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The VCR Tutor: Evaluating Instructional Effectiveness

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Abstract

People use a wide variety of devices. Operation of a device can usually be described in terms of knowledge of specific procedural sequences. However, execution of procedures may also depend upon knowledge of the device, its behaviour, and the relationships between device features and device actions. A video cassette recorder (VCR) is one commonly used device. Programming a VCR to automatically record a chosen television program is an example of a device manipulation task. In designing a device tutor, it is relevant to ask how instruction about device operation should be designed, and to ask whether knowledge engineering for a device tutor should focus on procedural knowledge or involve factual and referential knowledge as well. Four versions of a tutoring system for the VCR device and programming task have been implemented, incorporating different tutorial approaches using different types of knowledge. The effectiveness of these versions has been examined experimentally. Subjects who used the knowledgeable tutoring version learned to program a VCR simulation using fewer steps and with fewer errors and error types than subjects who used a prompting version of the tutor.

Introduction

Operation of a device involves explicit procedural knowledge, knowledge of sequences of actions that can be consciously described and physically executed. Execution of such procedures may also depend upon referential and factual knowledge about the appearance, behaviour, and operation of the device. Different perspectives about the knowledge involved in operation of a device lead to significantly different instructional strategies for a device tutor. If a pure procedural view of device use is correct, then prompting or correctness feedback systems may be a sufficient to teach. If a knowledgeable perspective is correct, then purely procedural approaches to instruction are likely to be less effective than knowledgeable instruction.

A device and task have been chosen as suitable for research in this area. The device is a video cassette recorder (VCR). VCRs are commonly used, but sufficiently complex that many people have difficulty operating them. Setting a VCR to automatically record a selected program is one of many procedural tasks involving VCRs. This task has been chosen as representative of tasks in many domains which involve manipulation of devices.

Alternate versions of a tutor can be used as a basis for empirical studies to evaluate instructional effectiveness (Mark, 1990). Four versions of a VCR device tutor have been implemented. Each version utilizes a different instructional approach. An experimental study has been carried out, comparing the effectiveness of the four prototypes. Results are discussed in terms of their relevance to theories of knowledge and instruction.

Theories of Knowledge

Knowledge can be categorized into types, based upon the degree of conscious awareness of knowledge and the purposes for which knowledge appears to be used. Knowledge of symbols and meanings can be called *referential* knowledge, verbal information (Gagné, 1974), or semantic knowledge (Mayer, 1987; McGraw & Harbison-Briggs, 1989). *Factual* knowledge is specifiable knowledge about objects and relationships between objects within the world. Mayer (1987) includes factual knowledge within his category of semantic knowledge, while McGraw and Harbison-Briggs (1989) classify it as part of a larger category of declarative knowledge, knowledge which can be readily described. *Procedural* knowledge of how to do things can be categorized as explicit or implicit. *Explicit* procedural knowledge can be consciously described in terms of an algorithm, rules, or procedures, and used to guide performance (Mayer, 1987). This has also been referred to as intellectual skill (Gagné, 1974) and declarative knowledge (McGraw & Harbison-Briggs, 1989). *Implicit* procedural knowledge is knowledge of how to do something that cannot be easily described verbally. Mayer (1987) refers to this as skills. McGraw & Harbison-Briggs (1989) reserve the term procedural knowledge to indicate implicit procedural knowledge. *Metacognitive* knowledge (Borkowski & Cavanaugh, 1979), also referred to as metaknowledge (McGraw & Harbison-Briggs, 1989), strategic knowledge (Mayer, 1987), or learning strategies (O'Neil, 1978), is increasingly believed to be important in the conscious monitoring of human information processing behaviour (Baron & Sternberg, 1987).

The knowledge type most obviously relevant to operation of devices is procedural knowledge. One viewpoint is that to achieve a goal such as the automatic recording of a program by a VCR, a person only needs to know a correct sequence of steps which can be executed to achieve that goal. Such sequences can be described explicitly. Once learned, they can be repeated in exactly the same way whenever the same goal is desired. One of several possible procedures for programming a VCR to record a specific television program is outlined in Figure 1. This sequence has been adapted from the documentation of a particular brand and model of VCR. Each step can be described in terms of simple manipulations of device features, such as pressing buttons and changing switches. The only conditions necessary for execution of this sequence are that the VCR and television are connected and that the VCR clock is set to the current time.

1 Power switch -> on
2 Open subpanel door
3 Clock-timer switch -> start
4 Select program number (press Prog Nbr button)
5 Select the channel you want to record (press Channel)
6 Select the day of the week (press Day button)
7 Set the recording start time (press Hour, 10Minute, Minute)
8 Clock-timer switch -> end
9 Set the recording end time (press Hour, 10Minute, Minute)
10 Clock-timer switch -> set
11 PROG REC switch -> on
12 Close subpanel door
13 Insert video tape into VCR

Figure 1: Procedural steps in programming a VCR

According to another view, more complex knowledge is necessary to operate devices. Norman (1988) discusses the operation of devices such as VCRs in terms of conceptual models which humans may use to relate visible device features to underlying device actions that may or may not be readily visible. The referential and factual knowledge contained in such models enables a user to identify significant features of a device and to choose appropriate actions to manipulate that device. Cognitive models of the world and of objects may be extremely important when the mapping between visible features and operations is hidden or poorly represented, when the outcomes of manipulations are not readily visible, or when there is sufficient variation in the world to make the ability to identify relevant features essential.

According to Norman's view, the procedural description of Figure 1 assumes referential and factual knowledge on the part of the VCR user. Referential knowledge is involved in the labelling of features. The VCR tutor displays similarly shaped and labelled buttons, for example Program, Rec and Prog Rec. Referential knowledge can be important in identifying and distinguishing between these buttons.

Factual knowledge about features can be described in terms of affordances, constraints, and mappings. Affordances of manipulatable features describe how features can be used. Buttons can be pressed, movable switches can be moved between settings, and doors can be opened and closed. Constraints describe how features cannot be used. Buttons cannot be twisted. Mappings describe the relationship of manipulations to system changes. Such knowledge is important in enabling the user to manipulate the device and interpret the results of such manipulations, and in assisting the user to identify similar and differing features of machines. For example, two types of VCR buttons may appear similar and have different effects when they are manipulated. A binary button will have alternating effects on alternating button presses. The Power button works in this way, switching the power off and on. Another type of button can be repeatedly pressed, producing the same effect each time. The Prog Nbr button increments a value each time it is pressed.

Other factual knowledge relates to the meaning and purpose of the different steps, and their relationships to one another. Such knowledge can help the learner to organize and monitor the sequence of steps which is being executed, to remember what is being done at any given point in the sequence, to remember what to do next, to correct errors when correctable errors are made, and to restart the sequence when errors cannot be corrected. It can also enable the user to identify and execute variations of a procedural sequence which will achieve a desired goal. Relating Clock-Timer settings to manipulations of the Hour, 10Minute, Minute, Day and Channel buttons can be important in organizing and carrying out the programming task taught by the VCR tutor.

Metacognitive skills related to learning and memory may affect cognitive tasks such as memorizing and monitoring execution of the procedural sequence. Metacognition may also influence users' strategies for using the tutor and responding to the behaviour of the device and the tutoring system. Without being specific to the device or task, metacognitive knowledge may indirectly influence learning about device operation.

Implementation

Four versions of the VCR tutoring system have been implemented on a Macintosh computer in object-oriented Allegro Common Lisp. Versions of the tutor differ in instructional approach. The level of understanding considered sufficient for knowledge communication is one criterion for categorizing instructional approaches. *Rote* learning is oriented towards memorization. It presents information that is to be repeated or mimicked without any other understanding on the part of the learner. In contrast, *knowledgeable* learning approaches emphasize the importance of understanding underlying qualities and relationships between information. Knowledgeable learning is similar in meaning to "instruction that supports cognitive mediation" (Winne, 1985). It indicates the explicit presentation of factual information to the learner. Another way to categorize instructional approaches is to look at the techniques that are used to teach and the processes in which students are expected to engage while learning (Gagné, 1985). *Prompting* explicitly tells or shows the learner what to do, but gives no further information. *Practice and feedback* is an instructional technique in which students are presented with tasks to execute and given feedback on their attempts to execute them. Such feedback may or may not be knowledgeable.

The four versions of the VCR tutoring system are identical except in their instructional approach. The versions, named Mark-I through Mark-IV, use the instructional approaches of *prompting with a fixed programming procedure* (Mark-I), *practice and feedback on correctness with a fixed procedure* (Mark-II), *practice and feedback on correctness with a flexible programming procedure* (Mark-III), and *practice with knowledgeable feedback* (Mark-IV). The fixed procedure for programming the VCR is shown in Figure 1. In reality there are many ways to achieve the desired final setting for recording a TV program. Mark-III and Mark-IV accept any valid procedural sequence which results in the desired settings. Mark-II and-III provide feedback only on correctness or incorrectness of each step, while Mark-IV provides knowledgeable advice and attempts to diagnose and correct deeper misconceptions that the learner might have about the device.

The four versions of the VCR tutor are identical except in instructional approach. The tutor architecture conforms to the intelligent tutoring system (ITS) model proposed by McCalla and Greer (1990). The core of the VCR tutor is a device simulation consisting of a manipulatable interface which resembles a VCR (Figure 2), and a device automaton whose settings and states describe the underlying structure and behaviour of a VCR. The VCR interface forms a major part of the communications component of the VCR tutor. It is the focus of the learner's interaction with the system. Through manipulation of interface features, the learner affects the states and settings of the underlying device automaton. The control component of the VCR tutor system collects events from the interface and notifies other components of those incoming events. As the learner interacts with the VCR simulator, events are reported to the device automaton of the simulation, and to the instructional components. The instructional components embody knowledge about the task to be taught and the instructional approach to be used. Events reported from the VCR interface are the observable learner behaviour upon which instructional behaviour of the VCR tutor is based. The instructional components control the selection of varying types of feedback, to guide the learner's performance in accordance with the tutoring approach. The communication component manipulates the VCR interface and presents textual information in accordance with the selected feedback. In addition to this dynamic feedback, subjects have voluntary menu access to a summary of procedural steps for the task (similar to Figure 1).

The tutoring approach underlying Mark-I, the first version of the system, is *prompting*. Gagné (1985) suggests that the repeated presentation of prompts for steps in a procedural sequence can support the memorization and subsequent use of that sequence. This view of learning assumes that any prerequisite knowledge for carrying out the steps of the action sequence is already available to the learner. Since only information about the correct operations to carry out is presented to the learner, this approach is unlikely to lead to generalization or discrimination.

Mark-I restricts a learners' possible actions so that only one predetermined correct step can be carried out at any time. This is done by manipulating the VCR tutor interface, disabling all displayed images except for the one the user is to manipulate next. The correct next step is visually apparent, remaining in normal video while disabled images are greyed. Only the desired event can occur. The teaching component of this prompting version of the tutor requires knowledge of a single correct sequence of manipulations which lead to a particular set of device conditions. Teaching knowledge is represented as a task automaton, whose states represent steps in the procedural sequence of Figure 1. Each state contains information about its expected event and related interface restrictions, and about device conditions relating to state transitions. A state may have several possible transitions with varying destinations, depending on conditions of the device automaton following execution of the correct step. A knowledge model of a single correct procedural task is sufficient to direct the tutorial component of the VCR tutor when prompting. Knowledge of the learner's most recent

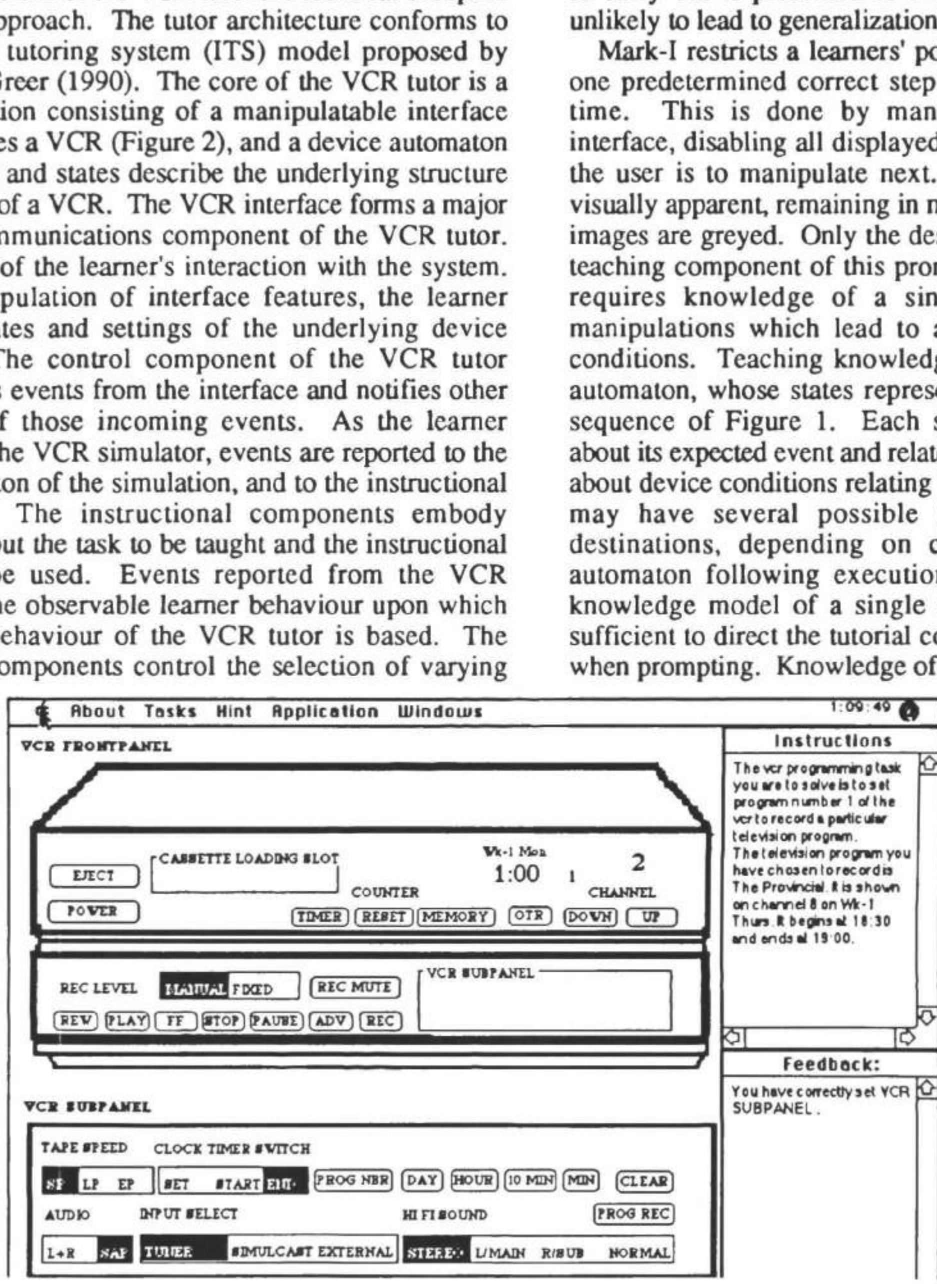

Figure 2: Sample VCR tutor display

action enables the task automaton to respond appropriately at any point in the task, so student modelling and diagnosis components are not required by Mark-I.

One approach to practice and feedback presents immediate feedback about the correctness or incorrectness of the last step of the procedural sequence executed by the student. Instead of being prompted for each correct step, the learner is allowed to try a variety of appropriate or inappropriate operations while manipulating the device. In response, the learner is informed of the correctness or incorrectness of those actions. This is similar to the rigid model tracing approach used in early versions of Anderson's LISP Tutor (Anderson & Reiser, 1985). Like prompting, this is a learning approach in which knowledge of a sequence of actions is believed to become proceduralized through practice. Correctness feedback is considered sufficient because it is assumed that necessary prerequisite knowledge is either already available to the learner, or discoverable through trial and error. Given that the learner can carry out a variety of actions and determine their correctness, this tutoring approach may foster discrimination and generalization. However, presentation of cases may not be varied or purposeful enough to indicate important similarities and differences characteristic of the domain.

Mark-II uses this type of rote learning approach while restricting acceptable user behaviour to a *single correct procedural sequence*, comparable to that allowed by the prompting approach (Mark-I). Mark-II presents only those visual cues which would be available from the actual device. All displays can be manipulated by the learner, who is given immediate textual feedback about the correctness or incorrectness of these actions relative to the fixed procedural sequence. Feedback indicates only that an action is or is not acceptable, without indicating why. If the learner makes a slip, such as going past the correct value when changing a setting, feedback indicates the mistake and instructs the learner to correct the slip. If the learner makes an error, such as pressing a button outside the correct sequence, the simulation retracts (undoes) this incorrect action before allowing the learner to continue. In this way, attention is directed to the required procedural sequence at the same time that realistic visual cues are presented.

Knowledge requirements for this single procedure correctness feedback version of the tutor are similar to those for prompting. An explicit knowledge model of the procedural task is the basis of the teaching component. The task automaton is extended by adding transitions to states to deal with incorrect events. Since the learner is not allowed to alter underlying device conditions through incorrect actions (results of such events are retracted), the set of states is not extended. The instructional component is different in that states send textual messages about the correctness of events to the communications component of the tutor when transitions occur, rather than triggering modifications of the simulation displays. Local knowledge remains sufficient to determine whether a subject's current action is correct or incorrect, and to identify the correct next step at a given time. An individual student model is not necessary.

Mark-III is similar to Mark-II in that it provides *practice with correctness feedback*. However, Mark-III expands the range of acceptable learner behaviour, allowing the learner to carry out *any potentially correct procedural sequence*. This approach resembles Anderson's later, more flexible, model-tracing tutors. In Mark-III a task automaton is used to model knowledge of the procedural task and to monitor learner behaviour, but it is extended to accept a variety of procedures for accomplishing the task. This requires alteration of both the set of states and the state transitions in the task automaton. Less importance is placed upon the sequence in which events occur, and more importance upon the examination of conditions affecting the device automaton. This local knowledge is used to determine whether the learner's current action is correct or incorrect. Feedback is only concerned with whether each individual step is consistent with reaching the desired final state, so an individual student model is not necessary.

Mark-IV is also built around *practice and feedback*. It attempts to promote *knowledgeable* rather than rote learning. Knowledgeable learning makes few assumptions about the learner's understanding of the domain. It attempts to identify missing knowledge and explicitly remediate misconceptions. Learner behaviour must not be restricted in ways that invalidate the device model to be taught. A student should be able to carry out any procedural sequence compatible with the VCR device and the ultimate solution of the task. A knowledgeable tutor must therefore deal with a wide range of learner behaviour. This includes slips, errors related to faults in learning, problems in reasoning and misconceptions resulting from incorrect models of the device (Norman, 1988), as well as correct behaviour. A knowledgeable feedback system should identify such behaviour and present relevant feedback. Instruction and feedback are concerned with conceptual models of the device as well as learner behaviour when manipulating the device. Generalization of knowledge and discrimination of relevant similarities and differences can be fostered explicitly.

Mark-IV is the most knowledge-intensive of the four versions of the VCR tutor. Extensive conceptual models of the task to be performed and of the learners' behaviour in manipulating the device are required. An extended task automaton accepts a variety of possible correct procedures. Local knowledge of the learner's last action is insufficient. Student modelling and individualized error diagnosis are introduced. A student modelling component tracks student behaviours and identifies characteristic behaviour patterns indicating problems. A catalog of known conceptual and procedural bugs is used to diagnose slips and errors related to procedural sequence, errors in reasoning, and underlying misconceptions reflecting incorrect models of the device. Slips, errors and misconceptions for the bug catalog were identified through detailed observation of ten individuals who used the Mark-III VCR tutor prototype. Mark-IV's knowledgeable feedback is targeted at correcting a learner's conceptual model of the device, as well as correcting the procedural sequence that the learner is attempting to execute.

A number of hypotheses about the effectiveness of different methods of tutoring follow from the theories of knowledge and instruction previously outlined. If a purely procedural view of the VCR programming domain is correct, then the only knowledge that is relevant in the VCR programming domain is procedural knowledge. Therefore, instructional methods such as prompting and practice with correctness feedback should be sufficient for instruction. It should be possible to learn and apply the desired procedures without difficulty. Knowledgeable feedback, while it may also lead to learning of the procedure, should not promote more effective application of procedural knowledge. In contrast, if a knowledgeable view of the VCR programming domain is correct, prompting may have limited value, since needed generalization and discrimination will be unlikely to occur. For practice with correctness feedback, the degree to which generalization and discrimination will occur is uncertain. Those who have used the prompting and correctness feedback versions of the tutor may learn how to carry out the procedural sequence, but they may also have difficulty in effectively applying that knowledge. If a knowledgeable view of the VCR programming domain is correct, knowledgeable instruction should teach students the VCR programming task, and enable learners to apply their procedural knowledge more effectively and avoid mistakes.

In the absence of a priori evidence about differences between the tutoring versions, the following null hypotheses were formed. It was hypothesized that no differences in VCR programming achievement would be observed when comparing groups of subjects who used the four versions of the VCR tutor. It was also hypothesized that no differences in time to complete the training regimen would be observed when comparing groups of subjects who used the four versions of the VCR tutor.

Experimental Methods

The subjects for this experiment were 80 undergraduate students at the University of Saskatchewan, who volunteered for the study. Most were registered in undergraduate computing classes. Subjects did not have previous experience in programming a VCR. They were told that the study was intended to examine the effectiveness of a VCR tutor, but were not given information about the instructional approaches involved, or the existence of differing versions of the tutor. Each subject was randomly assigned to one of the four instructional versions of the VCR tutor for training. Following testing, the test results of 4 subjects were found to be more than two standard deviations away from their group means. Those subjects were removed from the analysis, reducing the sample to 76.

Initial preparation for all subjects in the experiment was identical. Each subject was asked to read a written description of the domain, the programming procedure, and the use of the tutor. Details of the method of instruction were not given. The programming procedure described (similar to Figure 1) was procedural rather than conceptual. The programming procedure was also available to the student during training from a HINT menu. Training consisted of three trials. In each trial the subject chose a target TV program from an automated TV Guide, and then programmed the VCR simulation to record that TV program, receiving guidance from the tutor in accordance with the instructional strategy for that version.

Following training, each subject used a testing version of the tutor. The testing version of the tutor presented a VCR simulation similar to the Mark-III training version, accepting all possible correct variants of the procedure for accomplishing the task. The testing version analysed subject behaviour by tracking progress and identifying bugs (as in Mark-IV) and thus automatically collected data during the test. However, no feedback was given to the subjects, and the HINT menu describing the procedure was not available. During the testing period, subjects were asked to complete a single trial, involving the programming of the VCR simulation to record an assigned TV program.

Three measures of achievement were selected as indicators of learning in the VCR programming domain. The first achievement measure was the number of steps required to correctly program the VCR, without assistance, during the test. This measure captures notions of both accuracy and efficiency in carrying out the procedure. The second achievement measure was the total number of bugs diagnosed during the test. The third measure was the number of categories in the bug catalog in which errors were identified. These measures summarize the conceptual and procedural errors made by the student. The training time was the number of seconds that students spent in carrying out three practice runs at programming their version of the VCR tutor to record particular TV programs.

Results

Table 1 shows means and standard deviations for each group on each dependent variable. It also displays the F-ratio and significance levels from a one-way analysis of variance for each experimental measure. Significant differences among groups were found on all experimental measures. Post-hoc analysis using the Scheffe Method showed that subjects trained with the knowledgeable version of the tutor (Mark-IV) used fewer steps ($\alpha <=.01$).and had fewer total errors ($\alpha <=.05$).and types of errors ($\alpha <=.01$) than students trained with the prompting version (Mark-I). Students trained with a tutor providing practice with correctness feedback on all correct paths (Mark-III) also had significantly fewer types of errors than students who used the prompting version (Mark-I) ($\alpha <=.05$).. Post-hoc analysis of training time showed that training time with Mark-III was significantly greater than with Mark-I ($\alpha <=.05$).. There was no significant difference in training time between Mark-IV and the other versions.

Certain trends in the data, although not significant with such a small sample, merit some discussion. It is interesting to note that the two model tracing versions, Mark-II and Mark-III, led to very similar mean achievement but surprisingly different standard deviations. It is also interesting that Mark-IV with its knowledgeable feedback seems to promote marginally better achievement than any other version of the tutor.

	Mark-I (n=19)	Mark-II (n=18)	Mark-III (n=20)	Mark-IV (n=19)	F	P
Steps:						
Mean	107.7	89.6	69.4	54.6	5.26	0.002
St.D.	55.0	61.5	29.8	16.4		
Total Errors:						
Mean	28.5	21.0	10.0	6.1	4.06	0.01
St.D.	33.5	27.4	9.7	6.9		
Distinct Error Types:						
Mean	6.1	4.6	3.0	2.2	6.63	0.001
St.D.	3.7	3.9	1.8	1.6		
Training Time:						
Mean	1053	1360	1716	1330	3.37	0.02
St.D.	357	728	890	501		

Table 1: ANOVA Results for Experimental Measures

Discussion

Given that all students, regardless of tutoring approach, were able to correctly program the VCR simulation during testing, it appears that any version of the VCR tutor is sufficient to train potential VCR users. However, knowledgeable feedback promoted more effective acquisition of procedural knowledge than did prompting, at no additional cost in training time. These results support the idea that referential and factual knowledge are important in this seemingly procedural domain. The results lend credence to the claim that knowledgeable tutoring provides better advice to the learner and thus leads to improved achievement on procedural tasks. This is consistent with Norman's theories of knowledge and device use (Norman, 1988).

Only the Mark-IV version of the VCR tutor can be considered an intelligent tutoring system since it incorporates both individualized student modelling and knowledgeable feedback. This research suggests that knowledgeable tutoring is preferable in this procedural domain and shows that it can be provided by an intelligent tutoring system utilizing individualized student modelling. There is, however, a cost-benefit issue to be considered. Constructing the knowledgeable version of the tutor required cognitive modelling to develop a reasonably comprehensive and accurate catalog of bugs. Another important concern was to ensure that the knowledgeable version of the tutor would continue to run in real time, so that the computationally expensive diagnosis and student modelling would not render the simulation unusable. Additional modelling, programming, and performance enhancement costs are the norm in developing intelligent tutoring systems: "the cost of the I in the ITS". This research suggests that the investment can be worthwhile.

This research makes a number of contributions relevant to research about instructional systems.

- It surveys principles of knowledge and instruction that relate to device operation.
- It applies these principles to the design and implementation of various versions of a particular device tutor for a particular task.
- The resulting tutor versions are evaluated to investigate relationships between knowledge and instructional strategy in this domain.
- By comparing different versions of a single tutor, a tightly controlled experiment was assured.
- This evaluation methodology is applicable to the assessment of tutoring systems and the examination of theoretical assumptions underlying their design.
- The results support the claim that knowledgeable tutoring can lead to greater achievement in procedural domains, and so may be a preferable method of training.
- The research demonstrates that intelligent tutoring systems can provide effective instruction.

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