

Role of Implicit and Explicit Processes in Learning From Examples: A Synergistic Effect

Robert C. Mathews, Ray R. Buss, William B. Stanley, Fredda Blanchard-Fields, Jeung Ryeul Cho, and
Barry Druhan
Louisiana State University

Four experiments are reported in which subjects gained extensive experience with artificial grammars in explicit and implicit processing tasks. Results indicated that (a) implicit processing was sufficient for learning a finite state grammar but was inadequate for learning another type of grammar based on logical rules. (b) Subjects were able to communicate some of their implicit knowledge of the grammars to another person. (c) Consistent with rule induction but not memory array models of learning, verbal protocols indicated there was no tendency to converge on the same set of cues used to identify valid strings. (d) A synergistic learning effect occurred when both implicit and explicit processing tasks were used in the grammar based on logical rules but not in the finite state grammar. A theoretical framework is proposed in which implicit learning is conceptualized as an automatic, memory-based mechanism for detecting patterns of family resemblance among exemplars.

Explicit learning mechanisms for discovering and controlling task variables are similar to conscious problem solving. These processes include attempts to form a mental representation of the task, searching memory for knowledge of analogous systems, and attempts to build and test mental models of task performance (Gentner & Stevens, 1983; Johnson-Laird, 1983).

Implicit learning is thought to be an alternate mode of learning that is automatic, nonconscious, and more powerful than explicit thinking for discovering nonsalient covariance between task variables (Lewicki, 1986; Reber, 1969, 1976; Reber & Allen, 1978). Demonstrations of implicit learning of artificial grammars typically involve comparisons between groups of subjects who experience exemplars of a grammar under (a) instructions to figure out the rules of the grammar (rule discovery instructions) or (b) instructions that require attention to the exemplars without attempting to determine the rules of the grammar (e.g., groups of subjects asked to memorize the exemplars for a subsequent memory test). Typically, groups of subjects who implicitly learned the grammar do as well or better on subsequent attempts to discriminate between new valid versus invalid strings as subjects who

attempted to explicitly figure out the rules of the grammar (see Reber, 1989, for a review of this research).

Although there is extensive evidence for phenomena associated with implicit learning, it is not yet clear whether implicit learning is a separate, unique learning process. Five properties of implicit learning that should help distinguish it from explicit learning are examined here to determine if the evidence warrants postulation of two distinct learning processes (implicit and explicit). Each of these issues will be discussed below.

Passive Abstraction

One of the most intriguing aspects of implicit learning is that one can learn to respond appropriately to complex relations in the task environment without conscious effort to discover the underlying rules or structure of the task (e.g., Lewicki, 1986; Reber, 1976, 1989). For example, several implicit learning studies have demonstrated that attempting to figure out the rules of a grammar while examining strings generated by an artificial grammar does not facilitate subsequent discrimination of valid from invalid strings compared with simply attempting to memorize the strings (see Reber, 1989, for a review). In fact, some studies have provided evidence that explicit rule discovery instructions impair performance relative to more neutral instructions (Berry & Broadbent, 1988; Reber, 1976). Thus, a fundamental aspect of implicit learning tasks is that active, conscious thinking does not seem necessary to extract the regularities needed for performance on these complex tasks (Dulany, Carlson, & Dewey, 1984; Millward, 1981; Reber, Kassin, Lewis, & Cantor, 1980).

Abstractness of Implicit Knowledge

Reber (1969, 1976) claims that implicit knowledge is abstract and readily generalizes to different symbol sets when

This research was supported in part by National Science Foundation Grant BNS-8509493 to Robert C. Mathews, Ray R. Buss, and William B. Stanley, and in part by the Louisiana Board of Regents Grant 86-LBR(21)-021-10 through the Louisiana Quality Education Support Fund to Robert C. Mathews.

We gratefully acknowledge the contributions of Lee Brooks, Don Dulany, Larry Jacoby, Irving Lane, Arthur Reber, and Michael Stadler, all of whom provided valuable comments and editorial assistance on earlier versions of this article. We also wish to express our gratitude to the editor, Henry Roediger, for his patience and excellent advice during revisions of this article.

Correspondence concerning this article should be addressed to Robert C. Mathews, Department of Psychology, Louisiana State University, Baton Rouge, Louisiana 70803-5501.

the same underlying rule structure is used to generate the strings. However, exemplar models (Brooks, 1978, 1987; Vokey & Brooks, in press) can often account for implicit learning phenomena without postulating any automatic mechanism of abstraction by proposing that subjects respond through analogies to specific remembered cases. Exemplar models contend that the implicit knowledge is not abstract. Transfer to different stimuli should depend on the similarity between original and new stimuli. One study (McAndrews & Moscovitch, 1985) provides evidence for both abstraction and instance-based processing of artificial grammars.

Accessibility of Implicit Knowledge

Some recent experiments by Dulany et al. (1984) have sparked a debate about whether implicitly acquired knowledge of artificial grammars is accessible to conscious reflection and verbalization. The Dulany et al. (1984) experiments used the typical Reber procedure for the learning phase. However, subjects, in addition to classifying strings as grammatical versus ungrammatical in the test phase, were asked to underline parts of strings that make them grammatical and to draw a line through parts of strings that make them ungrammatical. Dulany et al. (1984) subsequently analyzed the extent to which rules implied by subjects' responses could be used to classify strings as valid versus invalid. They found that these rules predicted the accuracy of subjects' actual judgments extremely accurately under both learning conditions. Thus, Dulany et al. (1984) argued that subjects could consciously state the rules they used to classify strings following implicit learning of the grammar.

Subsequently, Reber, Allen, and Regan (1985) have argued that Dulany et al.'s (1984) procedure of having subjects underline and cross out portions of strings is not comparable to stating explicit rules. Reber et al. (1985) argued that the Dulany et al. task is more similar to a recognition task, whereas stating explicit rules used in making judgments is more like a recall task. Dulany, Carlson, and Dewey (1985) noted that finding a suitable recall measure for this task would be difficult. Because a large number of different grammaticality judgments are made during an experiment, subjects may no longer remember their judgment rules at the end of the experiment. Therefore, retrospective verbal reports might be incomplete or inaccurate (see Ericsson & Simon, 1984).

The study presented here used a novel approach to this general problem that lies between the two extremes of using retrospective versus totally concurrent verbal reports (i.e., the think-aloud procedure). A "teach-aloud" procedure was employed in which subjects were periodically stopped while working on the primary task (e.g., trying to discriminate valid from invalid grammar strings) and were asked to give verbal instructions for someone else to perform the task. Later, these instructions were given to another group of yoked subjects, who attempted to perform the same task without the benefit of any prior experience or feedback.

The teach-aloud procedure has several advantages. The relative level of performance of yoked subjects versus their experimental partners provides a direct measure of the extent to which knowledge of the grammar can be communicated

verbally to another person. If the verbal reports are obtained frequently enough, a fairly complete record of subjects' on-line awareness of their processing strategies during the task can be obtained (Mathews, Buss, Chinn, & Stanley, 1988; Stanley, Mathews, Buss, & Kotler-Cope, in press). The teach-aloud procedure also makes it quite clear to subjects that the purpose of the reports is "to allow someone else to perform the task just like you are." Finally, even though this technique does not necessarily eliminate the reactive quality of giving verbal reports, it lessens the possibility of direct interference from verbalizing while trying to perform the primary task. Potential reactive effects of verbalization were examined in this study by comparing the accessibility of implicitly acquired knowledge of the grammar in groups who verbalized all through training (Experiment 1) with that of others who did not verbalize until after they had developed expertise in discriminating valid from invalid strings (Experiments 2-4).

Convergence of Individual Grammars

Several researchers have observed that there seems to be wide individual variation in the knowledge acquired by individuals about an artificial grammar in a typical implicit learning experiment (Dulany et al., 1984; Reber, 1989; Reber & Allen, 1978). Moreover, the degree of individual differences in knowledge of the grammar following extensive training could have important implications for distinguishing between two general theoretical frameworks for implicit learning.

Recent successors to the research tradition viewing concept discovery as a process of rule induction (e.g., Bower & Trabasso, 1964; Bruner, Goodnow, & Austin, 1956; Levine, 1975) include production system models (e.g., Anderson, 1983; Klahr, 1984; Siegler, 1983) and classifier systems (e.g., Holland, Holyoak, Nisbett, & Thagard, 1986). The recent Holland et al. (1986) theory of induction based on classifier systems incorporates both implicit and explicit learning processes. Explicit processes can alter the current mental model that activates subsets of rules competing for control of behavior on a task. Implicit learning processes continually modify the strength of competing rules.

Competitive rule induction systems predict wide individual variability in the initial features abstracted by different individuals about an artificial grammar. Also, even after extensive practice with exemplars and nonexemplars of a grammar, one would not expect a large amount of convergence of different individuals' representations of the grammar because many different cues (e.g., bigram or trigram invariance rules; see Reber & Lewis, 1977) could be used to select valid strings. Once a sufficient set of cues has been identified, it would become strengthened with each successful prediction, and there would be no pressure for additional modification of the knowledge structure. Changes in the knowledge structures acquired by classifier systems are completely failure driven (Holland et al., 1986).

Estes (1986a, 1986b) has recently formalized the similarities among several memory-based theoretical perspectives. These memory array processing theories have in common the assumption that categorization is based on memory for past exemplars of a concept. Information in memory is assumed

to consist of a vector of stored feature or attribute values corresponding to experienced exemplars. Use of memory-based knowledge need not require explicit retrieval of past exemplars. Memory-based knowledge could be retrieved implicitly, resulting in awareness of the appropriate response without explicit recall of the prior exemplars, as in many parallel distributed processing (PDP) models (Rumelhart & McClelland, 1986). Variants of these models differ in terms of when computations concerning category features are performed. Brooks and his colleagues (Brooks, 1978; Jacoby & Brooks, 1984; Vokey & Brooks, in press) have used a type of memory array model known as an *exemplar model* to account for implicit learning of artificial grammars.

According to the memory array view, initial variability in the knowledge representation should be largely due to a limited knowledge base (few exemplars in memory) and variability in encoding. However, after extensive experience with highly similar exemplars, the knowledge representations of subjects should become more similar. Also, multiple opportunities to encode the same exemplar should increase the accuracy and similarity of memory-based representations across subjects. Therefore, memory array processing theories predict that extensive experience with exemplars of the grammar should create a strong tendency toward convergence in learners' knowledge of the grammar. Moreover, memory array theories predict continued growth and change in the knowledge base even after successful prediction has been achieved. In memory array models, each additional experienced item adds to the knowledge base irrespective of one's current ability to select valid strings.

Interactions Between Implicit and Explicit Learning Processes

Lewicki (1986) has proposed that implicitly acquired knowledge is totally independent of explicit knowledge. In Lewicki's theory, implicit knowledge is totally inaccessible to explicit conscious retrieval, and it cannot be modified by conscious learning mechanisms. In addition, implicit knowledge may remain inconsistent with existing explicit knowledge (Lewicki, 1986). Reber (1976) and Hayes and Broadbent (1988) have also emphasized the independence of the two types of learning. These authors have provided some evidence that explicit learning interferes with implicit learning when both are active simultaneously (Hayes & Broadbent, 1988; Reber, 1976; Reber et al., 1980).

We hypothesized that the two modes of learning interact positively when they occur *sequentially* rather than simultaneously. This hypothesis is based on the view that implicit learning is a memory-based learning mechanism that automatically identifies patterns of family resemblance among similar experiences (Mathews et al., 1988). This process is assumed to occur through pattern recognition mechanisms similar to those used in connectionist models (Rumelhart & McClelland, 1986). Facilitative interactions are expected because implicit patterns of family resemblance in the experiential knowledge base are presumed to play an important role in the generation of procedural rules and in activating poten-

tial conceptual models of the task. In addition, activated explicit knowledge (mental models) affects the encoding of exemplars into the knowledge base (e.g., Anderson, 1983), which affects the output of the implicit learning mechanisms.

Therefore, one of the major goals of this study was to systematically examine the interactions of using explicit and implicit learning processes sequentially during the discovery of complex concepts. Four experiments are reported. Experiments 1 and 2 focus on the issues of passive abstraction, abstractness of knowledge, accessibility of knowledge, and convergence with the use of the teach-aloud procedure to obtain information about subjects' knowledge of a finite state grammar over an extensive training period. Experiments 3 and 4 examine the interactions of using both types of learning in a finite state grammar (Experiment 3) and in a grammar based on biconditional rules (Experiment 4) that is thought to be more accessible to explicit generation of rules.

Experiment 1

Experiment 1 introduces the teach-aloud procedure and uses it to address the issues of passive abstraction, accessibility, abstractness, and convergence in learning an artificial grammar. An instruction manipulation was used to elicit implicit or explicit learning of the grammar. It is based on similar manipulations used in prior research in which one instructional set (rule discovery instructions) encourages subjects to search for the underlying rules of the grammar, and the other (memory instructions) has subjects memorize exemplars without knowing that they were generated by a grammar (e.g., Dulany et al., 1984; Reber, 1976; Reber et al., 1980).

A second factor, letter set change, was manipulated in this experiment to examine the abstractness of knowledge acquired about the grammar. The same finite state grammar can be instantiated with different letter sets (see Figure 1). Reber (1969) changed letter sets used to generate the grammar strings in the second part of an experiment and found no significant effects on performance. On the basis of this result he concluded that subjects had acquired the abstract structure of the grammar rather than only learning sets of specific strings. To test the abstractness of knowledge acquired about the grammar in this experiment, all subjects were transferred to a different letter set in Week 4. In addition, the different letter set groups received a new letter set in Weeks 2 and 3 as well. The purpose of the same versus different letter set manipulation in Weeks 2-3 was to see if practice with different letter sets enhanced transfer to a new letter set in the final week of practice. If transfer to the new letter set in Week 4 is equivalent for the same and different letter set groups, then additional evidence will be provided that abstraction of the grammar occurs automatically (i.e., in this case without being stimulated by experience with letter set changes).

In order to examine the theoretically important issue concerning the extent to which different individuals' knowledge of the grammar converge after extensive experience with exemplars of the grammar, it was necessary to continue the experiment for a large number of trials. In a typical experiment on the acquisition of artificial grammars, subjects study exemplars of the grammar for about 7 min, and then their

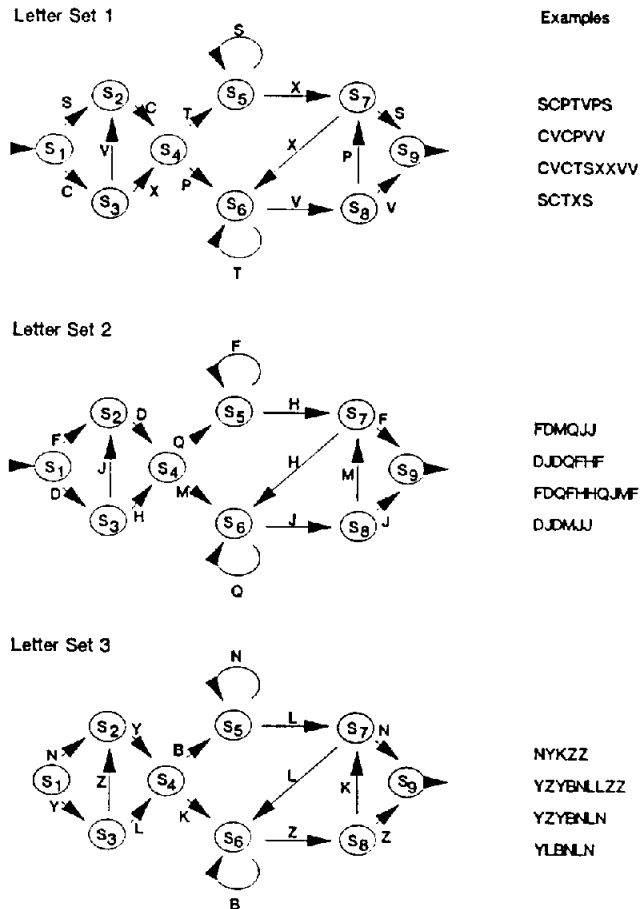


Figure 1. Expanded finite state grammar and examples of valid strings generated with three different letter sets used to instantiate the grammar.

ability to discriminate valid versus invalid strings of the grammar is tested. Although this is a sufficient amount of practice to obtain above-chance performance, the level of performance remains very low. Thus, little is known about the long-term efficacy of implicit versus explicit learning instructions for the acquisition of high levels of expertise with an artificial grammar. In this experiment, subjects practiced distinguishing valid from invalid grammar strings for a total of 800 trials, requiring about 10 hr of practice extended over a 4-week period. Hence, an additional contribution of this study was to compare the efficacy of the two types of processing (memory-based versus rule discovery) over an extended range of practice.

Another point of departure between this study and previous research concerns the continuation of memorization instructions during the first 3 weeks of the string discrimination task. Memory-instructed subjects in previous research have been told at the beginning of the string discrimination task that the items were generated by a complex set of rules and that they should now attempt to select strings that are consistent with those rules (e.g., Reber, 1976). Such instructions have the effect of transferring subjects to a rule discovery mental set

that precludes the possibility of subsequently continuing memory practice to obtain repeated measures of string discriminability at different levels of experience with exemplars of the grammar. In this experiment a measure of string discriminability was obtained without telling subjects that the items were generated by a grammar. This was accomplished by instructing subjects to select items in the string discrimination task that were *most similar* to an item in their memory set. This procedure is consistent with a variety of memory array models of this type of learning (see Estes, 1986a), and it allows repeated observations of string discriminability without changing the task instructions. Potential differences between conditions resulting from subjects being told to select strings based on similarity to past exemplars versus based on rules is also examined by transferring memory subjects to rule discovery instructions in the final week (Week 4) of practice.

Method

Subjects and design. The core design of this experiment is a simple 2×2 design, with task instructions (implicit and explicit) and letter set change (same and different letters) as the two independent factors. Thus, there were four main experimental groups of subjects.

The teach-aloud procedure was used to collect verbal reports of knowledge of the grammar throughout training in the rule discovery groups and in all four experimental groups in the transfer task of Week 4. To evaluate the validity of the knowledge verbalized by the experimental groups, six additional groups of yoked subjects were given the instructions provided by experimental subjects, and they attempted to perform the same string discrimination task without any prior training and without feedback. Two groups of 4-week yoked subjects were used to examine the validity of the verbalized instructions provided by the two rule discovery groups in Weeks 1-3. In Week 4 these initially yoked subjects were transferred to rule discovery instructions, and they performed the transfer task with feedback to determine whether the knowledge they acquired from previous instructions would enable them to perform the transfer task on their own. A new set of 1-week yoked subjects was used to test the validity of the instructions verbalized by all four main experimental groups in the transfer task of Week 4. Finally, two groups of control subjects (one with same letter sets in Weeks 2-3 and one with different letter sets) performed the string discrimination task for 4 weeks without instructions or feedback. The control subjects were included to test for possible learning without instructions or feedback (Fried & Holyoak, 1984). These groups were necessary to ensure that knowledge acquired by yoked subjects came from the instructions provided by the experimental subjects rather than being acquired on their own.

In all, there were a total of 12 independent groups of subjects, with 14 people in each group. There were the four main experimental groups: two groups of 4-week yoked subjects (Week 1-3 yoked groups) who received the instructions from the two rule discovery groups in Weeks 1-3, four groups of 1-week yoked subjects (Week 4 yoked groups) who received instructions from all four experimental groups in the transfer task in Week 4, and two groups of control subjects. Male and female undergraduate students ($N = 168$) received course credit for participating in this experiment.

Procedure. Each subject in the four main experimental groups participated in four experimental sessions scheduled 1 week apart, each lasting about 2.5 hr. The first part of each session began with the subjects' studying a list of 20 valid strings selected at random from a pool of strings generated from an expanded version of the finite state grammar (see Figure 1). During this study period, subjects in the explicit or rule discovery groups were asked to figure out the

complex set of rules used to generate the strings. Subjects in the implicit or memory groups were asked to memorize the strings on the study list for a subsequent memory test.

After completion of the initial study phase, subjects were seated in front of a computer screen, and they responded to 200 multiple-choice items. On each trial, five strings appeared on the screen, numbered 1–5. Only one string was a completely valid string generated by the grammar. The others had from one to four violations (letters that could not occur in specific positions according to the grammar). The positions of violations in the strings were randomly selected in such a way that no particular position in the grammar was more or less likely to be violated. Each screen contained one choice with no violations (the correct choice), one with one violation, one with two violations, one with three violations, and one with four violations. Rule discovery subjects were told to select the string that fit the complex set of rules that were used to generate the study list and to continue trying to figure out the set of rules used to produce the strings. Memory subjects were told to select the string that was most similar to an item in their memory set and to add each correct choice on the computer task to their memory set. The subject responded by pressing the number of his or her choice. The computer sounded a tone when the choice was correct and presented the correct choice when the response was wrong. The items remained on the screen for 5 s after each response during the feedback interval, and then the screen was cleared, and the next set of choices appeared. Subjects were allowed to take as long as they wished to respond to each screen.

After each sequence of 10 multiple-choice items, the computer displayed a message instructing the subject to pause and wait for further instructions. During this time subjects in the two rule discovery groups tape-recorded instructions to perform the task for their "unseen partner." Subjects were asked to record instructions for their partner so that he or she could perform the task "just like you did." It was emphasized that their instructions need not be eloquent, but they should be as complete as possible. In addition, it was stressed that it was less important to be correct and more important to get their partners to perform exactly as they did during each block of trials. Subjects were encouraged to give their partner some new information each time they recorded instructions. After recording their instructions, subjects pressed the "return" key on the computer to begin the next block of multiple-choice trials.

During the pauses between blocks of 10 trials, subjects in the two memory groups were asked to recall as many exemplars as they could from both the study list and previous correct multiple-choice items. They were asked to recall complete exemplars whenever possible but were told that partial recall of exemplars was also permitted. The memory subjects did not attempt to give verbal instructions for a partner to perform the task until Week 4. At the beginning of the Week 4 session, they were given the rule discovery instructions and were asked to verbalize between blocks of 10 trials.

Yoked and control subjects performed the same multiple-choice task, but without benefit from a study list or feedback about correct choices. *Yoked* subjects were given transcripts from an experimental subject to use in selecting their choices. They were given an exact, unedited transcript of the experimental subject's instructions corresponding to each block of trials. They were allowed to examine only the current block of instructions during performance on a particular block of trials. Each *Week 1–3 yoked* subject was yoked to an experimental subject in a rule discovery group. These subjects participated in four sessions. In Sessions 1–3 they received the transcripts from a particular experimental subject and attempted to perform the multiple choice task without any other training and without feedback. In Week 4 they were treated like experimental subjects: They were given rule discovery instructions, and they received feedback during the task. Each *Week 4 yoked* subject came for only one session. One

yoked subject in each of these groups received the Week 4 transcripts from a subject in each of the four experimental groups, and they attempted to perform the same task without feedback. *Control* subjects performed the same task without benefit of verbal transcripts or feedback.

Instrument. The artificial grammar used in these experiments is shown in Figure 1. It is an expanded version of one used by Reber and his associates (e.g., Reber et al., 1980). Four additional states (States 1–4) were added to the grammar to enable generating a larger number of strings without increasing the salience of the loops (Reber, 1989). The grammar used in these experiments generates a total of 177 valid strings within each instantiation (letter set).

The study list used each week consisted of a randomly selected set of 20 strings typed in random order on a page. These study strings did not occur in the subsequent multiple choice phase. The fact that items from the study set were not presented in the string discrimination task was not inconsistent with the memory groups' instructions to select the item that was most similar to an item in their memory set. The initial block of 10 multiple-choice trials contained 10 new valid strings. Each correct string was presented on the screen with four other strings containing one, two, three, and four violations, respectively. The strings were presented in a column in a random order and numbered 1–5. The strings containing violations were made from randomly selected valid strings, with the violations created by substituting letter(s) that could not occur in particular positions. All multiple-choice trial blocks after the first block (Blocks 2–20) contained five new valid strings and five that were repeated from earlier trial blocks in the same session. During the course of the 200 trials in each session, 105 trials consisted of first presentations or new exemplars, 47 trials consisted of second-time occurrences (of some of the previous 105 items), 32 trials were third repetitions of items, and 16 trials were fourth repetitions. Thus, across the 200 trials each week, 58 exemplars occurred once, 15 occurred exactly twice, 16 occurred a total of three times, and 16 occurred four times in the string discrimination task. The old (repeated) versus new designation only refers to items within a week. A new random sampling of the items was used to construct the study list and multiple choice items each week. Because each week's instruments used 125 of the total 177 exemplars generated by the grammar, approximately 70% of the exemplars were repeated across weeks with the same letter set.

Results and Discussion

Because of the complexity of this study, only results directly related to the five issues that are its focus will be mentioned. The primary dependent variable is the number of violations in strings chosen by a subject in successive sequences of five choices (trials). Given that the best choice (the valid string) on each trial contains no violations and the worst choice contains four violations, the range of scores for each sequence of five trials is 0 to 20 violations, with a score of 10 representing chance performance and lower scores indicating more knowledge of the grammar. We used this measure rather than the number of correct choices because it is likely to be more sensitive, particularly in the early stages of learning when a little knowledge might help eliminate the worst choice (four violations) but would not necessarily lead to selecting the correct string. The initial block of test trials in each week was analyzed separately from Blocks 2–20 for two reasons: (a) We wished to obtain a measure of the performance level immediately after the study list, and (b) there were no repeated items in the first block of trials—all 10 items were new strings.

Week 4 data were also analyzed separately because all experimental groups were transferred to rule discovery instructions in this final week. The significance level for these experiments was .05. The means for the Trial Block 1 data are shown in Table 1, and the means for data from Trial Blocks 2–20 of each week are shown in Table 2.

Passive abstraction. Consistent with past experiments on implicit learning (e.g., Reber, 1976), performance on the string discrimination task indicates that memory-instructed subjects acquired as much tacit knowledge of the grammar as did subjects instructed to discover the rules of the grammar. Even though the memory subjects were asked to base their judgments on similarity to previously seen exemplars, they performed as well as did rule discovery subjects on both old and new exemplars—even when the letter sets were changed. Planned comparisons between the implicit (memory) and explicit (rule discovery) groups indicated no significant differences on the Week 1–3 analysis of Trial Block 1 data and on the data from Trial Blocks 2–20. Inspection of the means in Tables 1 and 2 shows that generally the memory–same letter set group performed better than the other three experimental groups, which were very similar to each other. Thus, the strong conclusion that can be made from these data is that implicit (memory) instructions led to at least equivalent ability to discriminate valid from invalid strings as compared to explicit (rule discovery) instructions.

Abstractness of knowledge. The analysis of Trial Block 1 data in Weeks 1–3 indicated a significant effect of letter set change, $F(1,72) = 12.19$, $MS_e = 46.50$. Additional planned comparisons indicated that the same letter set group performed significantly better than the different letter set group with memory instructions, $F(1, 82) = 15.27$, $MS_e = 46.50$, but not with rule discovery instructions. A similar pattern of results was obtained in the analysis of Trial Blocks 2–20:

Table 1
Mean Violations in Block 1 as a Function of Task Instruction, Letter Set Change, and Week of Practice for Experimental Subjects in Experiment 1

Condition	Week 1	Week 2	Week 3	Transfer Week 4
Memory–same set				
Experimental	5.07	1.86	.82	2.22
Week 4 yoked	—	—	—	5.36
Memory–different set				
Experimental	6.32	5.18	4.96	3.04
Week 4 yoked	—	—	—	5.32
Rule–same set				
Experimental	6.82	3.14	2.14	3.03
Week 1–3 yoked	8.82	6.25	5.21	3.46
Week 4 yoked	—	—	—	5.57
Rule–different				
Experimental	7.14	4.46	3.75	2.07
Week 1–3 yoked	8.75	5.64	5.71	3.00
Week 4 yoked	—	—	—	5.18
Control–same set	8.86	8.68	9.18	9.90
Control–different set	9.14	9.82	9.28	9.90

Note. The expected value of chance performance is 10 violations.

Planned comparisons indicated that the effect of letter set change was limited to the memory groups, $F(1, 3190) = 8.90$, $MS_e = 183.31$. Thus, there is some evidence that memory groups acquired more knowledge of the grammar when exposed to the same letter set in Weeks 1–3. However, having the same letter set in Weeks 1–3 did not enhance learning with rule discovery instructions.

The most important analyses concerning the abstractness of knowledge issue concern the Week 4 data. Both the analyses of Trial Block 1 data and Blocks 2–20 of the Week 4 data indicated no significant differences among the experimental groups. As can be seen in Tables 1 and 2, all four experimental groups performed very well in Week 4, implying that abstract knowledge of the grammar was acquired by all four experimental groups. Neither explicit rule discovery instructions nor practice with different letter sets enhanced transfer to a new letter set in Week 4. The overall pattern of results suggests that having the same letter set for Weeks 1–3 may lead to more letter-set-specific knowledge (in the memory group); however, all four experimental groups acquired an equivalent level of abstract knowledge necessary for performance of the string discrimination task with a new letter set in Week 4.

Another type of evidence concerning the level of abstraction of subjects' knowledge of the grammar concerns the contents of their verbal instructions for their partners. Most of the instructions to yoked partners consisted of letter patterns to select (e.g., "select strings that begin with *SCT* or *CVC*" or "select strings that end in *VV*"). Because each of these instructions has some validity in terms of identifying correct strings, each could be viewed as a "rule" with some degree of abstractness (e.g., they apply to many strings; cf. Dulany et al., 1984). Across trial blocks there was a general tendency to elaborate and combine previous instructions (e.g., "select strings that begin with *CVC*, have several *Ts* in the middle, and end in *VV*") and to mention new patterns (e.g., "select strings that end in *SXS*"). Subjects seldom repeated exactly the same instructions across several trial blocks, and despite their being told to be as complete as possible, instructions verbalized in successive trial blocks rarely contained all of the previously given instructions.

An analysis of the contents of the verbal reports was performed in order to compare these verbal instructions with responses obtained when subjects were asked to recall exemplars (memory groups in Weeks 1–3). Subjects' verbal instructions for their partners were coded in terms of the specific letter patterns their partners were told to select. Then the content of the verbal reports was analyzed in terms of the specific sequences of three letters or trigrams mentioned in each block of instructions. Each valid trigram identifies a particular place (path) in the grammar. For example, there is only one place in the grammar that generates the trigram *VPS* (see Figure 1). There are 41 different valid trigrams that can be generated by the grammar for each letter set. The same analysis was also performed on memory subjects' recall data for Weeks 1–3 and on their verbal reports in Week 4.

These data may be summarized in a variety of ways, but they all show the same general pattern. The most frequently mentioned trigrams were the five beginning trigrams (*SCT*, *SCP*, *CVC*, *CXT*, and *CXP* for the letter set used in the top

Table 2
Mean Violations on Old (Repeated) and New Strings on Blocks 2–20 as a Function of Task Instruction, Letter Set Change, and Week of Practice for Experimental and Yoked Subjects in Experiment 1

Condition	Week 1		Week 2		Week 3		Transfer Week 4	
	Old	New	Old	New	Old	New	Old	New
Memory–same set								
Experimental	2.95	3.74	1.67	2.15	.96	1.42	2.77	3.23
Week 4 yoked	—	—	—	—	—	—	6.28	6.59
Memory–different set								
Experimental	3.90	4.68	3.05	3.63	2.91	3.36	2.41	3.17
Week 4 yoked	—	—	—	—	—	—	5.10	5.62
Rule–same set								
Experimental	4.56	5.12	2.97	3.29	2.28	2.45	2.85	3.15
Week 1–3 yoked	6.18	6.00	4.59	5.10	3.79	4.32	3.14	3.91
Week 4 yoked	—	—	—	—	—	—	4.52	4.76
Rule–different set								
Experimental	4.18	4.52	2.87	3.00	2.37	2.86	2.43	2.88
Week 1–3 yoked	6.06	5.87	5.02	4.98	4.53	4.47	2.64	3.44
Week 4 yoked	—	—	—	—	—	—	4.48	5.17
Control–same set	9.58	10.66	9.38	9.48	9.15	9.14	9.71	9.34
Control–different set	9.28	9.24	9.09	9.61	9.39	9.13	9.35	9.30

Note. The expected value of chance performance is 10 violations per trial block.

panel of Figure 1), the six ending trigrams (*TXS*, *PVV*, *SXS*, *TVV*, *VPS*, and *XVV*), and the two “runs” corresponding to the loops in the grammar (*SSS* and *TTT*). Given that the trigrams in this set of frequently mentioned items varied considerably in rate of occurrence in exemplars of the grammar and that their cue validity was not different from other rarely mentioned trigrams, we assume that these trigrams were mentioned so often primarily because of the salience of beginnings, endings, and loops to our English-speaking subjects (see Reber & Allen, 1978; Reber & Lewis, 1977).

Table 3 contrasts the mean proportions of these highly salient trigrams mentioned in verbal data each week with those of the remaining 28 nonsalient trigrams. The data in Table 3 from the rule discovery subjects show much more frequent mentioning of the high- versus the low-salient trigrams across all 4 weeks of practice. However, the recall data from the memory subjects (Weeks 1–3) include high levels of both salient and nonsalient trigrams. Yet in Week 4, when the memory subjects were transferred to rule discovery instructions, their verbal instructions showed the same bias

toward mentioning primarily the highly salient trigrams. This clear difference between the contents of *recall* responses (memory groups in Weeks 1–3) versus *rules* for a partner (rule discovery groups and memory groups in Week 4) demonstrates that subjects are more selective (i.e., abstract) when asked to provide rules for a partner than when recalling instances. Thus, on the basis of performance on the string discrimination task, knowledge about the grammar does not differ between the two instructional conditions; however, the type of knowledge retrieved by subjects when they are asked to provide rules is more selective than the knowledge they retrieve when recalling exemplars. It is interesting to note that the recall responses actually contained more valid information about the grammar (valid trigrams) than did the verbal instructions for a partner. This was true even though verbal instructions were obtained 20 times within a weekly session and each time subjects were asked to give additional information not provided on earlier responses.

Accessibility of knowledge. The clearest result of this study is the finding that subjects can communicate much of their

Table 3
Mean Proportion of Trigrams Mentioned as a Function of Task Instruction, Letter Set Change, Salience (High and Low), and Week of Practice in Experiment 1

Instruction letter set	Week 1		Week 2		Week 3		Transfer Week 4	
	High	Low	High	Low	High	Low	High	Low
Memory								
Same set	.95	.85	.96	.89	.96	.89	.56	.23
Different set	.90	.79	.84	.75	.91	.81	.60	.22
Rule discovery								
Same set	.39	.13	.51	.09	.50	.09	.47	.11
Different set	.52	.12	.54	.13	.60	.20	.61	.19

knowledge of the artificial grammar to another person. Figure 2 shows the performance of the experimental, Week 1-3 yoked, and control subjects across all 4 weeks of practice. The analyses comparing these groups in Weeks 1-3 showed that controls had significantly more violations than did yoked subjects both on Trial 1, $F(1, 164) = 22.20$, $MS_e = 11.19$, and in Blocks 2-20, $F(1, 6382) = 119.85$, $MS_e = 247.94$. However, yoked subjects did not perform as well as experimentals on Trial Block 1, $F(1, 164) = 17.38$, $MS_e = 11.19$, or in Blocks 2-20, $F(1, 6382) = 18.65$, $MS_e = 247.94$. Thus, not all of the experimental subjects' knowledge of the grammar was successfully communicated to their yoked partners.

The Week 4 yoked subjects' performance data are included in Tables 1 and 2. Planned contrasts indicated that the yoked groups with memory instructions did not differ from the yoked groups with rule instructions on either Trial Block 1 or Blocks 2-20. Thus, in Week 4, knowledge of the grammar was equally accessible for communicating instructions to a yoked partner in both the implicit (memory) and explicit (rule discovery) groups. Additionally, in Week 4, where Week 1-3 yoked subjects were given feedback and performed the task on their own (without transcripts), there was no reliable difference in performance between these transferred yoked

and experimental subjects. Thus, the knowledge acquired by these subjects from verbal instructions also transferred well to a new letter set.

Convergence of individual knowledge of the grammar. In order to assess the extent of convergence in individuals' knowledge of the grammar, it was necessary to analyze the content of verbalizations in a way that would permit comparisons across subjects. The trigram analysis described earlier is suitable for this purpose because it reduces each set of verbalized instructions to a subset of valid trigrams mentioned in the verbal instructions. Although this measure does not capture all of the information contained in the verbal instructions provided each week, it should be a sufficient sample of the verbalized knowledge to detect convergence in verbalized knowledge across weeks of practice.

Two reliability measures were used to assess the extent of convergence in individuals' verbalized knowledge across weeks of practice (in rule discovery conditions only, because memory subjects only verbalized instructions in Week 4): Kendall's coefficient of concordance (W) and the intraclass correlation coefficient (P). In both measures convergence of knowledge across weeks would result in an increase in the reliability estimates as a function of week of practice. Both measures produced low estimates of reliability (ranging from .15 to .32), and neither measure showed any tendency to increase across weeks of practice. Thus, there was no evidence of convergence in individuals' knowledge of the grammar after 10 hr of practice in distinguishing valid from invalid strings and after multiple opportunities to encode virtually all instances of the grammar. This result strongly supports rule induction models rather than memory array models. It suggests that once an adequate set of cues has been discovered to discriminate valid from invalid strings, additional experience with exemplars does not add to the knowledge of the grammar.

Experiment 2

One important result of Experiment 1 concerning abstractness of the knowledge acquired was that the groups who experienced only one letter set during the first 3 weeks of practice did as well as groups who had a different letter set each week on the new letter set in Week 4. However, because subjects were given a new study list each week containing exemplars with the new letter set, they could have explicitly figured out the mapping between a new and old letter set during this study period. In Experiment 2 the study lists were eliminated to see if transfer to a new letter set would still occur without this opportunity to determine the relation between new and old letter sets prior to the string discrimination task.

Another purpose of Experiment 2 was to examine possible reactive effects of the teach-aloud procedure. Subjects in Experiment 1 always performed some type of conscious thinking about the exemplars between trial blocks of the multiple-choice task. They either gave verbal instructions for a partner to perform the task (rule discovery groups), or they recalled exemplars (memory groups). Perhaps the secondary task influenced the processing of the grammar strings to the extent

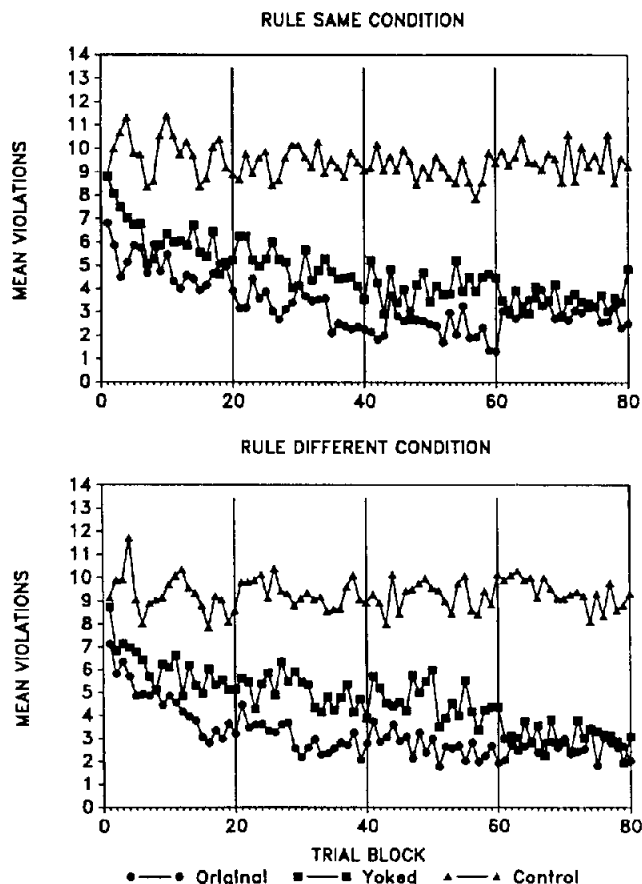


Figure 2. Performance of experimental subjects, Yoked Group 1, and control subjects in the rule discovery conditions across 4 weeks of practice (vertical lines separate weeks of practice).

that the verbalized knowledge of the grammar in Experiment 1 was not typical of knowledge acquired when performing only the primary task (distinguishing valid from invalid strings). In Experiment 2 subjects acquired knowledge of the grammar for 2 weeks, by performing only the string discrimination task without verbalizing, before attempting verbalization in Week 3. If the Week 3 verbalizations show levels of accessibility to implicit knowledge of the grammar similar to that found in Experiment 1, then we can be more confident that the accessible knowledge is typical of subjects' ability to access implicit knowledge rather than an artifact of the verbalization/recall procedure used during training.

Finally, one additional type of data concerning abstractness of individuals' grammars was obtained in Experiment 2 by asking subjects to verbalize instructions for a partner to perform the string discrimination task with a different, unknown letter set (abstract verbalization) in Week 4. In this task subjects must tell their partners about abstract features of the grammar because they do not know what specific letter patterns will occur in their partner's choices.

Method

Subjects and design. There were four groups of experimental subjects replicating the core 2 × 2 design of Experiment 1 and eight groups of 1-week yoked subjects (one group assigned to each Week 3 verbalization and a separate group assigned to each Week 4 verbalization in each of the four experimental groups). Male and female undergraduate students (N = 168) received course credit for participating in this experiment. There were 14 subjects in each group.

Procedure. The procedure of Experiment 2 was identical to that of Experiment 1 except that (a) the study lists were omitted from all four weeks, (b) there was no recall or verbalization between blocks of multiple-choice trials until Week 3, and (c) subjects were asked to give instructions for a partner with a different, unknown letter set in Week 4 (referred to as *abstract verbalization*). As in Experiment 1, there were four groups of experimental subjects: rule discovery-same letter set, rule discovery-different letter set, memory-same letter set, and memory-different letter set. One group of yoked subjects was assigned to each experimental subject for Week 3, and a different group of yoked subjects was assigned to experimental subjects for Week 4. This latter group received a different letter set from those used by experimental subjects in Weeks 1-4.

Because there were no study lists, the instructions for the memory groups had to be modified slightly. As in Experiment 1, subjects were told to add each correct choice to their memory set and to select their choices on the basis of the item that was most similar to a prior correct choice. However, these subjects began the experiment with a null memory set, so they were told to simply guess on their initial choices but then begin to select items on the basis of their accumulating memory set (similar to a continuous recognition procedure). All other aspects of the procedure were identical to Experiment 1.

Results and Discussion

The mean number of violations in string choices in Trial Block 1 of each week and in Trial Blocks 2-20 is presented in Tables 4 and 5. Results relevant to each of the main issues will be discussed below.

Passive abstraction. There were no main effects of instructions or interactions with instructions in either the analysis of

Table 4
Mean Violations in Block 1 as a Function of Task Instruction, Letter Set Change, and Week of Practice for Experimental And Yoked Subjects in Experiment 2

Condition	Week 1	Week 2	Week 3	Transfer Week 4
Memory-same set				
Experimental	8.75	6.28	4.40	7.00
Yoked subjects	—	—	6.90	7.46
Memory-different set				
Experimental	9.22	8.25	6.14	7.00
Yoked subjects	—	—	8.00	8.54
Rule-same set				
Experimental	9.50	5.64	4.82	7.96
Yoked subjects	—	—	6.25	9.00
Rule-different set				
Experimental	10.07	7.54	6.60	6.50
Yoked subjects	—	—	8.22	8.96

Note. Data from the regular yoked subjects are presented in Week 3, and data for the abstract yoked subjects are presented in Week 4 above. The expected value of chance performance is 10 violations.

Trial Block 1 data or that of Trial Blocks 2-20 (all *F*s < 1). As in Experiment 1, performance in selecting valid versus invalid strings was equivalent in the two instruction conditions, whether the choices were old exemplars, new exemplars, or exemplars formed using a new letter set. Thus, on the basis of performance on the string discrimination task, subjects acquired an equal amount of tacit knowledge of the grammar with (rule discovery groups) or without (memory groups) conscious attempts to determine the rules of the grammar.

Perhaps explicit learning adds nothing to performance in discriminating valid from invalid strings because rule discovery subjects are unable to generate valid rules other than those that are automatically generated by their implicit learning mechanism (we assume that the implicit learning mechanism continues to function automatically in the explicit conditions). That is, the set of valid rules that subjects can explicitly generate are a subset of the same rules (patterns of family resemblance) identified by the implicit learning mechanism. We hypothesized that explicit learning contributes to knowledge only when the domain contains rules that are not based on perceptual similarities across exemplars and, therefore, cannot be identified automatically through implicit learning. This hypothesis will be explored further in Experiments 3 and 4.

Abstractness of knowledge. The same letter set groups performed significantly better than the different letter set groups, both in the Trial Block 1 data, *F*(1, 48) = 11.19, *MS*_e = 29.64, and in Trial Blocks 2-20, *F*(1, 48) = 6.80, *MS*_e = 239.75. Mean violations (for both old and new items) are plotted as a function of trial blocks in Figure 3. In Figure 3 it can be seen that performance does get worse (i.e., more violations) when new letter sets are introduced in Trial Blocks 21 and 41 in the different letter set groups and in all groups in Week 4 (Trial Block 61). However, it is also obvious that performance does not decline to the initial levels of performance in Week 1, suggesting that there is some positive transfer across weeks because of abstract knowledge of the grammar.

Table 5
Mean Violations on Old (Repeated) and New Strings on Blocks 2–20 as a Function of Task Instruction, Letter Set Change, and Week of Practice for Experimental and Yoked Subjects in Experiment 2

Condition	Week 1		Week 2		Week 3		Transfer Week 4	
	Old	New	Old	New	Old	New	Old	New
Memory–same set								
Experimental	5.79	6.24	4.02	4.30	3.01	3.48	4.78	5.43
Yoked subjects	—	—	—	—	7.31	6.90	8.02	8.83
Memory–different set								
Experimental	5.55	6.07	4.99	5.06	4.33	5.26	4.96	5.44
Yoked subjects	—	—	—	—	7.54	7.44	7.29	8.69
Rule–same set								
Experimental	5.78	6.07	3.45	3.93	2.67	2.65	4.42	5.59
Yoked subjects	—	—	—	—	5.23	4.99	7.34	8.14
Rule–different set								
Experimental	5.12	7.36	5.39	5.61	4.10	4.65	4.56	5.13
Yoked subjects	—	—	—	—	7.14	7.76	9.16	9.05

Note. Data from the regular yoked subjects are presented in Week 3, and data for the abstract yoked subjects are presented in Week 4 above. The expected value of chance performance is 10 violations per trial block.

This pattern of results is consistent with the view that a subject's knowledge of the grammar is partly abstract and partly specific to a letter set. The abstract knowledge transfers to a new letter set, but performance on the new letter set is not as good as on the old letter set because the specific components of the knowledge (e.g., which specific letters can repeat) do not transfer.

As in Experiment 1, performance in Week 4 with a new letter set was equivalent whether or not subjects had prior experience with different letter sets. If it was necessary to decipher the mapping between new and old letter sets, one would think that prior practice mapping between new and old letter sets in Weeks 2–3 would lead to the development of efficient strategies for discovering the mapping between letter sets. Consequently, the availability of these strategies in the different letter set groups would facilitate performance on the transfer task in Week 4. However, performance in Week 4 was equivalent for the same and different letter sets groups, suggesting that experience in mapping between different letter sets did not facilitate transfer in Week 4. In other words, transfer occurs through the automatic abstraction of general knowledge of the grammar.

Accessibility of knowledge. The performance levels of the yoked subjects are shown in Tables 4 and 5. As in Experiment 1, yoked subjects performed better than chance in both Week 3, $t(2124) = 33.38$, and in Week 4, $t(2124) = 12.59$, but worse than their experimental partners, smallest $F(1, 4248) = 5.81$, $MS_e = 104.02$, for Week 3 Blocks 2–20, suggesting that some but not all of the experimental subjects' knowledge was communicated to their yoked partners. Planned contrasts indicated that the implicit (memory) yoked groups did not differ from the explicit (rule discovery) groups in Week 3 or Week 4. Thus, as in Experiment 1, knowledge of the grammar was equally accessible for the implicit and explicit groups.

Analyses of the contents of subjects' verbal protocols for Week 3 indicated they were also very similar to the verbal

reports obtained in Experiment 1. A trigram analysis on these protocols showed the same emphasis on beginnings, endings, and loops that occurred in Experiment 1. The mean proportion of high- and low-salient trigrams mentioned in each group in Week 3 were .56 and .19 in the rule discovery–same letter set group, .31 and .05 in the rule discovery–different letter set group, .51 and .19 in the memory–same letter set group, and .42 and .16 in the memory–different letter set group.

Experiment 3

Experiments 3 and 4 addressed the question of what happens when implicit and explicit learning processes interact through sequential use of both learning processes. These experiments also provided a stronger test of passive abstraction than provided by past research. In prior research, as well as in Experiments 1–2 of this series, implicit learning was elicited by instructions to memorize sets of exemplars. In Experiments 1 and 2 of this series, subjects were further instructed to make choices based on similarity to previous exemplars. It is possible that memorization of sets of exemplars or searching for similarities to past items in a memory set might be sufficient to stimulate explicit mechanisms of abstraction. Similarly, the traditional explicit processing task is weak in that subjects may quickly tire of looking for rules and revert to memory-based processing. The remaining two experiments employed a much stronger implicit–explicit manipulation that can also be used to mix the two types of learning to test for interactions when both processes are used.

The implicit task used in these final two experiments, the *match task*, is a short-term memory task. On each trial, subjects are presented with a single string (a valid string from the grammar) that they are to hold in memory for a few seconds until five choices appear on the screen. Then they select the identical string from the choices and press the

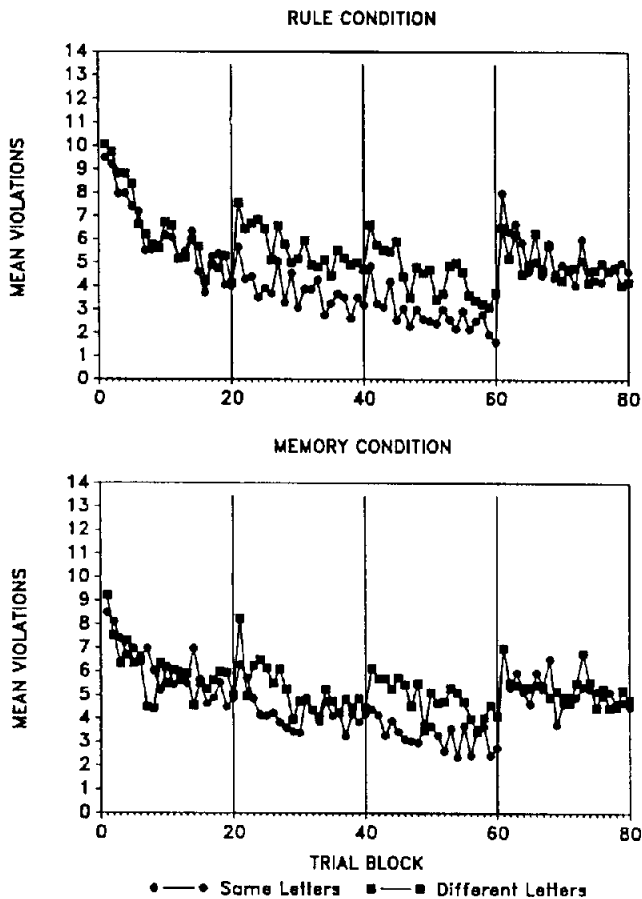


Figure 3. Performance of experimental subjects in all four groups across 4 weeks of practice (vertical lines separate weeks of practice).

number of that choice on the keyboard. In this condition subjects do not know the items are generated by a grammar during training, and there is no incentive for explicit abstraction of similarities among the items. In fact, thinking about similarities among the items across trials would be likely to interfere with the task of matching the correct string that was presented on a given trial.

In the explicit learning task, the *edit task*, subjects were exposed to the same set of items used in the match task. However, these items were presented initially in altered form, having one to four letters changed to create invalid strings. Subjects were told that the items they would see were “flawed” strings generated by a grammar. Their task was to figure out the rules of the grammar so that they could learn to identify and mark the incorrect letters in each string. On each trial the subject marked one to four letters in the displayed string that he or she thought were incorrect. Then the correct string was displayed as feedback. Thus, the edit task requires continuous generation and testing of possible rules for letters occurring in various positions in the strings.

On the basis of results of the first two experiments, we hypothesized that explicit learning processes do not add additional rules to subjects’ knowledge of the finite state gram-

mar beyond those automatically acquired through implicit learning. This hypothesis assumes that additional rules of this grammar, beyond those automatically detected through the implicit learning mechanism, cannot be discovered through explicit generation because the rules of the finite state grammar are unrelated to known mental models subjects could use to generate rules. This hypothesis implies that even with the more extreme implicit processing task used in this experiment, we should obtain the same results—equivalence of learning with implicit and explicit learning processes.

Another potential problem with interpreting the results of the first two experiments concerns giving feedback during the string discrimination task. Feedback was provided after every trial in the string discrimination task in the first two experiments to examine the convergence issue in Experiment 1 and to develop a high level of expertise before verbalization in Experiment 2. However, with feedback during the test phase, learning continues, and knowledge acquired through the test phase cannot be separated from knowledge acquired through an initial training procedure (e.g., memorization of a list of exemplars in the study list). In Experiment 3, no feedback was given during the first 70 trials of the string discrimination test so that we could measure exclusively knowledge acquired during the prior implicit (match) or explicit (edit) processing task.

Method

Subjects and design. There were 20 subjects in each of the five independent groups. The five experimental groups differed in the sequences of match (single-item memory task) and edit (string correction task) trials they had during the first phase of the experiment. The *match* group had 100 match trials and no edit trials. The *edit* group had 100 edit trials and no match trials. The *match/edit* group had 50 match trials followed by 50 edit trials. The *edit/match* group had 50 edit trials followed by 50 match trials. The *alternate* group had 50 match and 50 edit trials alternating tasks between each trial. Male and female undergraduate students ($N = 100$) received course credit for participating in this experiment.

Procedure. Each subject participated in one experimental session lasting about 2 hr. The experiment consisted of two phases. In the first phase subjects performed a total of 100 trials of the training task (match trials, edit trials, or a combination). In the second phase they performed 100 trials of the multiple-choice string discrimination test. Instructions for match trials consisted of telling subjects that on each trial they would see a single string of letters on the computer screen. They were to look at the string and retain it in their memory. The screen would go blank for 2 s, and then five choices would appear on the screen. The subjects’ task was to select the string that was identical to the one they were holding in memory. After each response, the computer informed them which was the correct choice, and then the next trial began.

The edit task instructions informed subjects that each letter string they would see was a flawed example of a string generated by a complex set of rules. Each string would have from one to four letters that were incorrect. Their task was to explicitly discover the rules of the grammar by marking the letters they thought were incorrect by using the arrow keys and space bar of the computer. After they pressed the return key, the computer indicated which were the invalid letters that they should have marked, and the correct string was displayed. Then the screen was cleared and the next trial began. It

should be noted that the same items were used for both match and edit conditions.

The match/edit and edit/match conditions received the appropriate sets of instructions immediately prior to beginning each task (e.g., before Trial 1 and Trial 51). The alternate group was given both sets of instructions before beginning Trial 1, and they were informed that the words "match" or "edit" would appear on the screen prior to beginning each trial to tell them which task to perform on that trial.

After completing the initial phase, all subjects were informed that the letter strings they had seen in the first phase were generated by a complex set of rules. They were told that some of the strings they would see in this phase were generated by the same set of rules. Their task was to pick the string on each trial that was a valid string generated by these rules. Subjects responded to 100 multiple-choice items in this phase of the experiment. On each trial five strings appeared on the screen, numbered 1–5. The subject responded by pressing the number of his or her choice. No feedback was provided during this part of the test phase. Subjects were allowed to take as long as they wished to respond to each screen. The teach-aloud procedure was used to collect verbal reports between each trial block. After each sequence of 10 multiple-choice items, the computer instructed the subject to pause and wait for further instructions. During this time subjects verbalized instructions to perform the task for their "unseen partner." After recording their instructions, subjects pressed the return key on the computer to begin the next block of multiple-choice trials.

To measure the generalizability of knowledge acquired about the grammar, the letter set was changed beginning on Trial 51 of the multiple-choice task. There was no feedback during the test phase until after Trial 70. Starting in Trial 71 on the multiple-choice task, the computer began giving feedback about which was the correct choice after each response. The purpose of this part of the test was to see how quickly subjects' performance on the new letter set would improve once feedback was initiated.

Instrument. The same artificial grammar used in Experiments 1 and 2 was used in this experiment. The instrument used in the test phase consisted of a subset of the same items used in Experiments 1 and 2. Each block of 10 multiple-choice items (including the initial block) contained 5 new valid strings and 5 old valid items that were repeated from the first phase of the experiment.

Results and Discussion

Data from Blocks 1–4 (same letter set), Blocks 5–6 (different letter set, no feedback), and Blocks 7–10 (different letter set with feedback) were analyzed separately. The results are shown in the upper panel of Figure 4.

Passive abstraction. Analyses for all three phases of the string discrimination test (same letter set without feedback, different letter set without feedback, and different letter set with feedback) indicated no differences among any of the training conditions. Figure 4 shows that all five training conditions produced very similar levels of performance in string discrimination. In the initial phase of the test (Trial Blocks 1–4) the match and match/edit groups performed slightly better than the edit and edit/match groups, but these differences were not significant, largest $F = 1.04$. These results provide the strongest evidence to date that there is an automatic induction mechanism capable of abstracting complex patterns of family resemblance without any conscious attempts to discern the patterns. In the match task, subjects held valid strings in memory just long enough to identify the

item in a set of five choices. During training, they did not know the items were generated by a grammar nor that they would be later asked to discriminate valid from invalid strings. There was no incentive or opportunity for any type of conscious rule abstraction or explicit organizational process prior to the string discrimination test. Yet this group performed as well as others who had prior knowledge that the strings were generated by a grammar and who were engaged in explicitly generating and testing the rules of the grammar.

The lack of performance superiority in the edit group and in the mixed groups (alternate, match/edit, or edit/match) relative to the purely implicit group (the match group) confirms the hypothesis based on the results of Experiments 1 and 2 that explicit rule generation plays virtually no role in acquisition of knowledge of this finite state grammar.

Abstractness of knowledge. Performances of all five groups deteriorated greatly when letter sets were changed in Trial Block 5 and remained at a low level even after feedback was introduced (Trial Blocks 7–10). However, subjects were performing at better than chance levels in both Trial Blocks 5–6, $t(398) = 6.21$, and Trial Blocks 7–10, $t(793) = 15.13$. Thus, there was some evidence of abstract knowledge, and the amount of abstract knowledge did not differ across the five training conditions.

Accessibility of knowledge. Following the procedure used in Experiments 1 and 2, subjects' verbal instructions for their "unseen partners" were analyzed in terms of the specific trigrams they told their partners to select. The mean proportions of salient and nonsalient trigrams mentioned in the first five blocks of the string discrimination task (before the letter set was changed) were .25 and .05 in the match group, .19 and .03 in the edit group, .22 and .04 in the alternate group, .22 and .03 in the match/edit group, and .17 and .03 in the edit/match group. These data are quite similar to the proportions of salient and nonsalient trigrams mentioned in the previous experiments, taking into consideration the fact that these subjects had only four attempts to verbalize the trigrams, whereas subjects in the earlier experiments had 20 such attempts (thus, the proportions of salient trigrams verbalized tended to be higher in the earlier experiments). The data were quite consistent across the five training tasks, indicating that the verbalizable knowledge of the grammar acquired under the different training conditions was quite similar. Also, these verbalizations were quite similar to those obtained in Experiments 1 and 2, which have been shown to contain valid information that a naive partner can use to perform the string discrimination task. Thus, these results, along with those of the first two experiments, indicate that implicitly acquired knowledge of the grammar is partially accessible to conscious reflection—even with a more extreme implicit learning task.

Experiment 4

We had predicted the null results of Experiment 3 (no differences among training conditions) on the basis of the assumption that subjects were not likely to generate valid rules of the finite state grammar above or beyond those that

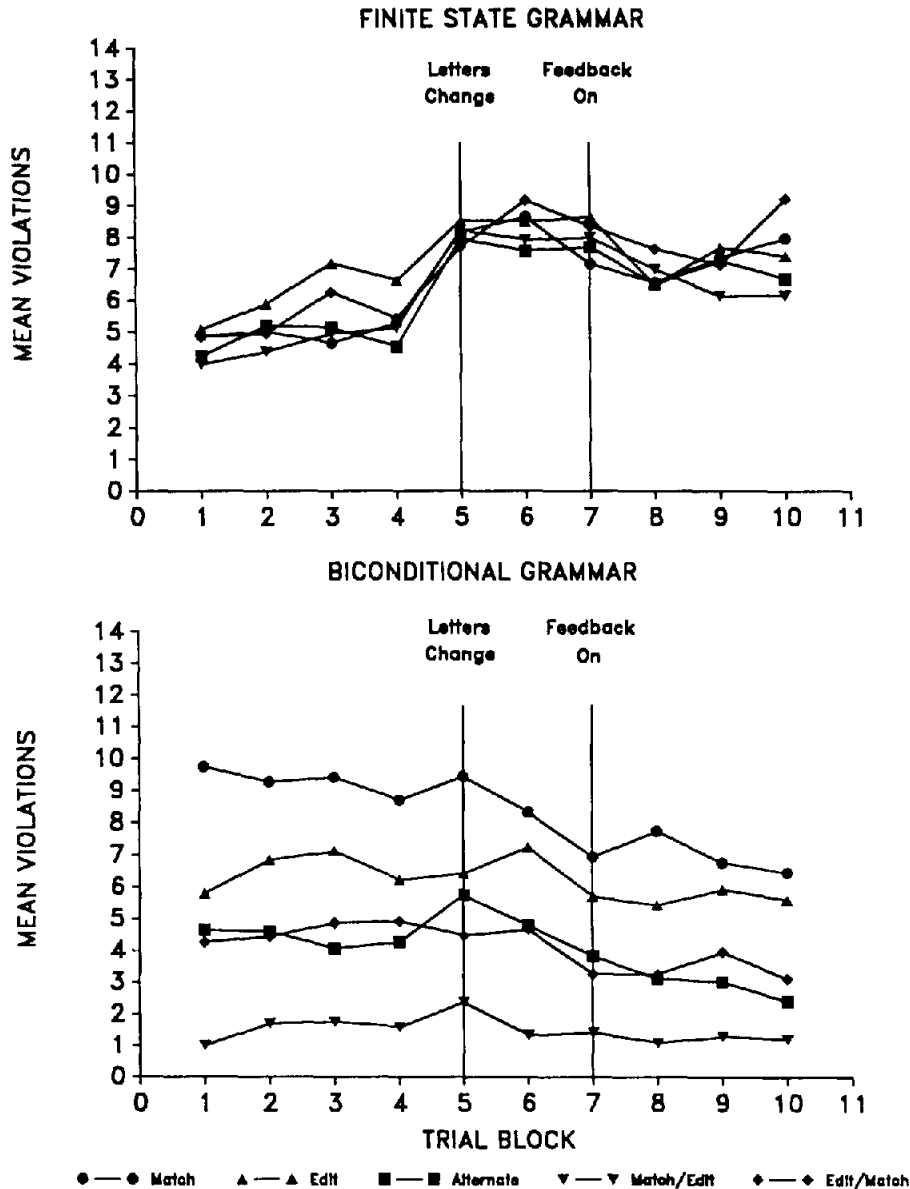


Figure 4. Performance on the string discrimination task as a function of training groups in experiment 3 (finite state grammar) and in Experiment 4 (biconditional grammar). (Specific letters were changed in Block 5, and feedback was introduced in Blocks 7-10.)

the automatic implicit learning processes would detect on the basis of family resemblances among correct strings.

From prior research we know that subjects are capable of explicitly generating simple logical rules (e.g., Bourne, 1970). Therefore, an artificial grammar based on simple logical rules should be accessible to explicit learning. In addition, a grammar based on biconditional letter correspondence rules (e.g., if there is an *A* in the first position, there must be an *X* in the fifth position) would generate sets of exemplars having a lower level of family resemblance than exemplars in the finite state grammar used in the previous experiments because of greater variation in letters across different positions in valid strings. For example, no constraints are imposed by the biconditional

rule mentioned above on which letters can occur in the first position.

Therefore, for Experiment 4 we devised a grammar based on biconditional rules. This grammar generates strings of eight letters with a period separating the first and second halves of the string. The rules of the grammar consist of three letter correspondence rules specifying which letters must occur in corresponding positions in the left and right halves of the string. The three correspondence rules were *X* goes with *T*, *P* goes with *C*, and *S* goes with *V*. Thus, for example, *TPPV.XCCS* is a valid string. Across the set of all valid exemplars generated by this grammar, each letter occurred in each position equally often. Thus, no specific beginning or

ending letter patterns can be abstracted to select valid strings. Across the set of valid strings generated by this grammar, there is a symmetry of repetitions across the halves of a string (e.g., the double *P* and double *C* in the above example). Although detecting this pattern might provide a clue for generating the right type of rules, it is insufficient for high levels of performance on the string discrimination task. To perform well on the string discrimination task, subjects must generate the explicit correspondence rules.

Experiment 4 replicated the design of Experiment 3 but used the biconditional grammar. In this experiment we predicted that the explicit task (the edit group) would facilitate learning relative to the purely implicit task (the match group) because biconditional rules can be generated explicitly and should be difficult to detect through implicit learning. We also predicted that the mixed conditions would result in the highest level of learning because the patterns of family resemblance detected by the implicit learning mechanism should help guide the generation of rules to select valid strings.

Method

Subjects and design. The design of this experiment exactly replicated that of Experiment 3, except that the exemplars were generated by the biconditional grammar rather than the finite state grammar. All other aspects of the design and procedure of Experiment 4 were identical to Experiment 3. Male and female undergraduate students ($N = 100$) received course credit for participating in this experiment. There were 20 subjects in each of five groups.

Instrument. Each string consisted of four letters followed by a period and then four more letters. There are three rules that specify which letters must occur in corresponding positions (first, second, third, or fourth) on each side of the period. The rules are *X* goes with *T*, *P* goes with *C*, and *S* goes with *V*. These six letters were the only letters that occurred in all strings (valid and invalid strings). Valid strings always had correct associates in the corresponding positions on each side of the period. For example, *XCSS.TPVV* and *PSTV.CVXS* are valid strings.

As in Experiment 3, each block of 10 multiple-choice items contained five new valid strings and five old items that were repeated from the first phase of the experiment. On each trial, one correct string (no violations) was presented with four other randomly selected strings containing one, two, three, and four violations, respectively. The strings were presented in a column in a random order and numbered 1–5. The strings containing violations were made from randomly selected valid strings, with the violations created by substituting letter(s) that could not occur in particular positions. As in Experiment 3, beginning with the first item in the fifth block of the string discrimination test, the letter set was changed, and feedback was begun on the 71st trial of the string discrimination test.

Results and Discussion

Passive abstraction and interactions. The mean performance for each of the five groups across test trial blocks is plotted in the bottom panel of Figure 4. An analysis of variance on the first four blocks of the test showed a significant effect of training task, $F(4, 95) = 12.63$, $MS_e = 104.50$. Newman-Keuls tests indicated that the match/edit group ($M = 1.51$) performed significantly better than all the other groups. The edit group ($M = 6.5$), the edit/match group (M

$= 4.63$), and the alternate group ($M = 4.40$) all performed significantly better than did the match group ($M = 9.29$), which was performing at nearly a chance level (10 errors per block). Thus, unlike all of the previous experiments with the finite state grammar, there was no evidence of automatic learning of the biconditional grammar with the purely implicit training task (match). Also, there was a very strong positive interaction when both types of learning were used in the mixed groups. All of the mixed groups had fewer violations than the match or edit groups, and the best performance occurred in the group that had 50 match trials followed by 50 edit trials.

Abstractness of knowledge. An analysis of variance on the second phase of the test, different letter set without feedback (Blocks 5–6), showed a significant effect of training task, $F(4, 95) = 9.95$, $MS_e = 55.27$. The means across the five training task groups were in the same pattern as in Blocks 1–4, with best performance in the match/edit group and worst in the match group (see Figure 4). The analysis on Blocks 7–10 showed a similar pattern. Again, there was a significant effect of training task, $F(4, 95) = 9.19$, $MS_e = 88.94$. Thus, transfer to a new letter set with this grammar depends on the type of training task in the same way that performance on the original letter set does: worst performance with the (implicit) match task, better performance with the (explicit) edit task, and best performance with the mixed conditions.

Accessibility of knowledge. The mean proportion of subjects who verbalized each of the three biconditional rules during the first five blocks of test trials (before the letter set was changed) is illustrated in Table 6. These results are congruent with the performance data, showing best performance in the match/edit condition and worst in the match group.

General Discussion

The purpose of these experiments was to examine the extent to which the alleged properties of implicit learning justify postulating two distinct learning processes. Especially on the basis of our results concerning passive abstraction of knowledge and the synergistic interaction of using both types of learning to acquire the biconditional grammar, it appears clear that two distinct learning processes must be recognized. The evidence for the distinctness of implicit learning, on the basis of each of the five issues addressed by this study, is discussed below, followed by some comments on developing a theory of implicit learning.

Table 6
Mean Proportion of Subjects Who Mentioned Each Biconditional Rule in Their Verbal Instructions in the Initial Phase of the String Discrimination Task in Experiment 4

Rule	Match	Edit	Alternate	Match/Edit	Edit/Match
X ↔ T	.05	.20	.45	.75	.35
P ↔ C	.05	.20	.45	.80	.35
S ↔ V	.05	.20	.45	.75	.35

Note. The n in each cell is 20.

Passive Abstraction

Experiment 3 offers the strongest evidence for an automatic learning process capable of acquiring abstract knowledge about the finite state grammar. The match versus edit training task used in this experiment represents a more extreme manipulation of explicit versus implicit processing than that used in previous research (e.g., instructional manipulations). In the match task subjects held single exemplars in memory long enough to select the same item from a subsequent set of five choices. These subjects did not know that the items seen across trials were generated by a grammar during this training task. They also had no opportunity or incentive to organize sets of exemplars for memory that could lead to conscious (explicit) abstraction of patterns of family resemblance. Yet, subsequent performance of this implicit learning group (the match group) on the string discrimination task was no different from the explicit (edit) group or any of the mixed conditions (alternate, 50 match/50 edit, or 50 edit/50 match).

In sharp contrast to the above results, the results of Experiment 4 demonstrate that implicit learning processes, which were completely sufficient for acquiring the finite state grammar used in the first three experiments, were totally inadequate for learning the biconditional grammar. The match group in Experiment 4 performed the string discrimination test at a nearly chance level. The edit group performed better than the match group, and the three mixed conditions led to even better performance. This pattern of results was predicted on the basis of the notion that automatic implicit learning processes are capable only of identifying common patterns of family resemblance among exemplars. The biconditional grammar was designed to have a limited amount of family resemblance among exemplars, so that high levels of performance would require going beyond these patterns of similarity and explicitly identifying the underlying rules. Thus, these contrasting results between Experiments 3 and 4 provide compelling evidence that more than one learning process is involved in learning complex cognitive tasks.

Abstractness of Implicit Knowledge

The importance of the abstractness issue is in determining if there is enough evidence of automatic (implicit) abstraction to conclude that implicit learning involves more than responding on the basis of memories of specific cases (e.g., Brooks, 1978, 1987; Jacoby & Brooks, 1984). The experiments discussed here provide evidence for the automatic abstraction of features of the finite state grammar.

The analyses of the verbal protocols in Experiments 1–3 provided a consistent picture of the knowledge used to communicate information about the finite state grammar. The type of knowledge available was not affected by the training task (i.e., implicit vs. explicit learning). Virtually all subjects expressed their knowledge in terms of series of instructions to select or avoid strings having specific letter patterns (e.g., “select strings that begin with *SCP*” or “select strings that end in *VV*”). Successive verbal reports across trial blocks tended to include elaborations and exceptions to “rules” provided on earlier trial blocks. This type of knowledge includes both

item-specific and more general (abstract) features of grammar strings. It is exactly the type of knowledge that should be acquired about the grammar, judging from the Holland et al. (1986) rule induction model.

Analyses of transfer performance also produced evidence suggesting that knowledge of the grammar is partly specific to the exemplars that a subject experienced (Brooks, 1978, 1987; Vokey & Brooks, in press) and partly more general or abstract knowledge of the grammar (Reber, 1969, 1976). There was considerable evidence that subjects could transfer what they had learned about the grammar to a different letter set. Also, the abstraction that occurred did not appear to require extensive explicit processing. In Experiment 1, there was virtually no interruption in individual learning curves when a new letter set was introduced in Weeks 2–4 in the different letter set groups and in Week 4 in the same letter set groups. The relatively automatic quality of this generalization process was also suggested by the equivalent level of performance of the same and different letter set groups on the new letter set in Week 4. Experiencing two previous changes in letter set in Weeks 2 and 3 was of no benefit to the different letter set groups in Week 4, as would be expected if subjects had to consciously abstract the invariant qualities of the grammar across different letter sets. Even in Experiment 2, in which subjects had no opportunity to view examples of the grammar with the new letter set prior to beginning the string discrimination task, there was very little interruption in performance when new letter sets were introduced.

The results of Experiment 3 indicate that feedback during transfer is necessary for effective transfer to a new letter set. In this experiment subjects attempted to select exemplars of the grammar instantiated with a new letter set without feedback for 20 trials before feedback was initiated. Even though subjects performed above chance during this no-feedback period, their performance was markedly worse than in transfer trials in previous experiments. The tentative conclusion is that some feedback trials (e.g., 10 to 20 trials) are essential for good performance on a new letter set. Additionally, the lack of improvement in performance in the final three blocks of trials in Experiment 3 when feedback was given suggests that transfer trials without feedback (Blocks 5–6) might strengthen inappropriate rules that become resistant to extinction when feedback is introduced (cf. Holland et al., 1986).

One final piece of evidence concerning the abstractness of knowledge of the grammar concerns the ability of subjects to communicate the abstract qualities of the grammar to a partner attempting to perform the string discrimination task with a different letter set. In Week 4 of Experiment 2, subjects were asked to provide instructions for a partner with an unknown letter set. These instructions were then used by yoked subjects to perform the string discrimination task. These yoked subjects performed better than chance, showing that some valid abstract knowledge of the grammar was communicated.

Accessibility of Implicit Knowledge

There was consistent evidence that subjects could access and communicate much of their implicitly acquired knowl-

edge of the grammars in all four experiments. Thus, the general notion that all implicitly acquired knowledge is non-conscious—that is, completely inaccessible to consciousness (Lewicki, 1986)—is not supported by these data. On the other hand, groups of yoked subjects never performed as well as their experimental partners. Thus, we do not wish to claim that all or even most implicit knowledge is accessible, only that implicit knowledge of artificial grammars seems to be more accessible than other types of implicit knowledge (e.g., Lewicki, 1986; Hayes & Broadbent, 1988).

Convergence of Individuals' Knowledge of the Grammar

Another theoretical issue addressed by these experiments concerns the extent to which individual knowledge acquired about the grammar or "correlated grammars" (Dulany et al., 1984) tends to become more alike or to converge after extensive experience with exemplars. Failure-driven models such as classifier systems (Holland et al., 1986) predict limited convergence because there are many cues available to select valid strings, and the knowledge base should cease developing once an adequate set of predicting cues has been selected and strengthened. Typical memory array processing models (Estes, 1986a, 1986b), on the other hand, predict a higher level of convergence after extensive experience with the same set of exemplars. Our results appear more supportive of the failure-driven theories. The amount of knowledge contained in the verbal reports seemed to reach asymptote along with the ability to discriminate between valid versus invalid strings. More important, even after 3 weeks of experience with a set of exemplars from the same letter set, reliability measures showed no increase in consistency of responses across subjects.

Synergistic Interaction of Explicit and Implicit Learning

The synergistic effect of using both implicit and explicit learning processes was clearly demonstrated in Experiment 4 with the biconditional grammar. Subjects in the match/edit condition in Experiment 4 greatly outperformed all other groups. Moreover, the performance curves for all of the mixed conditions appeared to be superior to either of the single-task conditions (match or edit; see Figure 4). Contrary to current thinking about the total independence (Lewicki, 1986) or negative interaction of the two types of learning (e.g., Hayes & Broadbent, 1988), this finding suggests that knowledge acquired implicitly and explicitly interacts positively in certain situations.

The superiority of the match/edit condition over all the others in Experiment 4 suggests that the optimal procedure for learning the biconditional grammar is to develop an implicit knowledge base *before* beginning to generate an explicit model of the task. This finding is reminiscent of the finding in perceptual recognition studies that forming a hypothesis too early may prevent best use of the information available to the person (Bruner & Potter, 1964; Wyat & Campbell, 1951). Because this is the first demonstration of a

synergistic effect of using both implicit and explicit learning processes, we do not yet know how general this effect is. However, we suspect it may have considerable generality, given that most real-world tasks seem to involve both memory-based and model-based knowledge. If further research confirms the generality of this effect, it could have important implications for education: Perhaps complex tasks are best approached with a period of initial passive observation before formal instruction is attempted.

Toward a Theory of Implicit Learning

This study provides strong evidence that two different learning processes are involved in complex cognitive tasks. Even though these processes are generally consistent with notions about implicit versus explicit learning in the literature (especially as used by Reber, 1969, 1976), we propose a slightly different conceptualization and labeling of these processes that is more related to a theoretical description and that avoids some problems with the term *implicit learning*. One problem with the current use of the term *implicit learning* is that it places too much emphasis on the nonconscious quality of the implicit learning mechanism. Experiments 1–3 demonstrated that implicitly acquired knowledge of artificial grammars is certainly not *totally* inaccessible to consciousness. Moreover, the term *implicit learning* is easily confused with the term *implicit memory* (Schacter, 1987), which is used in situations in which evidence for memory is obtained by tests that do not require explicit recall of the material.

We propose that subjects draw on two different knowledge sources to guide their behavior in complex cognitive tasks. One source is based on their explicit conceptual representation or mental model of the task (e.g., Johnson-Laird, 1983), which we will refer to as *model-based processing*. The second, independent source of information is derived from *memory-based processing*, which automatically abstracts patterns of family resemblance through individual experiences with the task (Brooks, 1978, 1987; Estes, 1986a, 1986b; Hintzman & Ludlam, 1980; Medin & Schaffer, 1978). Clearly, knowledge based on compilations of memories of past experiences with the task could be quite different from knowledge based on one's current mental model of the task. Hence, dissociations between verbalized knowledge and task performance could occur when one source of knowledge is used for verbalization and the other is used to guide performance (see Stanley et al., in press).

Other researchers have made a similar distinction between conceptual versus data-driven processing (Jacoby, 1983; Matlin, 1983) or analytic versus nonanalytic cognition (Brooks, 1978, 1987; Jacoby & Brooks, 1984). However, there are some important differences between our conceptualization and these other notions. With respect to memory-based knowledge, we wish to emphasize that this knowledge reflects an interaction between properties of the current situation with remembered qualities of past experiences (e.g., Tulving, 1983), as opposed to being driven simply by qualities of the present stimulus itself (the data). Also, we do not wish to imply that memory-based knowledge is nonanalytic, as suggested by the Jacoby and Brooks (1984) distinction. We

believe that memory-based knowledge selectively identifies patterns of common attributes or features shared by many exemplars. Further, the set of features identified through memory-based knowledge need not coincide with predictions based on current mental model of the task. With respect to our concept of model-based processing, it is similar to the notion of conceptually driven processing or analytic cognition, but we wish to focus on the current, conceptual model of the task that the subject is using. In discovery-oriented tasks subjects may radically change their mental model of the task during learning.

Our conceptualization is perhaps most similar to that recently proposed by Berry and Broadbent (1988) and elaborated in Hayes and Broadbent (1988). Hayes and Broadbent (1988) proposed the following:

One type of learning is selective, effortful and reportable, and is the type of learning which would normally be referred to as "problem solving." Let us call this *s-mode* (selective mode) learning. The other mode of learning involves the unselective and passive aggregation of information about the co-occurrence of environmental events and features. Let us call this *u-mode* (unselective mode) learning. Each type of learning will be briefly considered below, and it will be argued that the difference between them is an "architectural" one; each reflects the operation of different processes within the cognitive system. (p. 251)

Our conceptualization also views the two types of learning as reflecting different architectural features of the cognitive system. However, we propose that the U-mode (memory-based processing) is also selective (to patterns of family resemblance with prior experiences). We also suggest that the S-mode (model-based processing) is capable of drawing on previous explicit knowledge (mental models), making it less dependent on working memory than in the Hayes and Broadbent model. Finally, we place less emphasis on the nonconscious nature of memory-based knowledge and more emphasis on the opportunities for synergistic interactions between the two modes, rather than on their potential interference with each other.

Conclusion

In conclusion, the results of this study are consistent with the notion that people possess an automatic knowledge-processing or induction routine that enables them to recognize family resemblances or covariance among exemplars of a grammar. Unlike many other situations (e.g., solving geometry problems) in which conscious hypothesis-testing or problem-solving strategies are essential for learning, knowledge of a finite state grammar can be acquired implicitly through memory-based processing that occurs automatically as a result of experience with exemplars of the grammar. However, in other situations in which family resemblance patterns among instances are inadequate to sustain task performance, explicit model-based reasoning becomes necessary for high levels of performance.

References

Anderson, J. R. (1983). *The architecture of cognition*. Cambridge, MA: Harvard University Press.

Berry, D. C., & Broadbent, D. E. (1988). Interactive tasks and the implicit-explicit distinction. *British Journal of Psychology*, *79*, 251-272.

Bourne, L. E., Jr. (1970). Knowing and using concepts. *Psychological Review*, *77*, 546-556.

Bower, G. H., & Trabasso, T. (1964). Concept identification. In R. C. Atkinson (Ed.), *Studies in mathematical psychology* (pp. 32-94). Stanford, CA: Stanford University Press.

Brooks, L. R. (1978). Nonanalytic concept formation and memory for instances. In E. Rosch & B. B. Lloyd (Eds.), *Cognition and categorization* (pp. 169-211). Hillsdale, NJ: Erlbaum.

Brooks, L. R. (1987). Decentralized control of categorization: The role of prior processing episodes. In U. Neisser (Ed.), *Concepts in conceptual development: Ecological and intellectual factors in categorization* (pp. 141-174). Cambridge, MA: Cambridge University Press.

Bruner, J. S., Goodnow, J., & Austin, G. A. (1956). *A study of thinking*. New York: Wiley.

Bruner, J. S., & Potter, M. C. (1964). Interference in visual recognition. *Science*, *144*, 424-425.

Dulany, D. E., Carlson, R. A., & Dewey, G. I. (1984). A case of syntactical learning and judgment: How conscious and how abstract? *Journal of Experimental Psychology: General*, *113*, 541-555.

Dulany, D. E., Carlson, R. A., & Dewey G. I. (1985). On consciousness in syntactical learning and judgment: A reply to Reber, Allen, & Regan. *Journal of Experimental Psychology: General*, *114*, 25-32.

Ericsson, K. A., & Simon, H. A. (1984). *Protocol analysis: Verbal reports as data*. Cambridge, MA: MIT Press.

Estes, W. K. (1986a). Array models for category learning. *Cognitive Psychology*, *18*, 500-549.

Estes, W. K. (1986b). Memory storage and retrieval processes in category learning. *Journal of Experimental Psychology: General*, *115*, 155-174.

Fried, L. S., & Holyoak, K. J. (1984). Induction of category distributions: A framework for classification learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *10*, 234-257.

Gentner, D., & Stevens, A. L. (1983). *Mental models*. Hillsdale, NJ: Erlbaum.

Hayes, N. A., & Broadbent, D. E. (1988). Two modes of learning for interactive tasks. *Cognition*, *28*, 249-276.

Hintzman, D. L., & Ludlam, K. (1980). Differential forgetting of prototypes and old instances: Simulation by an exemplar-based model. *Memory & Cognition*, *8*, 378-382.

Holland, J. H., Holyoak, K. J., Nisbett, R. E., & Thagard, P. R. (1986). *Induction: Processes of inference, learning, and discovery*. Cambridge, MA: MIT Press.

Jacoby, L. L. (1983). Remembering the data: Analyzing interactive processes in reading. *Journal of Verbal Learning and Verbal Behavior*, *22*, 485-508.

Jacoby, L. L., & Brooks, L. R. (1984). Nonanalytic cognition: Memory, perception and concept learning. In G. Bower (Ed.), *The psychology of learning and motivation: Vol. 18* (pp. 1-47). New York: Academic Press.

Johnson-Laird, P. N. (1983). *Mental models*. Cambridge: Harvard University Press.

Klahr, D. (1984). Transition processes in quantitative development. In R. J. Sternberg (Ed.), *Mechanisms in cognitive development* (pp. 101-140). New York: W. H. Freeman.

Levine, M. (1975). *A cognitive theory of learning*. Hillsdale, NJ: Erlbaum.

Lewicki, P. (1986). *Nonconscious social information processing*. New York: Academic Press.

- Mathews, R. C., Buss, R. R., Chinn, R., & Stanley, W. B. (1988). The role of explicit and implicit learning processes in concept discovery. *Quarterly Journal of Experimental Psychology, Section A: Human Experimental Psychology, 40A*, 135-165.
- Matlin, M. (1983). *Cognition*. New York: CBS College Publishing.
- McAndrews, M. P., & Moscovitch, M. (1985). Rule-based and exemplar-based classification in artificial grammar learning. *Memory & Cognition, 13*, 469-475.
- Medin, D. L., & Schaffer, M. M. (1978). Context theory of classification learning. *Psychological Review, 85*, 207-238.
- Millward, R. B. (1981). Models of concept formation. In R. E. Snow, P. A. Frederico, & W. E. Montague (Eds.), *Aptitude, learning, and instruction: Cognitive process analysis* (pp. 245-295). Hillsdale, NJ: Erlbaum.
- Reber, A. S. (1969). Transfer of syntactic structures in synthetic languages. *Journal of Experimental Psychology, 81*, 115-119.
- Reber, A. S. (1976). Implicit learning of artificial languages: The role of instructional set. *Journal of Experimental Psychology: Human Learning and Memory, 2*, 88-94.
- Reber, A. S. (1989). Implicit learning and tacit knowledge. *Journal of Experimental Psychology: General, 118*, 219-235.
- Reber, A. S., & Allen, R. (1978). Analogy and abstraction strategies in synthetic grammar learning: A functionalist interpretation. *Cognition, 6*, 189-221.
- Reber, A. S., Allen, R., & Regan, S. (1985). Syntactical learning and judgment, still unconscious and still abstract: Comment on Dulany, Carlson, and Dewey. *Journal of Experimental Psychology: General, 114*, 17-24.
- Reber, A. S., Kassin, S. M., Lewis, S., & Cantor, G. (1980). On the relations between implicit and explicit modes in the learning of a complex rule structure. *Journal of Experimental Psychology: Human Learning and Memory, 6*, 492-502.
- Reber, A. S., & Lewis, S. (1977). Toward a theory of implicit learning: The analysis of the form and structure of a body of tacit knowledge. *Cognition, 5*, 333-361.
- Rumelhart, D. E., & McClelland, J. L. (1986). *Parallel distributed processing: Explorations in the microstructure of cognition* (Vol. 1). Cambridge, MA: MIT Press.
- Schacter, D. (1987). Implicit memory: History and current status. *Journal of Experimental Psychology: Learning, Memory and Cognition, 13*, 501-518.
- Siegler, R. S. (1983). Information processing approaches to development. In W. Kessen (Ed.) & P. H. Mussen (Series Ed.), *Handbook of child psychology: Vol. 1. History, theory, and methods* (pp. 129-211). New York: Wiley.
- Stanley, W. B., Mathews, R. C., Buss, R. R., & Kotler-Cope, S. (in press). Insight without awareness: On the interaction of verbalization, instruction and practice in a simulated process control task. *Quarterly Journal of Experimental Psychology, Section A: Human Experimental Psychology*.
- Tulving, E. (1983). *Elements of episodic memory*. Oxford: Clarendon Press.
- Vokey, J. R., & Brooks, L. R. (in press). Taming the clever unconscious: Analogic and abstractive strategies in artificial grammar learning. *Cognition*.
- Wyat, D. F., & Campbell, D. T. (1951). On the liability of stereotype or hypothesis. *Journal of Abnormal and Social Psychology, 46*, 496-500.

Received June 20, 1988

Revision received March 23, 1989

Accepted March 28, 1989 ■