems in the near future. An operational instructional system may have to provide these experiences through regular classroom instruction or special laboratory experiences.

Major deficiencies of a general purpose student-subject matter interface:

(1) Mathematics—Object manipulation to develop basic number concepts; the manipulation of three dimensional geometric figures, line drawings, bisection of angles, drawing perpendic-ulars, etc. as in geometry. The “Rand Tablet” which is currently operative on some experimental CAI systems provides the graphic response capability required for teaching courses in mathematics, science, and handwriting. The Rand Tablet allows the student to make line drawings, graphs, and diagrams which are simultaneously displayed on a cathode ray tube screen, and evaluated for accuracy by the computer. The Rand Tablet may be operational in future CAI systems.

(2) Reading—Oral response detection for very young children.

(3) Science—The limitations of the general purpose interface in the area of science instruction depend upon the extent to which actual experiences with scientific phenomena can be simulated. Will student learning of scientific concepts be adequate in simulated laboratory experiences, or will direct experience with the actual phenomena be required? Although a number of investigators are presently engaged in the development of simulated science laboratory programs for CAI, these programs have not as yet been evaluated, thus, we must await an answer to the question of the value of simulated experiences in science. One recent doctoral dissertation completed at Penn State has some bearing on the issue of simulated versus actual experience with scientific phenomena. Brosius compared the learning effects of watching films of the anatomy and dissection of the earthworm, crayfish, perch, and frog in biological science with the experience of having the student perform the actual dissections of the animals. Student achievement was measured in terms of achievement of factual information of the anatomy of the animals, skill in the performance of actual dissections, skill in the manipulation of scissors, scalpel, forceps, and probes, and attitude towards science. The filmed demonstrations were as effective as actual dissection on all measures, except the achievement of factual information in which the film method was actually superior to the method involving actual dissection. This study suggests that filmed demonstrations may be just as effective as direct experience in facilitating learning of some concepts in biological science.

Although present technology may be inadequate to accommodate all instructional applications outlined in this paper, it is expected that improvements in the interface will emerge which will closely approximate the requirements of many educational tasks.
The writer's general position is that the interface should "ideally" provide as wide a latitude of stimulus display and response capabilities as possible to accommodate a variety of instructional problems. However, while we wait for the necessary technology to emerge much valuable work can be accomplished with relatively simple interface devices. As we work with first generation equipment we must be especially alert to its limitations in planning the objectives of instruction. Experiences which cannot be adequately provided via CIA must be provided by other "off-line" methods, such as textbooks, workbooks, educational television, laboratories, teacher demonstrations, and maybe even a lecture or two.

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