9 TOWARD A MODEL OF ACQUIRING PROCEDURES FROM TEXT

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INTRODUCTION

Understanding how procedures are acquired from text is of both practical and theoretical importance, whether the focus is on the mental processes involved in acquisition, or on how differences in the text affect these processes. From a practical point of view, understanding this process, termed *procedure acquisition* in this paper, is important because all of us follow procedures from written instructions frequently in our daily lives. We fill out forms, assemble children's toys, follow recipes, and are given instructions for using everything from frozen lasagna to home computers. In addition, following procedures is typically a part of our jobs. Sticht (1977) found that in the U.S. Navy, 75 percent of the reading on the job was what he called *reading to do*, where people read in order to carry out some task.

The Need for Research on Procedural Text

There is a body of practically-oriented research on the issue of how usable procedural text or instructions normally are, and whether they can be improved. This research makes clear the value of research on procedural text and also shows the weakness of our current understanding.

Do People Read Instructions?

One problem with procedural text in daily life is that people often do not read it when they should. Although many people normally read instructions, a sizable minority does not. For example, 75 percent of the subjects interviewed by Wright (1981) said that they would read all of the instructions for a videocassette recorder or item of similar complexity, but this means that a quarter of the people would not. In addition, for most other consumer items, 30 percent to 40 percent of people said that they would not read any instructions. This means that at least a quarter of the people buying an item are likely not to read the instructions for it.

One reason that people do not read instructions may be because they do not feel that they need go to the trouble. If they think that there is an easier way to do the task, then they may not bother with the instructions. For example, Barnard, Wright, and Wilcox (1979) found that 30 percent of 200 undergraduates at Cambridge University

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filled out a simple one-question form the wrong way. They were asked to mark which one of three alternatives applied to them, but instead many deleted (marked through), the alternatives that did not apply. It seems more likely that these subjects simply did not read the instructions and instead guessed at how they should answer, than that they did read the instructions but were unable to understand them. Another example is the experiments by LeFevre and Dixon (1986), where subjects presented with instructions and an example that contradicted each other, ignored the instructions and followed the example. People may have learned from experience that instructions are often hard to understand and follow, and this may explain why they often prefer to use other strategies like guessing or following an example. Understanding the procedure acquisition process is not likely to be directly useful in motivating people to read instructions, but if it leads to an improvement in procedure instructions, then people may be more likely to read them.

Can People Follow the Instructions That They Read?

The problem of people not understanding the information they are given is a serious one. Kammann (1975) cites studies by the Bell Telephone Company that found that the instructions for dialing that are provided in the telephone book are correctly applied only 62 percent of the time. He suggests a rule of thumb: even when instructions are used, they are understood only about two-thirds of the time.

Wright (1981) has suggested that problems with understanding procedural text fall into three basic categories: The first is content; sometimes the information in the instructions is wrong. The second is presentation; the language and illustrations used in the instructions may be hard to understand. The third is structure; information may not be appropriately organized for the task. Thus, good procedural text has good content, presentation, and structure; but it is not easy to specify how to determine that a piece of procedural text has these qualities. While a specific piece of procedural text can be improved, it may not be clear which improvements actually made a difference. For example, Felker and Rose (1981) rewrote the FCC radio rules for recreational boaters into "clear English" and showed improvements in both the speed and accuracy of people's application of the rules. However, the fact that the rewritten rules were simply shorter, reducing the original 49 pages of material to 11, may have produced the better performance, rather than the new style of the material. In addition, even professional writers cannot always improve performance with a document. Duffy, Curran, and Sass (1983) found that new versions of technical prose prepared by three different technical writing companies failed to show improvement over the original.

Thus, even the community of practical technical writers cannot reliably improve a text or specify how it would be done. The need for further research and theoretical development is painfully clear.

Theoretical Value of Studying Procedural Text

While understanding procedure acquisition has practical importance, procedural text and the processes of procedure acquisition have distinctive qualities that make them interesting to study from a theoretical viewpoint. One quality is that when reading instructions to carry out some task, a reader's processing of the text is likely to be different from the processing involved when reading stories. Kieras (1981) showed that the task that readers are required to perform can affect how they read a text, so that reading for comprehension involves different amounts and types of processing from reading to identify a main idea. Reading in order to be able to execute some procedure is also likely to have characteristic ways of processing. Another distinctive quality of procedural text is that problems in understanding can be revealed directly in performance. The reader must use the knowledge from the text in order to do something, and so examining what the reader does can be used to assess what the reader acquired.

There is a severely limited amount of research on procedure acquisition. This is surprising, given the practical importance and the theoretical interest of procedure acquisition. The lack of research in this area is unexpected and not easy to understand; it is an important area, instructions are frequently poorly written, and there is no reason to think that procedures are any less theoretically interesting than stories. The dearth of research means that rather than simply review existing literature, this paper will focus on theoretical analysis and will try to outline a theory of procedure acquisition. The current lack of such a theory means that the sparse empirical research seems incoherent because studies cannot easily be related to each other or generalized to situations beyond those studied. Outlining a model of the acquisition of procedures from text will be the first step toward providing a perspective for existing work and will suggest where more research would be fruitful.

Scope of This Paper

In order to present a clear picture of the model, with its strengths and limitations, it is important to define procedure acquisition and to specify what kinds of written material and what aspects of the procedure acquisition process the model is concerned with. The kind of text of interest is *procedural text*, which is text intended to convey a procedure. Procedural text may vary in its level of procedural detail, ranging from a complete, detailed procedure that can be executed more or less directly from the text, through instructions that demand more inferences to be made by the reader, all the way to text that provides only general knowledge about the task and expects readers to infer the actual procedure by themselves. This paper will consider both text that presents incomplete procedures and thus demands some inference, and text that attempts to provide a complete, detailed procedure. However, text that does not try to present an explicit procedure will not be considered because, in this case, the reader's task is problem solving rather than procedure acquisition.

Because a reader's strategies and performance are different with different tasks, it is important to define what tasks are relevant. For the purposes of this discussion, procedure acquisition tasks include (a) reading instructions and performing each step as it is read; (b) reading a whole procedure through and then remembering it long enough to perform it; and (c) reading a procedure and memorizing it for performance later. While instructions may be hard to follow simply because they are poorly written, the task itself may be difficult and complex; such a procedure may be hard to acquire however well the text is written. While procedure complexity certainly deserves study, the writer of procedural text typically has no control over it. Thus, we will focus on effects of how procedural text is written and not on the effects of different kinds of procedures.

The rest of this paper is organized as follows: First, the theoretical model will be described, first in overview, and then some of the theoretical properties of the processes in the model will be described in some detail. Second, using the model as a framework, the relevant studies in the research literature will be surveyed based on what processes in the model each study addresses. A brief conclusion will summarize further research directions and practical implications.

A MODEL OF PROCEDURE ACQUISITION

Our goal is to outline a model of procedure acquisition that constitutes the first steps toward a theory. The model has been suggested both by some research (such as Kieras & Bovair, 1986) and theoretical considerations (notably Anderson, 1983, 1987). In this paper, we will outline the model and describe it in more detail and will then use it as a framework to interpret existing data. The model will also be used to identify gaps in our current understanding of procedure acquisition and to suggest how such gaps may be filled.

The model of procedure acquisition to be outlined was first described in Kieras and Bovair (1986) and is illustrated in Figure 9.1. It distinguishes two major comprehension processes: the basic reading comprehension process, and a procedure comprehension process. The procedure comprehension process consists of three sub-processes: procedure construction, immediate transfer, and an acquisition monitor. Finally, there is a procedure interpreter that actually executes a procedure once its representation has been built. The model assumes that the basic reading comprehension process produces a propositional representation of the input text (cf. Kintsch, 1974). Procedure comprehension processes then use the propositional representation to construct a correct representation of the procedure that can be executed by the interpreter. Once the interpreter can correctly execute the procedure, then knowledge compilation processes (Anderson, 1983, 1987) can begin to operate. Since knowledge compilation takes place after the procedure comprehension processes it is not discussed in detail.

Knowledge Representation in the Model

Procedural and Declarative Knowledge

The model assumes a distinction between procedural and declarative knowledge, along the lines of Anderson (1976). Declarative knowledge consists of a network of propositions in the form of HAM or ACT structure (Anderson & Bower, 1973; Anderson 1976, 1983), while procedural knowledge is represented as production rules (Anderson 1976, 1983). Like propositions, production rules are a good representation for knowledge because they provide a modular representation consisting of discrete components that are of roughly the same "size," and can be counted and used to make quantitative predictions. Examples of the use of production rules in this way may be found in Kieras and Bovair (1986), and Bovair, Kieras, and Polson (1988).

Examples of procedure text and the corresponding production rules are shown in Tables 9.1 and 9.2 (cf. Kieras and Bovair, 1986). The syntax of the production rules in Table 9.2 is (*Name IF (condition) THEN (action)*), where the condition tests for information in working memory, and everything in the action part of the rule will be executed if the condition is satisfied. In Table 9.2, the first rule is named *Start*. Its condition will be satisfied if the goal to do the procedure is present in working memory, and the note that the procedure is being done is not present. If the condition of this rule is satisfied, then the action will be executed, resulting in the goal of doing the first step and the note that the procedure is being done being added to working memory. This changes working memory so that the condition of the first rule is no longer satisfied, but now the condition of the second rule in Table 9.2 is satisfied.

Thus, each production rule modifies working memory in a way that "triggers," or *fires*, the next rule in the sequence. To correctly represent a procedure, the production

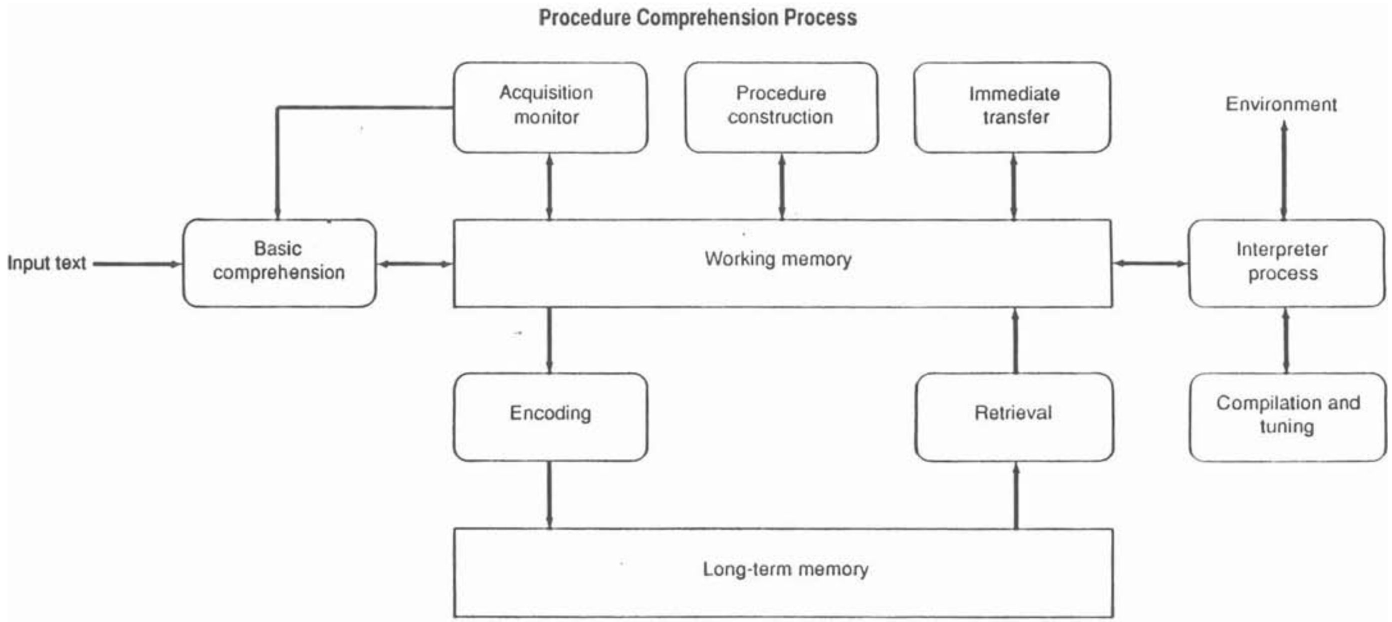

FIGURE 9.1 An outline of a process model for acquiring a procedure from text. *Source*: The acquisition of procedures from text: A production system analysis of transfer of training, by David E. Kieras and Susan Bovair. *Journal of Memory and Language*, 25(5), October 1986.

TABLE 9.1 Example of Procedural Text

If the command is to do the X procedure, then
Step 1: Press the red button
Step 2: If the red light is on, set the selector to X.
Step 3: If the blue light is on, then the system is ready.
Step 4: If the white light is on and the green light is off, press the blue button.

rules have to have a properly coordinated set of conditions and actions. Generating the correct set of rules from the input propositions is the job of the procedure comprehension process.

Acquiring a procedure from text is closely related to the process of acquiring procedures in general, which has been studied under the label of *acquisition of cognitive skill* (Anderson, 1981). Learning the procedures for a word-processing pro-

TABLE 9.2 Production Rules for Example Procedure

(Start	IF	((GOAL DO X PROCEDURE)
		(NOT (NOTE DOING X PROCEDURE)))
	THEN	((ADD GOAL DO STEP ONE)
		(ADD NOTE DOING X PROCEDURE)))
(Step1	IF	((GOAL DO X PROCEDURE)
		(GOAL DO STEP ONE))
	THEN	((PRESS RED BUTTON)
		(DELETE GOAL DO STEP ONE)
		(ADD GOAL DO STEP TWO)))
(Step2	IF	((GOAL DO X PROCEDURE)
		(GOAL DO STEP TWO)
		(LOOK RED LIGHT ON))
	THEN	((SET SELECTOR TO X)
		(DELETE GOAL DO STEP TWO)
		(ADD DO STEP THREE)))
(Step3	IF	((GOAL DO X PROCEDURE)
		(GOAL DO STEP THREE)
		(LOOK BLUE LIGHT ON))
	THEN	((DELETE GOAL DO STEP THREE)
		(ADD DO STEP FOUR)
		(ADD NOTE SYSTEM READY))
(Step4	IF	((GOAL DO X PROCEDURE)
		(GOAL DO STEP FOUR
		(NOTE SYSTEM READY)
		(LOOK WHITE LIGHT ON)
		(LOOK GREEN LIGHT OFF))
	THEN	((PRESS BLUE BUTTON)
		(DELETE GOAL DO STEP FOUR)
		(ADD GOAL FINISH)))
(Finish	IF	((GOAL DO PROCEDURE)
		(GOAL FINISH)
	THEN	((DELETE GOAL FINISH)
		(DELETE GOAL DO PROCEDURE)
		(DELETE NOTE DOING PROCEDURE)))

gram to the point where they can be executed rapidly and without effort is an example of the acquisition of a cognitive skill. Anderson (1976, 1983) proposed that there are three stages in the skill acquisition process, as had Fitts (1964) before him. The first is the *declarative stage*, where a declarative representation of relevant knowledge is used by skill-independent production rules to produce behavior. In Anderson's model, knowledge of a procedure is assumed to be initially in declarative form. During this stage, the procedure can only be executed in a conscious, controlled way that often involves some degree of problem solving.

In Anderson's second stage, the *knowledge compilation stage*, the skill has been practiced enough that it can be executed with much less effort. At this stage the skill is represented as production rules, with each step represented in a separate rule; and when given the initial goal and appropriate context information, the rules run with no pause for problem solving. The third stage is the *tuning stage*. With practice, the rules become more and more efficient, steps are collapsed into one another, and the procedure is executed rapidly and with little effort.

Our model of procedure acquisition concentrates on the declarative stage of skill acquisition, where the text is translated into a declarative representation of the procedure. Although the later stages of skill acquisition are obviously important, they are assumed to be the result of practice and experience rather than reading the initial text, and therefore of less interest for this paper. Thus, the focus here will be on the text and how readers can generate a procedure from it, not on how people can remember a procedure over a long period of time, or how they improve in performance with practice. In this context, it is interesting to note that if we take Sticht's (1977) reading-to-do tasks as being largely procedural, then much real-world procedure acquisition is also concerned with generating and immediately following a procedure from text, rather than memorizing the procedures; Sticht found that 80 percent of reading on the job is for tasks that the reader has already done before.

Declarative Representations of Procedures

The model assumes that a procedure is first represented in declarative form and becomes represented as production rules only after the procedure has been acquired and practiced. However, it is both possible and convenient to describe this declarative form *as if* it were a set of production rules. This characterization is possible because the content of a procedure can be represented in either form, and convenient because a set of production rules can be easily checked for completeness and correctness by trying to execute them. Thus, it is useful to think of the reader as constructing a declarative version of the production rules that are needed to execute the procedure. Once a complete and correct declarative representation of the procedure has been constructed, then the true procedural representation can be constructed. Thus, although the initial representation of a procedure is easily expressed as production rules, the actual representation is assumed to be declarative.

The main thrust of this assumption is one of maintaining theoretical traditions and clarity; it seems accepted that declarative representations can be constructed and manipulated by complex, knowledge-driven, inferential processes, such as comprehension and problem-solving, while developing procedural knowledge is governed by more elementary, automatic mechanisms. If we assume that the reader temporarily represents a procedure as a declarative isomorph of the procedural production rules, it is easy to integrate standard theoretical reading mechanisms with standard theoretical cognitive skill mechanisms. Of course, other formats for the declarative representation of a procedure are possible; we have adopted production rule isomorphs only because of their formal adequacy and direct relationship to the assumed format of procedural knowledge. It would be worthwhile to construct a full simulation model of the procedure acquisition process to determine the viability of this representation and to explore alternatives.

Following the GOMS model of procedural knowledge proposed by Card, Moran, and Newell (1983), the model assumes that procedures are organized hierarchically in terms of *goals* and subgoals. For each goal, there is a procedure, called a *method*, for accomplishing the goal. A method consists of steps that can be either elementary actions, termed *operators*, or assertions of subgoals that need to be accomplished. The mapping between GOMS models and production rules is provided by Bovair, Kieras, and Polson (1988), and all of the example procedures and methods used in this paper follow the conventions described.

Processes Involved in Learning Procedures from Text

Reading Comprehension.

The reading comprehension process in this model of procedure acquisition is assumed to be the same as for any other reading task and consists of reading processes like those described in Just and Carpenter (1987a). Thus, this process will have problems with procedural text similar to those it would have with technical prose or narrative text. The reading comprehension process reads and processes the instructions one sentence at a time, parsing each sentence, and doing the basic referential and semantic analysis needed to create the propositional representation for each sentence in working memory. A typical referential analysis might involve simply attaching the label for a particular object to the appropriate concept. Thus, a knob might be referred to as *the tuning knob*, and this label must be attached to an instance of the concept KNOB. Note that for a procedure to be executed, the actual physical objects referred to must also be identified in the environment, so that the specified action can actually be performed. But it is not clear if identifying the external referent occurs during the reading comprehension process or if it occurs later.

Procedure Comprehension Processes.

In our model, the procedure comprehension processes build a declarative representation of the procedure from the propositional representation of the procedure text. Procedure comprehension is similar to what Just and Carpenter (1987a) describe as text-level processes in reading comprehension, in which schemas are used to integrate the text: for example, in comprehending narrative text, such processes use inference to fill in the causal chain of events. While establishing the causal and temporal chain is particularly important in stories, it may also be an important part of constructing a procedure. The idea that there are procedure comprehension processes that take place after reading comprehension is somewhat similar to the distinction proposed by van Dijk and Kintsch (1983) between the processes that produce the text base and those that produce the situation model.

Procedure comprehension consists of three major sub-processes. This first is the *procedure construction* process, which takes the representation of the text and constructs the declarative form of production rules. The others are the *immediate transfer* process, which checks to see if newly constructed rules are already known, and the *acquisition monitor* process, which monitors whether a new rule has been fully learned.

Procedure construction. Our model assumes that the propositional representation of the text is used to construct an executable propositional representation of the procedure; but our understanding of the procedure construction process is quite limited, and it is not clear just how this construction takes place or what stages might be involved. It is possible to describe a general outline of the process; but in order to work out the details, a simulation model would need to be built and more research performed.

The assumptions of the model provide the framework within which procedure construction can be characterized. The theoretical problem is to determine how the production rules are constructed based on the information in the text. In other words, just how is text like that in Table 9.1 translated into rules like those in Table 9.2? Procedure construction involves heavy use of implicit information; for example, for each step in the procedure, the information about the goal, the current context, and the next step are all typically implicit but need to be explicitly encoded into the condition and action of a production rule. Problem solving may be required to infer missing information and details of the actions to be performed if they are not stated explicitly.

We can elaborate on some of these construction processes. In deciding what the goal of a procedure is, the reader is likely to be influenced by a variety of cues in the procedure text. Sometimes the goals will be stated explicitly: *If the goal is to do the MA procedure, then* . . . , but it may be signaled more indirectly, as in Table 9.1 by means of a short lead-in phrase such as *if the command is to do the X procedure* . . . or a heading. In the absence of more specific statements of the goal of the procedure, readers may simply assume that the end state of a procedure is the goal state.

The reader of procedural text must also generate rules that will perform the correct actions in the right order. The text may directly help the reader by using labels such as Step 1: as in the example in Tables 9.1 and 9.2, in which the step labels are incorporated into the rule conditions and actions. Also, production rules can have several elementary actions in a single rule. This would mean that a statement such as *Press button A and press button B* would be translated into one rule with both button pushes in its action. On the other hand, a useful assumption for newly learned procedures is that there is only one such action to a rule (Bovair, Kieras, & Polson, 1988). However, even when a single action is explicitly indicated in the procedure statement, there may be more than one step implied, and therefore more than one rule will need to be built. For example, Step 2 in Table 9.1 appears to correspond directly to a single production rule, as shown in Table 9.2. But it can also be interpreted as conveying two steps. The first is performing the actions to determine the state of the light (e.g., finding and looking at the light), while a second is setting the selector. This means that two production rules would need to be built to represent this step, one that checks the light and stores its state in working memory, and one that tests the state of the light and acts accordingly.

In a further complication, what seems to be a single step may actually be a whole method rather than a single rule. For example, Dixon (1982) used statements like *The left knob should be turned in order to set the alpha meter to 20.* Apparently, this could easily be translated to:

(IF ((GOAL SET ALPHA METER TO 20)) THEN ((TURN LEFT KNOB)))

However, this simple translation is not correct, because simply turning the left knob will not get the meter set to 20; the knob must be turned while the meter is monitored. When the right value is reached, the knob turning is stopped; if the meter overshoots, then the knob is turned in the opposite direction, and so forth. This single statement seems more accurately characterized as the user having the goal of setting the meter, and executing knob-turning and meter-monitoring methods in order to accomplish that goal.

Immediate transfer. Based on the results in Kieras and Bovair (1986), there is an immediate transfer process that compares the representation of the current rule to the already-known rules. If the current rule is new, then it must be maintained in working memory and encoded into long-term memory, which takes time. If the current rule is the same as, or very similar to, an existing rule, then at most small modifications of the existing rule will be required, and these take very little time. This immediate transfer process is responsible for large savings in the time to learn new procedures if they have steps in common with previously read or learned procedures (Kieras, Tibbits, & Bovair, 1984; Kieras & Bovair, 1986; Bovair, Kieras, & Polson, 1988).

Acquisition monitor. Finally, procedure comprehension also seems to involve an executive control process (Schumacher, 1987) that monitors the acquisition of the steps of the procedure. Kieras and Bovair (1986) had subjects learn procedures from a step-by-step, self-paced presentation and found that the reading time for each step of a procedure remained high until the subject could execute the step without error. At this point, when the step is apparently learned, the reading time for the step decreases sharply. Thus the subject allocates more time to steps not yet acquired and less time to acquired steps. This ability to allocate time between new and known material was also found by Johnson and Kieras (1983), who studied the effects of prior knowledge on reading and recall of simple expository text and found that subjects concentrated their time on the unknown information. The acquisition monitor process must be able to distinguish known from unknown steps to decide which information should be studied in more detail.

Executing and Debugging Procedures

Once the declarative version of a procedure has been constructed, then a procedure interpreter process accesses the representation and executes the procedure. This execution will succeed if the declarative representation has been correctly constructed. After this stage has been reached, the processes of skill acquisition that create a procedural knowledge representation of the procedure may begin.

FACTORS AFFECTING PERFORMANCE IN ACQUIRING PROCEDURES FROM TEXT

Performance Measures

In assessing performance with procedural text, the task chosen will affect processing and thus performance measures. For example, there is some evidence that reading to execute a single step immediately may be different from reading to execute the whole procedure later (Dixon, 1982). There is also evidence that subjects asked to read procedural text for recall may read it differently from when they read for immediate execution (Dixon, 1982; Kintsch, 1986). The model outlined here suggests that tasks differ because they call different processes into play. If subjects are presented with procedural text to be recalled, they may simply memorize it as text and not as a procedure, thus involving only the reading comprehension and text-encoding processes. Procedures presented one step at a time for immediate execution of each step will involve both reading comprehension and procedure comprehension processes. However, the procedure comprehension stage will not need to integrate the procedure steps into a whole procedure, nor will the procedure have to be encoded into long-term memory.

If the concern is to assess how well procedural text allows the reader to actually perform the procedure, the best measures of success will be how quickly and accurately the reader can perform the procedure. In addition, reading time is a useful measure of both reading comprehension and procedure comprehension processes. Because verbal recall of a procedure may not involve much of the procedure comprehension processes, it has little value as a measure in the study of procedural text, in contrast to its role in much reading research. Measuring how well the procedures can be executed after a delay is a far more useful measure of retention.

Given the limited number of measures and tasks that are typically used in the study of procedural text, it may be difficult to distinguish the different processing stages that the model predicts from each other. For example, it may be hard to distinguish reading comprehension and procedure comprehension from each other, given that reading time reflects both processes. However, the syntactic complexity of the text should affect reading comprehension, while the complexity of the procedure should affect procedure comprehension; and so it may be possible to distinguish the procedures with an appropriately designed study.

Factors Affecting Reading Comprehension of Procedural Text

Reading comprehension effects in procedure acquisition are hard to assess by themselves because it is difficult to separate them from the effects of procedure comprehension or even execution. One reason for this is that experiments are typically not designed to study reading comprehension of procedural text separately from the other stages, frequently using overall measures that include all three stages. Basic comprehension should not be a source of execution problems unless a procedure is so incomprehensibly written that it is hard to construct a complete procedure at all, and so execution measures are not likely to reveal much about the basic comprehension stage. Even when more direct measures of reading comprehension such as reading times are collected, they can be affected by both procedure comprehension and reading comprehension.

One way to alleviate our inability to distinguish basic comprehension from procedure comprehension is to make the reasonable assumption that procedural text has the same reading comprehension processes and problems as other technical prose. Some factors that affect the comprehension of technical prose have been summarized by Kieras and Dechert (1985). One example that is well known from the comprehension literature is that negatives are harder to comprehend than affirmatives; the same is true of procedural text. Jones (1966) investigated the use of the qualifying negative *except* on the performance of a task. In one experiment, subjects were given the command *Mark the numbers 1, 3, 4, 6, 7* for a long string of digits 1 through 8, arranged randomly. Subjects seeing this command were faster and made fewer errors than subjects who saw the equivalent command *Mark all the numbers except 2, 5, 8*, although the number of items to be remembered is smaller. File and Jew (1973) gave airline passengers waiting for their flight some emergency instructions to be recalled that were presented in either written or oral form, were either affirmative or negative, and were either active or passive. Subjects tended to recall in an affirmative, active form, regardless of how the material had been presented, and their recall was better when the instructions had been presented in the affirmative form; but there was no difference between active and passive presentation.

While slower performance on instructions containing negations may be due to effects on reading comprehension, it may also be that it is more difficult to construct a procedure if it is presented in a negative form. One way to explain the results, from a study by Wright and Wilcox (1979), is as procedure construction effects. They found that while affirmative forms were always better, two negations could sometimes produce faster and more accurate performance than one. Subjects were required to perform one of two tasks, and the instructions contained either zero, one, or two negations. In the single-button task, the subject was required to either respond by pressing a button or not respond at all, based on the instruction and a presented letter. For example, *Do not press if the letter is P* has a single negation, while *Do not press unless the letter is P* has two. In the two-button task, the subject had to choose between one button or another, such as, *Press the right-hand button if the picture is a circle; press the left-hand button if not.* Wright and Wilcox found that in the single-button task, two negations in the instructions produced faster, more accurate performance than only one, but that one negation was better than two in the two-button task. If these effects were due only to reading comprehension effects, both tasks should show the expected pattern that two negations were harder than one.

The Wright and Wilcox effects may be a result of the way negations in text are translated into production rules. A production rule with a negated *action* is impossible, because the action is executed only if the rule condition is met; so a statement with a single negation like *Do not press if the letter is P* cannot be translated into

IF ((letter present) (letter is P)) THEN (NOT (press)).

Rather, in order to be executed it has to be transformed into

IF ((letter present) (NOT (letter is P))) THEN (press).

A statement containing two negative elements like *Do not press unless the letter is P* can be simply recoded into an affirmative form and then directly translated into

IF ((letter present) (letter is P)) THEN (press).

Simply recoding the whole statement into the affirmative form may be relatively easy, compared to moving the negation from the action to the condition. However, this may only be true for the single-button task; in the two-button task, the subject may attempt to construct a rule for each button, and this may remove the advantage for the double negative.

Although procedural text may have reading comprehension problems similar to those of other technical prose, such as difficulty with negative forms, it is likely to have characteristic reading comprehension problems as well. For example, procedural text seems to be especially prone to problems with reference. Wright (1981) suggests that people make errors with phrases used to qualify numbers, such as *at least* or *not more than* because they seem to concentrate on the number and disregard the qualifier. Such problems may arise either because of the difficulty of establishing the meaning of such open-ended terms, or the difficulty of building a procedure with them. Fisher (1981) analyzed the errors made on functional literacy tests, which are in large part tests of ability to use procedural text. For example, an item on such a test might be *Look at the program for a Business Administration course. Circle the term in which the subject "Salesmanship" is given.* Fisher found that 20 percent of the errors made on such items could be interpreted as a result of the reader failing to take into account a word, part of a word, or phrase in the instructions. For example, subjects might be given *lieutenant-general* in the instructions but circle examples of *general* in the material. Also, 16 percent of the errors were a result of the subjects giving more information than was requested, as when they were given *fruit dishes* and they circle both fruit and vegetable dishes. As Just and Carpenter (1987b) point out, these results suggest that a total of 36% of the errors may be a result of interpreting a referent too broadly. Just and Carpenter (1987b) have suggested that errors due to referential difficulties in procedural text could arise because the vocabulary used in procedural text is more likely to contain unknown terms, and these may lead to semantic and referential problems. For example, if the components are novel in an assembly task, the user may not know what a referent looks like. The presence of unknown terms may also explain why subjects interpret referents too broadly; for example, they may not know the difference between *lieutenant-general* and *general* and assume that these are different names for the same thing. Such problems may be obscured in ordinary reading tasks and materials but are unavoidable in procedural tasks, where subjects have to demonstrate their understanding overtly.

Factors Affecting Procedure Comprehension

Knowledge Required for Procedure Acquisition

Instructions do not spell out a procedure in the detail needed to actually construct and execute it. Readers must therefore try to infer these details from other knowledge. In many situations, a subject must build a procedure that includes many details of exactly what must be done that are usually not included in the instructions. For example, consider a step from the Smith and Goodman (1984) assembly task, *Now you are to wrap one end of the wire around one of the short bolts.* Before readers can actually carry this step out, they must find a short bolt and pick it up, then decide how to wrap the wire, and then select the part of the bolt where the wire should be wrapped.

The physical objects involved in the procedure can be a source of knowledge about how to perform various actions; how to operate a control is often suggested by the shape of the control, and the labels can suggest when to operate it. Instructions usually assume that the reader has at least some appropriate domain knowledge; for example, readers are usually assumed to know what a child's wagon looks like, or how to use a screw-driver, or turn a knob. If the objects and the prior knowledge support the required inferences, then inferring the necessary details will be quick, and constructing and executing the procedure will be easy. But if the knowledge is not available, then readers must try to fill in the gaps by engaging in problem solving, with varying levels of success. For example, although detailed procedures are often called "recipes," actual cooking recipes assume knowledge of cooking methods and equipment. If a reader does not know how to execute the *simmer* method, then the chicken cacciatore is likely to end up burnt. A direction like *add the softened butter* may cause problems for the cooking novice, because he or she has to figure out how to get the butter softened before executing the adding step. Because readers vary so much in their knowledge, even procedures that appear well specified may still demand major problem-solving efforts by some readers. For example, although the procedures used in Kieras and Bovair (1986) were intended to provide all the executable detail, some subjects thought that the lights on the control panel were push buttons and became very confused when pushing them had no effect.

If readers have the appropriate background knowledge, they may still be able to construct a correct procedure even when the propositional representation derived from the instructional text is defective. For example, in a study by Mohammed and Swales (1984), subjects used the manufacturer's instructions to set the time and the alarm on a digital alarm clock. Their subjects were either native or non-native speakers of English with either a science or a non-science background. The striking result was that non-native speakers with a science background were faster than native speakers of English with a non-science background. This result implies that it is not basic comprehension that is critical in using instructions but the ability to infer the details needed to construct correct procedures.

If knowledge needed to infer some detail used in constructing a procedure is not available, then the reader may not be able to do some step in the procedure. The problem may be identified at any stage in the process of procedure acquisition. For example, if a step in some procedure requires a reader to *Degauss the CRT*, then the reader must know how to degauss something, what the CRT is, and where to find it. When does the reader find out that he or she does not have this knowledge? The reader may be able to tell either during reading, because these words are unfamiliar, or during procedure construction, when he or she cannot construct a degaussing method from the instructions. But the reader may have to wait until procedure execution for it to become clear that how to degauss the CRT is not apparent from the execution context. For example, there is no push button on the device labeled *CRT Degauss*. Thus, frequently the reader may recognize a lack of knowledge in the reading comprehension or procedure comprehension stages, but sometimes the procedure must be executed in order for problems to become obvious.

Thus, the execution stage is the last chance to map the text onto the world, and so problems found here tend to be those that were not anticipated during procedure construction, and they may not be solvable by rereading the instructions. For example, readers may find that they do not know where a particular knob is. In addition, determining the correct sequence of steps is typically done during procedure construction; but if the text does not specify the order of steps, and the reader does not have the knowledge needed to infer it, then the correct order may have to be determined during execution by trial and error.

Supporting Inferences Needed to Construct an Executable Procedure

In the absence of useful cues from the physical objects, or appropriate background knowledge, the reader of procedural text may be able to make the proper inferences if the text itself contains the necessary information. Wright (1981) gives the example of a patient who has to decide how faithfully to follow the prescription orders given by the doctor or pharmacist, and how to interpret instructions such as "take two tablets a day." Providing information about the consequences of not following the orders, or about what the drug is supposed to do may help the patient make these decisions. Thus, whenever a reader must make inferences in order to construct a procedure, providing an explanation may help the inference processes.

While readers may not be able to make the correct inferences because of lack of knowledge, they also may not realize that the inferences they are making are incorrect. Evidence for this comes from a study by Kieras, Tibbits, and Bovair (1984), who compared experts and novices in a device operation task. The instructions were presented either in a linear step-by-step form or in a hierarchical menu, where making a menu choice gave the reader the appropriate step-by-step instructions. The hierarchical menu resulted in faster, more accurate performance if the subject was familiar with the device, but step-by-step instructions were better if the device was unfamiliar. With step-by-step instructions, lack of knowledge is not a problem because relatively few inferences are needed; but the hierarchical menu system apparently tempted subjects to try to infer parts of the instructions, and their lack of knowledge sometimes led them astray.

Explanatory material that can be used to support inferences in procedure construction can be divided into two main types. The first can be described as *how-it-works information* about components of the system and their relationships, while the second is *goal structure information* that explains why the steps are done in terms of what is accomplished. For example, in directions for assembling an electrical device, information about how electric circuits work is how-it-works information (Smith & Goodman, 1984). In providing goal structure information, a reader might be directed to assemble two float devices and a small connector bar and then might be told that this is done in order to make the base of a crane (Konoske & Ellis, 1986).

The helpfulness of a how-it-works explanation was demonstrated by Kieras and Bovair (1984), who found that subjects given a mental model of a device performed better during step-by-step training of the operating procedures for the device, compared to subjects who received only the procedure training. This experiment required the subjects to read through all the steps in the procedure before attempting to execute them from memory, and subjects were both faster and more accurate when they were given the mental model. In addition, the mental model was especially useful to subjects who were required to infer the operating procedures. The advantage for the mental model may be attributed to an improvement in memory for the procedures, due to these subjects being able to reconstruct the procedure by inference from the how-it-works knowledge. But the model may have also helped subjects infer the procedure so that they did not need to spend as much time on procedure construction. In addition, a similar study by Smith and Spoehr (1985) found that per-syllable reading times for instruction steps were faster for subjects given a device model, suggesting that the explanation benefited reading comprehension or procedure comprehension or both.

The value of goal structure information was shown by Smith and Goodman (1984). They provided subjects with instructions for a circuit assembly task that were either step-by-step directions with little explanation (the *linear* condition), or that had additional explanatory material. This material was either pure goal structure knowledge (the *structural* condition), or a mixture of goal structure and how-it-works information (the *functional* condition). They found that reading time and errors were worst for step-by-step instructions, and that the structural condition showed the best recall and transfer to a similar circuit, with the functional condition close behind. This implies that the goal structure information is the most useful for procedure construction, although clearly these results are too sketchy to resolve the issue of the merits of goal structure versus how-it-works information. Konoske and Ellis (1986) performed similar experiments in which they provided subjects with step-by-step instructions for the assembly of a model crane that seem to have been either with no explanation or with goal structure explanations. Subjects with goal structure information performed better both initially and after one month. However, in one experiment, the subjects were U.S. Navy personnel with mechanical experience, and for these subjects, there was no advantage for the explanatory information. This suggests that subjects who have the requisite domain knowledge benefit less from explanatory material.

Evidence of the organizing value of goal structure information is provided by Dixon (1987a), who had subjects draw pictures using components described in the instructions; for example, *This will be a picture of a wagon. Draw a long rectangle with two circles underneath.* He found that when information about what the picture will be is presented first, the directions are read faster. When the presentation order is reversed, Dixon suggests that readers buffer the information about the picture components until they find the organizing goal information, and try to guess the relations between the component steps. The guessing hypothesis is supported by the fact that most of the reading time difference comes when reading the components, and that the size of the effect is related to how difficult it is to guess relationships between components presented by themselves.

Another view of explanatory material proposed by Reder, Charney, and Morgan (1986) is that it consists of *elaborations*, which are typically either examples that provide specific instances of a procedure, or *analogies* that try to relate the new procedure to one the reader already knows. The study by Reder et al. (1986) suggests that providing such elaborations in a procedural text helps during reading only if readers do not know what task they will be asked to perform. In this study, subjects read general information on computers and computer commands, and then did tasks that required issuing several commands in sequence. Subjects were either provided with elaborations in the text or not, and were told what the task would be either before or after reading. If the task instructions were given after reading, the time per task and the efficiency (measured by the total number of commands issued, and the number of commands compared to the minimum required) were best for the elaborated manual. If task instructions were given first, it did not matter if the text contained elaborations or not. This is consistent with the interpretation that the elaborations helped subjects remember the information required to construct later-specified procedures; if the readers knew the procedure specifications prior to reading, they could apparently select the relevant material for encoding while reading, meaning that the elaborations are less useful. In a second experiment, where the elaborations were divided into elaborations of command syntax and of computer concepts, syntax elaboration showed improved performance, but the conceptual elaboration did not. This second experiment provides more support for the idea that it is goal structure information like command syntax that helps, not the general, conceptual how-it-works information. Note that this is consistent with the point argued in Kieras and Bovair (1984), that the explanatory material has to support the inference of specific procedures to be useful.

Examples seem to be especially important in procedural text. An example provides an instance of a complete, executable procedure; and it may be far more efficient to translate the example into a procedure and modify it where necessary, than to build a whole new procedure from the text. This may explain the result from a study by LeFevre and Dixon (1986), who found that when subjects were asked to answer series completion or classification questions, given an example and instructions that contradicted each other, they followed the example. However, conclusions drawn from this study must be limited because the example and test problems used were both pictorial, while the instructions were in the form of text. Subjects may prefer the pictorial example because it is in the same modality as the test problem and so seems simpler. However, most users of computer reference manuals would probably testify to the extreme usefulness of examples compared to descriptive text; this is clearly a topic in desperate need of further research.

In addition to being presented early in the instructions, goals need to be clearly signaled to the reader by being made explicit. Dixon, Faries, and Gabrys (1988) have shown that readers who are relatively unfamiliar with the task to be performed are more affected by text form than readers familiar with the task. Using recipes as their instructions, they found that explicit forms such as *soften the butter* rather than implicit ones like *blend the softened butter* . . . were read more quickly and were more likely to be remembered by subjects unfamiliar with cooking. The explicit form may signal to low-knowledge readers that they need to do something to get the butter softened, and that the statement is in fact the goal of a method and therefore important. With the implicit form, they may not realize this.

Procedure Construction

Importance of Procedure Construction

Constructing a procedure from the representation of the text is perhaps the single most important step in acquiring a procedure. Holland, Rose, Dean, and Dory (1985) attempted to characterize good instructions compared to poor ones for the tasks of tying a necktie or assembling a model car. They found that the good and bad instructions could not be distinguished by text characteristics likely to affect reading comprehension such as length of text or length of sentences; indeed, some of the best instructions had the most complex syntax and sentence structure. The important differences between good and bad instructions seemed to be those of content; in particular, poor instructions omitted important details like the orientation of parts in the assembly task, and often included the wrong level of detail. For example, in the task of tying a necktie, it is useful to be told how the tie should look after each step, but details of the exact positions of the hands are confusing.

Organizing Information to Aid Procedure Construction

One important issue is how to present the information so that a procedure can be constructed as efficiently as possible. There are many potential organizations for presenting procedures, and the preferred ones must be those that facilitate the construction process. Spoehr, Morris, and Smith (1983) have pointed out that the organization of information may be studied at two levels: the *micro-level*, where the contents of a single step are the focus; and the *macro-level*, where the focus is on understanding how the steps can be best organized.

With regard to macro-organization, our model assumes that procedures are organized hierarchically, with the hierarchy determined by the goal structure. This implies that instructions should have a hierarchical structure. Gordon, Munro, Rigney, and Lutz (1978) looked at the structure of stories, instructions, and definitions, using their own analyses of the text structure of each type of text. They defined rewrite rules to express the text structure for each type of text, and generated the corresponding tree diagrams. They found that definitions have little structure, while stories and instructions are hierarchical, with stories having a more hierarchical structure than instructions. This structure difference may arise because stories have both a strong temporal and causal structure, while procedures may have less causal structure. Gordon, Munro, Rigney, and Lutz (1978) found that the degree of structure appears to be important for how well the text is remembered, as the strongly constrained stories are recalled best and the unconstrained definitions recalled the least. The intermediate level of structure observed for instructions seems to suffice for short procedures, but long ones impose a greater load on memory and their recall is poor.

A hierarchical structure for procedures in memory is also suggested by Graesser (1978), who studied memory for common procedures, such as how to wash a car or catch a fish. One group of subjects generated the procedures from their own knowledge, another group answered *why*? questions about them, and the third group listened to the procedures and tried to recall them. It is important to note that although subjects listened to the procedures before recalling them, such very familiar procedures were clearly not acquired or learned in the usual sense; and so this study actually examined the structure of already-known procedures. Graesser scaled the hierarchy and relational density, using the answers to the *why*? questions, and found that statements higher in the hierarchy, related to many other statements, were better recalled. If procedures are stored in memory in hierarchical form, as this work suggests, then presenting them in this form may assist in the process of constructing the procedure.

A relatively well-researched aspect of organization is the order in which elements of a procedure are presented. The best order may be the one where the procedure elements are presented in the order in which they are used in executing the procedure; this idea is what Dixon (1982) calls the *use-order principle*. At the level of the complete procedure, this seems obvious; if the steps of a procedure are not presented in the order in which they are to be executed, then the reader will have to put them into the correct order; and this may well be difficult, as suggested by results reported in Kieras (1985). But the use-order principle may also hold at the level of individual steps. A step will be easier to construct if its elements are presented in the order in which they are used in the task.

There are several studies of micro-organization effects. Smith and Spoehr (1985) found that reading a procedure step in an assembly task is faster when information about the action, actor, and object in the step is presented first rather than orientation, location, or modality. In this case, the actor, action, and object information probably is needed first, while orientation, location, and modality provide the details of the operations to be performed. Dixon (1982) presented single steps in various orders of their action or condition components, which he labeled in a somewhat confusing manner. A "condition" could be a "consequence" of the action, as in *Turn the knob so that the meter reads 20*, or an "antecedent" of the action, as in *if the blue light is on, press the button*. He found that for both types of condition, presenting the action first produces faster reading than putting the condition first. On the other hand, Spoehr, Morris, and Smith (1983), using the same meter-setting task, distinguished more clearly Dixon's types into the forms *antecedent condition*, *action*, and *consequent of the action*. They used all six possible orders of antecedent condition, action, and consequent and found that the order antecedent, action, consequent was read the fastest. Dixon (1982, 1987c) argued that his result supports the idea that actions are of primary importance in building a procedure, while Spoehr, Morris, and Smith argued that their result supports the use-order principle. The reader first has to determine whether to do something, then what to do, and then what the final state should be (when to stop turning the knob). Spoehr, Morris, and Smith suggest that one reason for the difference between their results and those of Dixon (1982) is that his results averaged the antecedent-first and consequent-first conditions, giving an apparent advantage to the action-first condition. The nature of the task to be performed may also affect the preferred order; for example, Dixon (1987b) has found that when subjects were looking for a particular light to be either on or off, then action-second sentences were read faster than action-first. He also found that while action-first pairs are generally read faster if the task is to execute the step, antecedent-action pairs are read faster if the task is verbal recall.

One possible problem with these studies of micro-level order is differences in comprehensibility produced by the order manipulations. For example, in the Spoehr, Morris, and Smith (1983) study, the order of the components is confounded with comprehensibility of the instructions; *So that the gamma meter reads 20 if the sigma indicator is on turn the right knob* seems rather more difficult to read than *if the indicator is on turn the right knob so that the gamma meter reads 20*, not because of the use-order issues but due to violations of normal English sentence structure.

The apparently contradictory results on micro-level order present a confusing picture; the optimum order is not clear, nor is it clear why the results can be so different for apparently similar tasks. Perhaps conceptualizing the task differently might help. In performing a task from instructions, the reader must construct a procedure with the steps in the correct order for execution. Thus, presenting the steps in their execution order, according to the use-order principle, should help the reader to construct the procedure, leading to shorter reading times, and possibly fewer errors and shorter execution times as well. But labeling parts of the procedure with arbitrarily-defined labels, such as antecedent, action, or consequent, does not seem a particularly useful way to think about the content of the instructions. As discussed above, there may be several production rules that need to be built for a single condition or consequent; so it is not obvious that the steps conforming to such labels will be related in a simple way to how they are used in constructing a procedure.

Immediate Transfer and Acquisition Monitor Processes

Immediate Transfer

As described by Kieras and Bovair (1986), the immediate transfer process can be responsible for large savings in the time to acquire new procedures. But it is not clear if the content or organization of the procedural text would affect these savings. The transferability of steps depends on their similarity, which is basically determined by the procedures themselves rather than how they are presented. But it is possible that the instructions could help transfer by emphasizing the similarity of steps or hinder it by obscuring the similarity.

According to Kieras and Bovair (1986), the transfer process is quite limited; subjects can transfer steps that are either the same, or that have only a single minor point of difference in their goal. This implies that the transfer process may be quite sensitive to differences in how the procedure is written. For example, using different terms to refer to the same object may hamper the transfer process. Foltz, Davies, Polson, and Kieras (1988) found that simply changing the name of a procedure from *Delete* to *Erase* produced a failure to transfer. Because of a small change in how the procedure was described, readers treated a procedure as new that in fact was virtually the same as a previously learned one.

Acquisition Monitor

The work by Kieras and Bovair (1986) mentioned above is one of the few pieces of evidence for the acquisition monitor process. Readers spend more time reading a step that has not been acquired, and less on a step that they have just learned. However, these results provide no indication of how the acquisition monitor process occurs or what might affect it. Another piece of evidence for the process is the result described above that in tying a necktie it helps to tell the reader how a tie should look after every step (Holland, Rose, Dean, & Dory 1985), which suggests that the acquisition monitor can use such information to check for correct acquisition of the procedure steps.

Factors Affecting Execution of Procedures

Some instructions may allow more efficient, faster-executing procedures to be generated than others. The work by Wright and Wilcox (1979) mentioned above is a possible example. In that study, instructions for a button-pushing task were sometimes easier with two negations than one. As discussed above, this result could be due to differences in the ease of constructing the procedures. But an execution time effect of number of negations in also possible. For example, Dixon (1987b) found that execution is faster if subjects must check to see if a light is *on* than if it is *off*, although reading times are similar.

Another potentially important factor in the execution of procedures is how well they can be remembered. If a procedure is easier to remember, then it is likely to be easier and faster to execute. A memory failure means that the reader will have to try to reconstruct the procedure through inference or trial and error, and this will take longer and produce more errors. Thus, assisting memory for a procedure by supporting reconstruction should result in improved execution performance. An example of this can be found in the mental model work of Kieras and Boviar (1984) mentioned above. Subjects who were provided with a mental model of the device executed the procedures faster and with fewer errors both immediately and after a week. The mental model may have helped retention by enabling reconstruction of steps that had been forgotten. A similar advantage for providing a model was found by Smith and Spoehr (1985) in an experiment where subjects performed a step immediately after reading it. Subjects provided with a model showed a small increase in execution accuracy.

Facilitation of retention and recall may explain some of the results obtained by Eylon and Reif (1984). Subjects were given information and training on deriving an argument in physics. Subjects who were given the goal structure of the arguments were better able to recall the argument than subjects who were simply given the steps without information about the goals. If the goal structure was presented as a deductive hierarchy, subjects recalled better on deductive problems; but if the goals were based on a historical organization, they recalled better on historical problems. Thus the explicit presentation of the goal structure facilitated the recall of procedures. Smith and Goodman (1985) found a related effect of explanatory material on transfer to new procedures. Subjects given information about the goals had better execution accuracy on a transfer task than subjects given only linear step-by-step instructions.

Comparison to Nontextual Instructions

There are important aspects of procedural text and instructions that are outside the scope of the model. For example, Booher (1975) found differences in performance between pictorial and text presentation for the same procedure, but the model can explain this difference only in very general terms. One of the interesting differences in performance between pictorial and text presentation is that time to complete a procedure such as *Set the power switch to ON position on the control panel. Check that power indicator illuminates*, was faster when presented with a picture consisting of a series of icons, but fewer errors are made with text. In particular, pictures were better for presenting static objects, while text was better for presenting the actual actions to be taken. Booher's results suggest that part of the difference between text and pictorial procedures may lie in the procedure comprehension stage; the pictorial presentation may result in faster performance because fewer inferences may need to be made in order to generate the procedure. For example, Stone and Glock (1981) found that one advantage of pictures is that they help eliminate orientation errors. However, the fact that text is better than pictures (Booher, 1975) for action steps implies that certain types of information are difficult to extract from a picture, causing errors. This may be why both Booher (1975) and Stone and Glock (1981) found that pictures and text together result in the best performance.

The *flowchart* is another visual form of presentation for procedures; it usually produces better performance than text. A flowchart may help procedure construction because only relevant information needs to be processed, and it may help execution because it relieves memory load. Kammann (1975) found that multibranch flowcharts are both faster and have fewer errors than text. In addition, performance with multibranch flowcharts is better than with binary flowcharts. Because Kammann measured only total time to do the task, no distinction can be drawn between construction and execution effects. Wright and Reid (1973) found that an algorithm presented as a flowchart produced fewer errors than prose. Holland and Rose (1981) compared performance with text versions of instructions such as *If you are a parent or a homeowner, and not both under 26 or a veteran, mark Box A*, to that with two algorithmic versions, one being a flowchart, the other being a verbal version in list form such as

(1) If you are a parent, then go to (2), otherwise skip to the next question,
(2) If you are a homeowner, then go to (3).

Performance with prose presentation was the worst both in terms of response time (which included both reading and execution time) and accuracy, while an algorithm presented as a flowchart was the best, having a particular advantage on the more difficult problems.

CONCLUSIONS

Future Research Needs

The most fundamental need in future research on acquiring procedures from text is simply an urgent need for much more research on this type of text. The new research should use more refined paradigms that allow the stages and processes involved to be isolated; studies using gross measures such as the total time to perform a task are simply not very informative.

With regard to the model outline here, many issues at each stage of the model need to be addressed. For example, the distinction between reading and procedure comprehension needs to be further clarified. While the surface form of the text can be considered separately from the form of the procedure, it may serve as an important cue to guide procedure construction. One important issue is how the procedure content is signaled or conveyed in English; several possible cues were discussed as part of the procedure construction process, and it is important to establish the roles such cues play. For example, the work discussed here suggests that identifying the goal structure is important in building a procedure; it could act like a macrostructure (Kintsch & van Dijk, 1978) in ordinary comprehension. Also, since the theme of a paragraph can be signaled to readers by initial mention (Kieras, 1980), initial mention may also signal the top-level goal of a procedure.

Another problem that needs more work is the apparent difficulty of reference in procedural text. The problems pointed out by Fisher (1981), Wright (1981), and Just and Carpenter (1987b), such as interpreting a referent too broadly by ignoring qualifiers, are potentially serious; and yet little is known about why people have such problems and what improvements to procedural text could prevent referential problems.

Practical Applications of Current and Future Research

Both the work described here and potential future research have important and useful practical implications. For example, one conclusion that can be drawn from the work described here is that the procedure comprehension stage—and in particular the procedure construction process—is the critical one. This implies that writers of procedural text should concentrate on ensuring that the procedure construction goes smoothly.

For example, procedural text should above all be correct and should provide all the steps of a procedure. It is probably wise to assume that the reader has less knowledge rather than more, and provide some detail. Readers can typically ignore details that they already know (Kieras, Tibbits, & Bovair, 1984), although some types of detail, such as the actual position of the hands in operation tasks, are likely to be confusing (Holland, Rose, Dean, & Dory, 1985). However, if important details are missing, readers may not be able to infer them without extensive problem solving. Providing a goal structure organization for the text is likely to be helpful (Graesser, 1978; Eylon & Reif, 1984), as will explanations that provide information directly useful in constructing the procedure, such as an effective mental model. (Kieras & Bovair, 1984).

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