# THE ACQUISITION OF PROCEDURES FROM TEXT

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Quite often people must learn procedures from written instructions. In the context of the currently developing theory of procedural knowledge and cognitive skill, this task must involve the formation of production rules from the information available in text. This process has not been systematically explored; the results reported here provide an initial characterization. Two main conclusions will be presented. The first is that using a production rule representation can provide a very precise characterization of the difficulty of learning procedures. The second is that apparently there are powerful comprehension-like processes that operate very early in learning on declarative representations of production rules. This supplements Anderson's (1982) description of the acquisition of skill, in that much of the work of learning a procedure can take place before a procedural representation has been formed.

Our approach is to have subjects learn procedures for operating a simple piece of equipment by reading step-by-step instructions. By measuring the reading time, and the accuracy of execution of the procedure, we are able to essentially track the acquisition of individual rules. The procedures are related, so some transfer of training is possible. A major result is that this transfer can be predicted very well based on the production system representation for the procedures. This paper is highly condensed; full details can be found in Kieras and Bovair (in preparation).

## METHOD

The subjects learned how to operate a device consisting of a simple control panel, which is described in Kieras and Bovair (in press, in preparation). The goal of operating the device was to get a certain indicator light to flash. Each procedure consisted of several steps, illustrated in Tables 1 and 2. Table 1 is the procedure for a "normal" situation, in which the device is operating properly. Table 2 is the procedure for a "malfunction" situation. The device could be in one of several malfunction states, in which some imaginary component of the device was not operating. Depending on the nature of the malfunction, the device either could be made to work by an alternate procedure, or could not. The final step in each procedure was to signal success or failure in getting the device to work. Note that this was a rote learning situation; the internal organization of the device was not taught to the subjects. Each subject learned a series of 10 such procedures in a fixed order. There were three different orders, chosen as described below, with a separate group of 20 subjects for each order.

Table 1
An Example of a "Normal" Procedure

If the command is to do the MA procedure, then do the following:

Step 1. Turn the SP switch to ON.

Step 2. Set the ES selector to MA.

Step 3. Press the FM button, and then release it.

Step 4. If the PF indicator flashes,
then notice that the operation is successful.

Step 5. When the PF indicator stops flashing, set the ES selector to N.

Step 6. Turn the SP switch to OFF.

Step 7. If the operation was successful,
then type "S" for success.

Step 8. Procedure is finished.

Table 2
An Example of a "Malfunction" Procedure

If the command is to do the MA procedure, then do the following:

Step 1. Turn the SP switch to ON.

Step 2. Set the ES selector to MA.

Step 3. Press the FM button, and then release it.

Step 4. If the PF indicator does not flash,
then notice that there is a malfunction.

Step 5. If the EB indicator is on, and the MA indicator is off,
then notice that the malfunction might be compensated for.

Step 6. Set the ES selector to SA.

Step 7. Press the FS button, and then release it.

Step 8. If the PF indicator does not flash,
then notice that the malfunction can not be compensated for.

Step 9. Set the ES selector to N.

Step 10. Turn the SP switch to OFF.

Step 11. If the malfunction could not be compensated for,
then type "N" for not compensated.

Step 12. Procedure is finished.

To learn each procedure, the subjects first read a set of step-by-step instructions for the procedure, such as those in Tables 1 and 2, and then attempted to execute the procedure on the device. If they made an error, they were immediately informed, and then began to read the instructions again. They were required to execute the procedure correctly three times in a row before proceding to the next procedure. The data recorded were the reading time on each step of the instructions, the accuracy of each step while executing the procedure, and the speed and accuracy of a final retention test, which will not be discussed here.

## THEORETICAL ANALYSIS

The step-by-step instructions exemplified in Tables 1 and 2 were prepared so that each sentence in the instructions appeared to correspond to a single production rule, one for each step or action (internal or external) involved in the procedure. Each procedure could then be expressed as a series of production rules. Table 3 provides an example corresponding to Table 1. The syntax of these rules is very simple and will not be discussed here. See Kieras and Polson (in press) for a full description of the production system notation, along with a description of the user-device interaction simulation that was used to test the production rules for accuracy. The system's working memory contains descriptions of either GOALS, or NOTES, which consist of non-goal items concerning processes underway, the environment, or specifications of the tasks to be accomplished.

In earlier work with this device (see Kieras and Bovair, 1983) it was noticed that the time required to learn the procedures under rote conditions varied over a very wide range. Obvious variables like the number of steps in the procedure, or serial order, could not explain this variation. Rather, the explanation appeared to lie in the order in which the procedures were learned, and the relation between the steps in a new procedure and those that the subjects had already learned. A <u>transfer process</u> was defined to explain how this transfer of training would work in terms of production rules, and formalized as a LISP program.

The transfer process compares the production rules for a new procedure with the production rules for all the procedures that have already been learned. Each rule in the new procedure can then be placed in one of three categories: The rule is <u>identical</u> to a previously learned rule, or the rule is completely <u>new</u> compared to the already learned rules, or it is <u>generalizable</u> with an old rule. The generalizable category requires some explanation: If the rule from a new procedure is similar to an already known rule, differing in only one term in the description of a goal or note in working memory, then this term in the old rule can be replaced with a "wild card," which matches any term in memory, and the rule from the new procedure can be discarded.

Table 3
Example of Production Rules

```
(MA-N-START
IF (AND (TEST-GOAL DO MA PROCEDURE)
        (NOT (TEST-GOAL DO ??? STEP)))
THEN ((ADD-GOAL DO SP-ON STEP)) )

(MA-N-SP-ON
IF (AND (TEST-GOAL DO MA PROCEDURE)
        (TEST-GOAL DO SP-ON STEP))
THEN ((OPERATE-CONTROL *SP ON)
      (WAIT-FOR-DEVICE)
      (DELETE-GOAL DO SP-ON STEP)
      (ADD-GOAL DO ES-SELECT STEP)) )

(MA-N-ES-SELECT
IF (AND (TEST-GOAL DO MA PROCEDURE)
        (TEST-GOAL DO ES-SELECT STEP))
THEN ((OPERATE-CONTROL *ESS MA)
      (WAIT-FOR-DEVICE)
      (DELETE-GOAL DO ES-SELECT STEP)
      (ADD-GOAL DO FM-PUSH STEP)) )

(MA-N-FM-PUSH
IF (AND (TEST-GOAL DO MA PROCEDURE)
        (TEST-GOAL DO FM-PUSH STEP))
THEN ((OPERATE-CONTROL *FM PUSH)
      (WAIT-FOR-DEVICE)
      (OPERATE-CONTROL *FM RELEASED)
      (DELETE-GOAL DO FM-PUSH STEP)
      (ADD-GOAL DO PFI-CHECK STEP)) )

(MA-N-PFI-CHECK
IF (AND (TEST-GOAL DO MA PROCEDURE)
        (TEST-GOAL DO PFI-CHECK STEP)
        (LOOK *PFI FLASHING))
THEN ((ADD-NOTE OPERATION SUCCESSFUL)
      (DELETE-GOAL DO PFI-CHECK STEP)
      (ADD-GOAL DO ES-N STEP)) )

(MA-N-ES-N
IF (AND (TEST-GOAL DO MA PROCEDURE)
        (TEST-GOAL DO ES-N STEP)
        (LOOK *PFI OFF))
THEN ((OPERATE-CONTROL *ESS N)
      (WAIT-FOR-DEVICE)
      (DELETE-GOAL DO ES-N STEP)
      (ADD-GOAL DO SP-OFF STEP)) )

(MA-N-SP-OFF
IF (AND (TEST-GOAL DO MA PROCEDURE)
        (TEST-GOAL DO SP-OFF STEP))
THEN ((OPERATE-CONTROL *SP OFF)
      (WAIT-FOR-DEVICE)
      (DELETE-GOAL DO SP-OFF STEP)
      (ADD-GOAL DO TAP STEP)) )

(MA-N-TAP
IF (AND (TEST-GOAL DO MA PROCEDURE)
        (TEST-GOAL DO TAP STEP)
        (TEST-NOTE OPERATION SUCCESSFUL))
THEN ((DELETE-NOTE OPERATION SUCCESSFUL)
      (ADD-NOTE TYPE S-FOR SUCCESS)
      (DELETE-GOAL DO TAP STEP)
      (ADD-GOAL DO FINISH STEP)) )

(MA-N-FINISHED
IF (AND (TEST-GOAL DO MA PROCEDURE)
        (TEST-GOAL DO FINISH STEP)
        (TEST-NOTE TYPE S-FOR SUCCESS))
THEN ((DELETE-NOTE TYPE S-FOR SUCCESS)
      (DELETE-GOAL DO FINISH STEP)
      (DELETE-GOAL DO MA PROCEDURE)) )
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The assumption is that the only rules that require substantial effort to learn are the completely new ones; the identical and generalizable rules should be very easy to learn, since all or almost all of their content is already known. Thus, the number of new rules in a procedure should be closely related to the difficulty of learning the procedure. In the data reported in the rote condition in Kieras and Bovair (1983) the number of new rules in a procedure accounts for 79% of the variance among the mean training times for the 10 procedures, supporting the value of the production system analysis of transfer in the learning of procedures.

By using three different training orders, this study was designed to get a more comprehensive set of data on the relation of the production rule representation to transfer of training. The three different training orders were chosen by analyzing the production rule sets for each procedure using the transfer process program, and selecting training orders that produced substantial variation in the number of new rules in each procedure, and also the number of new rules in each serial position in the training order.

## RESULTS

### Training Time

The total training time for a procedure is defined as starting when a subject begins the first reading of the first sentence of the instructions, until the last step of the last attempted execution. The training times for each subject on each procedure in the three training order conditions (a total of 600 observations) were analyzed with multiple regression in terms of the transfer status of the rules in each procedure. Figure 1 shows the predicted and observed mean times and the final regression equation. The most important predictor variable was the number of new rules in each procedure (NEW), which alone could account for 69% of the variance. The partial regression coefficient for NEW is substantially larger than those for identical (OLD) rules and generalizable rules (GEN), which were very similar. In addition, there were other effects, notably some learning-to-learn effects (FIRST and ORDER), and an apparent "overload" effect (C2FIRST), in which the first procedure in the second training order condition was very complex and took an extremely long amount of time to learn. Details appear in Kieras and Bovair (in preparation). Despite these other effects, however, the production system variables provided by the transfer process explain the training times very well; in fact, the number of new rules is a better predictor than the subjects' individual means!

Thus, by analyzing the procedures in terms of production rules, and the relations between them, it is possible to account for the difficulty of the learning the procedures with great precision.

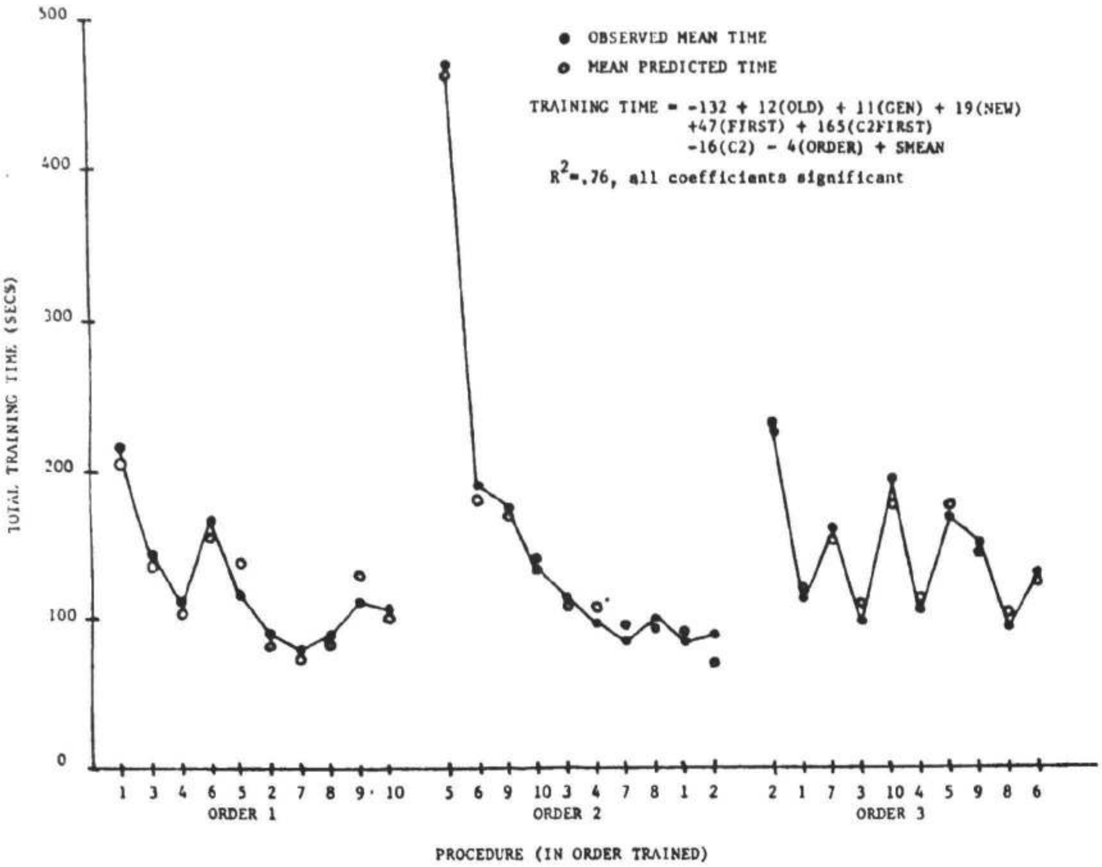


Figure 1. Predicted and observed mean training times.

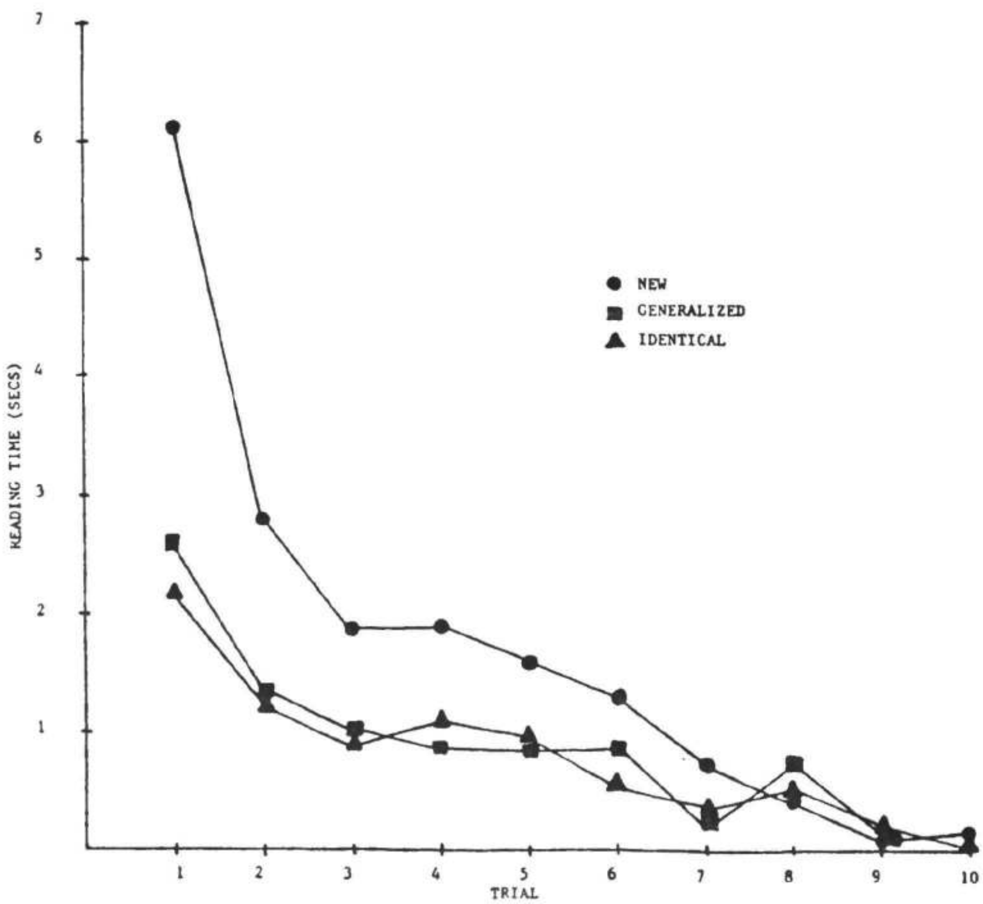


Figure 2. Sentence reading times.

Reading Time

The time required to read each sentence of the instructions, was averaged over procedures, but classified by training trial (e.g. first reading, second reading, etc.) and by the transfer status of the corresponding production rules. Figure 2 shows these means. The key point is simple. There was a substantial difference in the reading times for instruction steps depending on the transfer status of the corresponding production rule. The reading times for generalizable and identical rules were almost identical, but reading times for new rules were much longer. A key result is that this difference appears on the first reading, meaning that subjects can immediately distinguish whether a sentence describing a step corresponds to a new rule or an old one, and govern their reading and study time accordingly.

## CONCLUSIONS

A basic conclusion is that production rules, as a way to represent procedural knowledge, can provide a detailed account of learning. This supports the approach suggested by Kieras and Polson (in press) who suggest that the production-rule theory of skill acquisition is useful for practical applications. That there are other phenomena involved, such as the "overload" described above, is clarified by the production system analysis as well.

These results present a puzzle for the theory of skill acquisition as formulated by Anderson (1982). The transfer process defined here has many similarities to some of Anderson's compilation and tuning processes. However, his processes are defined in terms of operations on procedural representations. These are constructed as a by-product of the activity of general interpretive procedures that are driven by an initial declarative encoding. However, in these results, rules are being compared, modified, and constructed very rapidly, and apparently before they exist in a procedural form. As Figure 2 shows, a generalization process can apparently occur on the first reading, and is almost as fast as recognizing an identical rule. Although there is no rigorous basis at this time for saying so, it seems that these aspects of the results are not reasonably subsumed under Anderson's compilation and tuning processes.

Instead, perhaps the work of relating new and old rules is done by processes similar to those proposed for macroprocessing in comprehension (e.g. Kieras, 1982), which can compare, modify, and construct complex propositional representations while reading is going on. Thus, subjects translate the instruction sentence into a declarative representation of a complete production rule, which can then be related to other such representations. As in Anderson's proposals, this declarative representation would be interpreted by a general procedure for following instructions, and the procedural form of the rules would eventually be formed. However, correct execution of the procedure would begin when the declarative rule set has been successfully encoded, and the time required to do so would depend on how much use could be made of previously learned rule representations. Thus, when procedures are acquired from text, comprehension-like processes can play a major role early in learning, leaving the compilation and tuning processes to govern learning once the initial declarative form of the rules is in place.

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