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ABSTRACT

This paper explores the cognitive approach to instruction and provides several strategies for using knowledge engineering information in the instructional development process to strengthen the systems approach to training. When students learn using the behavioral approach to instruction, drawbacks have been noted because gaps are apparent between the students' high performance levels on objective tests and their inadequate problem solving performance levels. Augmentation of the behaviorist process with applications of knowledge engineering can result in obtaining detailed information about student misconceptions relative to expert knowledge. This information is then applied to individualized learning prescriptions. Normally, instructional developers are working under significant resource and time constraints, and this modified systems approach is an efficient solution to this problem.

INTRODUCTION

The systems approach to training has now functioned for two decades in public education, the armed forces, and the private sector, experiencing a high rate of success. The systems approach to training includes the following phases: analysis, design, development, implementation, and evaluation. When these steps were defined in the literature, the definitions were founded on principles of the behaviorist school of education (e.g., Skinner, 1950). However, the behaviorist emphasis on product over process has proved to have some drawbacks, which are discussed in the literature (e.g., Wittrock, 1978), yet until recently few tangible solutions existed for instructional developers to use in addressing these drawbacks.

The purpose of this paper is to propose some specific strategies we can use to integrate the strengths of the cognitive approach to instruction into the systems approach. The ultimate goal of this proposal is to improve the quality of learning, a requirement in today's complex, highly technological world. The strategies presented apply to the analysis, design, and evaluation phases and do not directly aid the development and implementation phases. This paper represents only the beginning of a solution to some of these drawbacks, but it will ideally foster further research and development work to transfer the theory into practice. This paper contains the perspective of someone who has not only monitored the research for two decades but who has also been a practitioner. It provides a multidisciplinary approach, drawing from the following disciplines: computer science (artificial intelligence, user interface design), education (educational psychology, educational technology, instructional design), cognitive science, and human factors engineering.

The paper begins with a brief discussion of the behaviorist versus the cognitive approaches to education/training and then provides a discussion of knowledge engineering. The core of the paper is the description of several strategies that instructional developers can use. The strategies should be useful for training/education managers and developers. Those involved in higher-cognitive-level instruction should find this approach particularly interesting. Although the specific design and evaluation strategies proposed are targeted at computer-based training (CBT), the approach can be useful for many different delivery formats.

THE BEHAVIORIST VS. COGNITIVE SCHOOLS AND THE DEVELOPMENT PROCESS

Table 1 provides a brief comparison of the behaviorist and cognitive approaches to instruction. This comparison forms the foundation on which to base the proposed strategies. We obtained performance objectives from the behaviorist school, which focuses on changing the behavior of the learner. The measure of success in a behaviorally oriented training program is test performance. In the cognitive school, however, the measure of success is in the method rather than in the answer. The focus is on tracking the mental activities of the learner and comparing them to the mental activities of an expert solving the same problem.

In the instructional design and development process, the selection of which school to follow is critical. Behaviorist-oriented education can be rather impersonal (e.g., programmed instruction) and step-by-step in format. Cognitive-oriented instruction, however, needs to be tailored more to an individual's misconceptions if incorrect knowledge organizations are to be identified and corrected.

In the cognitive approach, the student is apparently storing information in some sort of mental model (Gentner and Stevens, 1983). This mental model may be accurate, that is, the same model as that of an expert, or it may have missing or inappropriate linkages (Norman, 1980). Often, instruction is responsible for conveying the mental model to the student and sometimes, through no conscious fault of the instructor/instruction, the mental model that is formed is inaccurate. The consequences of this inaccurate mental model are flawed solutions to subsequent applications of the learned information. The challenge in cognitive science is to begin to understand both expert and novice mental models; knowledge engineering is the name for this process.

KNOWLEDGE ENGINEERING

Knowledge engineering is the study of expert knowledge to obtain heuristic information (rules of thumb) as well as knowledge organization and then to formally represent that knowledge in computer-compatible format. Expert knowledge is obtained through a variety of techniques. Chovan (1986) provided a review of knowledge extraction techniques useful for CBT. The most common methodology is interviewing or "brain picking," which usually involves intensive questioning of a single, recognized expert by a knowledge engineer (who is usually conversant with both psychology and computer science). The knowledge engineer tape records the interview(s) and creates graphical representations of the information he/she is drawing out of the expert. Unlike textbook knowledge, the information drawn out in these interviews relies heavily on heuristics. An expert often skips steps that seem necessary in a textbook and adds others which are not documented. The knowledge engineer then creates a formal representation separate from the expert (e.g., semantic net) and then goes back to verify it with the expert. Another approach to extraction of knowledge is to use an on-line tool in which the expert and novices solve problems and then explain their reasoning (Stoddard, Emerson, and Kern, 1986).

In the instructional context, we compare student novice knowledge with expert knowledge. Knowledge engineering stems from the cognitive science community, but is now experiencing limited use in the instructional community as well (e.g. Lasaik 1986; Merrill, Li, and Soulier, 1988). Merrill et al has recently completed a thorough knowledge engineering analysis of the instructional design process for the purpose of creating an expert system. He queried instructional design experts and, with a frame and rule-based representation, formally represented the knowledge base for use in the expert system.

If cognitive-oriented instruction is to be provided, some understanding of student versus expert knowledge organization is necessary. This information is then used not only to organize a lesson and construct questions but also to construct feedback. Highly individualized instruction approaches one-on-one tutoring, with specific misconceptions identified and then corrected with tailored feedback. Provision of such specific feedback requires techniques that are not traditionally known or used by instructional developers. The sections following will describe some specific approaches for integrating the results of knowledge engineering into the instructional design of a lesson.

STRATEGY FOR THE ANALYSIS PHASE: OBSERVATION DURING JOB/TASK ANALYSIS

Analysis, the first step of the systems approach to instruction can vary in scope depending upon the application. The analysis can be a needs analysis for the specific type of training--but it can also include extensive job and task analyses. The emphasis on analysis in creating effective performance-based training has increased in recent times because (1) the skill level of the entering workforce is expected to decrease, (2) in-house training is being recognized as essential for safety and productivity on-the-job, and (3) training budgets are relatively low and thus cost effectiveness is a key issue. The step-by-step prescriptions for performance of job and task analyses one finds in the literature are consistent with the behaviorist school of education. Emphasis is placed on systematic examination of tasks, determination of the level of training required for each task, and then determination of task relationships for the purpose of instructional objective writing. The tasks are generally located through examination of existing training or standard operating procedure manuals. Eysenck (1984) does provide a chapter on a cognitive approach to task analysis, but it is not for an instructional context.

Many recognized strengths are inherent in the job and task analysis process, yet often the results are not implemented. Because the results do not adequately approximate what really happens on the job. This gap is caused by the lack of consideration of heuristic issues/tasks. Therefore, the strategy proposed for analysis here is integration of an interview observation process into the job and task analysis process. In addition to the well-accepted steps of completion of the task profile questionnaire, an employee should be observed while performing tasks. The analyst should note with whom the employee interacts and how, when manuals are consulted, and how time is apportioned on subtasks. Obviously, the analyst does not have time to analyze all tasks to this depth, but this sampling will provide linkages and nodes in the task analysis, making it more meaningful.

STRATEGY FOR THE DESIGN PHASE: TAILORED FEEDBACK

Normally, an instructional designer and a subject matter expert write a question and then immediately construct the feedback: one correct answer is accepted and incorrect answers prompt a standard hint and then the student is asked to try again. Sometimes, incorrect answers result in the student's being routed back to a prior instructional sequence and then returned to the same question. This type of feedback is behaviorally oriented, yet experience has shown that often students get frustrated by it. They did not "get the point" the first time. Therefore, why should they be expected to "get it" by being taught with the same approach again?

The strategy proposed here is to provide more tailored feedback, especially powerful for short answer questions. Specific types of wrong answers can each receive different feedback tailored to the type of error committed (see Fig. 1). In addition, suboptimal answers (those which are partially correct but contain some misconception) can also be recognized and be provided tailored feedback so that the student can reason to the correct answer. Such feedback information can be obtained through paper and pencil tests or through interviewing instructors before to design. It can also be obtained during early pilot testing with a sample of the target population. The information is easily recorded and analyzed through a computer-managed instruction system transparent to the user. The feedback database can then be expanded to address likely incorrect answers. This approach admittedly involves a much more complex design and a longer design process, yet the payoff from the student's perspective is potentially great. An iterative approach to design, such as this, is now widely supported in many software development efforts (Norman, 1983).

At Los Alamos, this strategy has been used on several CBT projects. The result has been a more motivated student who is challenged by the "smarter" computer.

STRATEGIES FOR THE EVALUATION PHASE: SCORING AND LEARNING PRESCRIPTION

The evaluation component of CBT design is crucial to student learning, for much constructive feedback can occur here. In a behaviorist approach to evaluation, the student's test is scored and the student is told the score. Then he/she is given the paper with the incorrect answers marked, and sometimes the correct answer is provided (or the student must figure it out). If it is a complex problem, the student's solution and not his/her proof is used in the scoring.

Two strategies for using knowledge engineering information to improve such an evaluation process are proposed here: (1) a scoring system based upon an expert solution to problems and (2) a learning prescription. The scoring system for problem solving CBT may be complex, with points allocated not only for the bottom line answer but also for the sequence of actions the user takes. Thus, the misconception in problem solving is identifiable. In a behaviorist approach, the nature of the student's errors is difficult to identify. In the cognitive approach, one can examine the course of the student's actions. For example, a student obtains final score of 66%. Analyzing the the scoring breakdown reveals that the student obtained a perfect score for the first two-thirds of a problem solving process and no points for the final third. It is therefore easy to see that there is a specific misconception associated with the content of the final third of the task/problem. In the cognitive approach, the student is given the score and the expert solution. The expert solution can be in the form of two separate screens, with the expert solution graphically presented on one and the student's solution presented on the other. It can also be presented in a printed log. The log notes the incorrect answers and gives the correct response (expert solution), along with point values.

A learning prescription is the tailored follow-up to the scoring system/student log. The score and log provide information about what went wrong. However, what does the student do next? The learning prescription is generated after categorizing the type of errors observed on the log. The student is provided a listing of what learning resources to consult in light of his/her misconceptions. These resources might be consulting an instructor or reading a chapter of the text or repeating the CBT. It is possible to generate such a learning prescription through use of a programming language (e.g. Pascal). If an artificial intelligence programming language is used (i.e., Lisp or Prolog) then the degree of tailoring possible is much greater.

SUMMARY

Because education is not yet a well understood science, new approaches need to be explored continuously. In addition, the demands of our highly technological society are challenging techniques proved effective in the past. No longer can understanding at the lower cognitive levels be acceptable, for on-the-job task performance requires regular evaluation, synthesis, and analysis. The intent of this paper is not to downgrade the behaviorist approach to instruction, for the approach has upgraded the quality of education. It can, however, be augmented with cognitive-oriented strategies for the purpose of further facilitating learning. Our need for novices to function at an expert level is increasing as the information explosion continues.

This paper provided a few possible strategies, particularly tailored for use by CBT developers. No doubt, many other strategies are possible. Those proposed here need to be rigorously tested, for validation has not yet occurred. However, each of these strategies has been tested in prototype CBT at Los Alamos, and formative evaluation results are favorable. This paper should not only prompt replication and validation of such strategies but also generate new strategies. The gap between the cognitive science researchers and the instructional developers needs to be narrowed.

BIOGRAPHY

Mary Stoddard Trainor earned her doctorate in science and mathematics education from the University of California at Berkeley. She is currently the Deputy Group Leader of the Cognitive Systems Engineering Group at the Los Alamos National Laboratory. Her research interests have focused on user interface design, on-line help, computer-based training, and intelligent tutoring systems. She has been in the field of technical training since 1974 and has published more than 30 professional articles. She has recently been elected the president-elect of the Association for the Development of Computer-based Instructional Systems (ADCIS).

TABLE 1

THE PROCESS OF LEARNING

BEHAVIORIST SCHOOL	COGNITIVE SCHOOL
(Skinner, Thorndike)	(Wittrock, Ausubel, Bruner)
• Focus is on behavioral changes	• Focus is on process of acquiring knowledge
• Learning is a passive response from the learner to environmental factors	• Learning is an active process
• Mental activities of the learner are irrelevant to understanding learning	• Mental activities of learner that lead to response are central

Figure 1

COGNITIVE-ORIENTED FEEDBACK SYSTEM •

QUESTION #1 → *IF CORRECT, GO TO FRAME XXX*

FIRST RESPONSE	ERROR 1 *subtle hint*	ERROR 2 *subtle hint*	ERROR 3 *subtle hint*	ERROR 4 *subtle hint*
SECOND RESPONSE	ERROR 1 *suggestion*	ERROR 2 *suggestion*	ERROR 3 *suggestion*	ERROR 4 *suggestion*
THIRD RESPONSE	ERROR 1 *direct hint*	ERROR 2 *direct hint*	ERROR 3 *direct hint*	ERROR 4 *direct hint*

•Devised by Linda Nonno & John DeVries, Los Alamos

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