Problem solving by reference to rules or previous episodes: The effects of organized training, analogical models, and subsequent complexity of experience

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Subjects learned a microcomputer drawing package under different conditions of training or organization and practice complexity. Training instructions were presented in either a random or an organized order, and with or without an analogical model of the software package. Practice trials varied in visual and logical complexity. Performance on paper-and-pencil and problem-solving tests was better following the model than following the no-model condition when practice trials were logically complex; the reverse was true when they were logically simple. Performance on the test of problem solving was also better following organized training than following randomly ordered training when practice trials were visually complex; the reverse was true following visually simple practice. We propose that the subjects performed the tasks by engaging in either episode-based or rule-based processing, and that performance was optimized when the processing used at encoding and retrieval was the same. The acquisition of skill in solving real problems is explained as procedural compilation.

In this paper, we examine the effects of the nature of the learning experience on subsequent problem solving, using an ecologically valid task of a type and complexity that many people face in their everyday experiences. We address the proposition that knowledge acquisition and problem solving in complex domains may be based either on the representation of particular previous episodes, or on the abstraction of rules, features, or concepts from those episodes. In addition, we investigate whether the consistency of experience in encouraging either rule-based or episode-based representations affects people's representations of a domain, and their problem-solving skill in it. Finally, because hands-on skill in problem solving frequently includes a heavy perceptual-motor procedural component, we ask whether people's acquisition of hands-on skill in solving such actual problems is affected by the same variables that influence the acquisition of skill in solving hypothetical problems.

A number of authors have suggested that people deal with new events by retrieving information either about holistically similar previous experiences or about ab-

stracted characteristics of those experiences. In this paper, we will refer to the first kind of processing as "episode-based processing." We will use this term to refer to any relatively holistic processing of an event involving minimal identification of component aspects of meaning. We will refer to the second kind of processing as "rule-based processing." This term will refer to processing of an event that involves the abstraction of any of a variety of aspects of meaning (e.g., features, rules, concepts, schemata, etc.). These terms are broadly defined, and each incorporates several criteria, which may or may not be correlated empirically. However, the terms are derived from similar concepts and processes prevalent in the problem-solving and categories literatures (e.g., Brooks, 1987; Gick & Holyoak, 1983; Holland, Holyoak, Nisbett, & Thagard, 1986; Holyoak & Koh, 1987; Homa, 1984; Jacoby & Brooks, 1984; Reber & Allen, 1978; Whittlesea, 1987).

This distinction between episode-based and rule-based processing parallels the distinction in the problem-solving literature between analogy-based and schema-based problem solving. Several investigators have demonstrated that problem-solving performance is improved when people, engaging in episode-based processing, access previous problems that are similar analogically or in other ways. Under such conditions, people identify a problem as similar to one they have previously experienced, and then map the solution of the previous problem onto the new one (Bassok & Holyoak, 1989; Holyoak, 1984). Whether or not people are successful at retrieving earlier problems and their solutions depends to a large extent on the similarity—particularly "surface" similarity—between the

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two problems (e.g., Holyoak & Koh, 1987; Ross, 1989; Stein, Way, Benningfield, & Hedgecough, 1986).

In contrast, problem solving can also be facilitated by retrieval of more abstract information. When this occurs, people's performance may be viewed as rule-governed. Holyoak (1984; Gick & Holyoak, 1983, 1987) has suggested that many results demonstrate that people can form abstract schemata that characterize sets of problems sharing similar structures. For example, Gick and Holyoak (1983) have demonstrated that transfer is more likely to occur when two previous problems, rather than one, have been presented. Similarly, Bassok and Holyoak (1989) have demonstrated that transfer is facilitated when original problems are presented in relatively abstract, domain-general contexts.

The studies described above demonstrate that performance on problem-solving tasks can be improved by encouraging people to solve problems in two different ways. First, people can learn to solve problems in an episode-based (e.g., analogy-based) fashion. Second, they can engage in rule-based (e.g., schema-based) processing. The studies discussed above are primarily from the literature on problem solving. However, another body of literature is also relevant to how people learn to solve problems: the literature on learning and memory. In this paper, we also focus on the effects on problem solving of three variables frequently studied by researchers in learning and memory: presence or absence of an analogical model, organization, and complexity of experience.

First, presentation of an analogical model of the domain during training should encourage people to identify and abstract rules and concepts in the domain.¹ Mayer (1979) has suggested that the effects of analogical models on learning result from the fact that such models provide "assimilative contexts" for the new material. According to this approach, analogical models encourage people to integrate new information with a preexisting rich and meaningful knowledge structure. This integration presumably provides the learner with a useful organization for the new material, as well as with attributes and rules that may generalize from the familiar to the novel domain. For example, Rumelhart and Norman (1981) have pointed out the general usefulness of such a model or combination of models in training people to use text editors. Gentner and Gentner (1983) also found that subjects' ability to solve different types of simple electronics problems varied systematically with the type of analogical model for electricity on which they were trained.

Second, whether or not training materials are organized can affect whether people encode new material in a rule-based or an episode-based fashion. Because organization involves features or characteristics that are shared by groups of stimuli, taking advantage of it necessarily involves some sort of abstraction. Homa (1984) obtained results consistent with this hypothesis, using an artificial category-learning task. The results of that study suggested that when learning materials were presented in a ran-

dom order, subjects processed them in a relatively holistic way. In contrast, when materials were organized, subjects engaged in more abstract, analytic processing. Similarly, Elio and Anderson (1981) found that on an artificial category-learning task, subjects learned more quickly and performed better on a transfer test when they had received blocked, rather than random, presentations of category exemplars.

Finally, the complexity of the materials used in training can affect the processing mode with which people encode new material. Although extremely complex experiences can make learning virtually impossible (see Schooler, 1984), moderate degrees of complexity may encourage people to abstract rules and structures. Empirical evidence supports this hypothesis. For example, in studies of category learning, subjects who were exposed to highly variable examples of artificial categories were more likely to demonstrate transfer when new exemplars were subsequently presented (Fried & Holyoak, 1984; Posner & Keele, 1968), suggesting that high variability of examples encourages the abstraction of category prototypes.

There is no commonly agreed-upon definition of task or environmental complexity. However, many definitions concur in suggesting that, in comparison with simple tasks, complex tasks require people to make multiple decisions, which may be inherently open-ended in nature. In addition, in comparison with simple tasks, complex tasks may be described on many characteristics or dimensions (e.g., Schooler, 1984; Streufert & Streufert, 1978). Given the relatively large number of dimensions on which complex problems can differ, similarity-based retrieval of previous complex problems or tasks could easily lead to the retrieval of problems that are similar not in the characteristics critical for successful problem solution, but on some other dimension(s) or characteristic(s) that are irrelevant or even misleading to solution. In contrast, because simple problems are likely to vary on fewer dimensions, similarity-based retrieval of previous episodes should be more likely to lead to successful problem solution.

The principles of transfer-appropriate processing (e.g., Barclay, Bransford, Franks, McCarrell, & Nitsch, 1974; Bransford, Franks, Morris, & Stein, 1979; Morris, Bransford, & Franks, 1977; Stein, 1978), derived from the encoding-specificity hypothesis (Tulving & Thomson, 1973), suggest that combinations of these task variables should interact in their effects on people's problem-solving performance. This approach posits that performance on a memory task will be best when the processing required at retrieval is similar to that evoked at encoding. Brooks (1987) has suggested that the principles of transfer-appropriate processing apply to rule-based and episode-based encoding: people use the processing required by the current episode (i.e., holistic and episode-based versus analytic and rule-based) as a type of retrieval cue to access relevant information from previous events. If two events are processed in the same way, the process-

ing of the second can serve as a retrieval cue for the first. In contrast, if two events involve qualitatively different processing, retrieval is more difficult.

According to this approach, sequential combinations of training variables that are congruent in their tendencies to elicit rule-based or episode-based processing should yield better performance than combinations that are not congruent. There is empirical support for this hypothesis. In a series of studies, Mayer has demonstrated that providing people with analogical models for the material they are learning (computer programming, recalling scientific text, solving probability problems) has systematic effects on subsequent performance: such models generally improve people's understanding of underlying concepts and performance on complex, far-transfer tasks. In contrast, they have either no effect, or a deleterious effect, on performance on simple, near-transfer or verbatim memory tasks (Mayer, 1975, 1976, 1983; Mayer & Bromage, 1980; Mayer & Greeno, 1972). Similarly, Halasz and Moran (1983) found that providing people with a device model for how a computer-simulated stack calculator worked improved their performance on complex tasks, but decreased their performance on simple tasks. All of these findings suggest that performance tends to be best either when model-based training is paired with complex tasks or when no-model training is paired with simple tasks. This pattern is consistent with the hypothesis that series of experiences that are congruent in encouraging either rule-based or episode-based processing yield better performance than do series in which the experiences differ in the types of processing they encourage.

In this study, we tested this hypothesis. We expected that analogical models and organization would lead to better performance when combined with complex learning experience than when combined with simple experience. Similarly, training that does not involve an analogical model or organization might lead to better performance when paired with simple, rather than complex, practice experiences. Finally, we expected that hands-on problem solving on the computer would have a larger procedural skill component than would engaging in solving hypothetical, paper-and-pencil problems. Therefore, we checked to see whether performance on these "real" problems would be influenced by the same variables as performance in solving hypothetical problems.

Since we were interested in learning and problem solving of the type that people encounter in everyday life, we trained subjects to use a commercial microcomputer drawing package. We designed an instruction procedure that included manipulations of task complexity, organization, and the presentation of an analogical model. Some investigators of the acquisition of computer-related skills have used commercially written manuals for training (e.g., Elias, Elias, Robbins, & Gage, 1987). However, the training materials provided by commercial software companies give experimenters little control over training variables. Therefore, we designed all of the training, practice, and assessment materials used in this experiment.

The instruction procedure included a training period, during which we manipulated whether subjects received an analogical model and whether the instructions were organized or randomly ordered. Both the model and the organization were based on the same conceptual grouping of the "tools." The grouping was based on analogies with objects a person would use in ordinary drawing tasks, and was intended to lead the subjects to impute characteristics of the "real-life" objects to the software tools. For example, we expected that tools depicted in a "stencils" box would be assumed to draw two-dimensional shapes. The principles underlying the groups of tools were stated explicitly only for subjects in the model condition. Therefore, we expected that subjects in the model condition would be more likely than subjects in the no-model condition to ascribe characteristics of the real drawing tools to the software tools. We expected less of a difference between the organized and random presentation groups, since the organization group, in contrast with the model groups, would have to derive the principles themselves.

Following the training period, subjects solved a series of either simple or complex practice problems. Two types of complexity were manipulated. The first—visual complexity—was defined as the diversity of visual patterns that a subject saw and could choose to use. The second—logical complexity—was defined as the number of choices and steps involved in practice-trial problems. We expected that these two types of complexity might affect different aspects of learning. Because logical complexity reflected "structural" aspects of the problems and their solutions, we expected that it might be particularly effective in eliciting the abstraction of the system's rules. In contrast, visual complexity affected only "surface" aspects of the problems—that is, the appearance of the pictures and the variety of patterned fills that could be selected in drawing. Therefore, this type of complexity might have a greater effect on actual hands-on problem solving (i.e., that requiring greater perceptual-motor procedural knowledge) than would logical complexity.

Finally, the subjects were assessed on a variety of criterion measures. Some of the measures were intended to assess the subjects' retrieval and use of information to solve hypothetical problems using the software package. These paper-and-pencil measures were also intended to reflect component skills necessary in solving problems with the package. They included a measure of the accuracy with which the subjects predicted the outcomes of sequences of "commands" from the package, and a measure of the subjects' ability to evaluate possible problem solutions. In addition, we hypothesized that actual performance with the package would differ from performance on hypothetical problems in the amount of perceptual-motor procedural knowledge required; therefore, we included a measure that would reflect the subjects' skill at using the package. In particular, because there is evidence that exposure to complex environments increases cognitive flexibility (Schooler, 1987), we examined how our complexity manipulations affected our subjects' ability

Table 1
Background Subject Characteristics

Characteristic	<i>M</i>	Range	<i>SD</i>
Age (years)	36	18-60	10.64
WAIS Block Design raw score	36.25	13-50	8.11
WAIS Vocabulary raw score	59.88	35-70	7.50
Previous computer experience	1.77	0-5	1.53
Everyday life complexity	4.88	2-7	1.14

Note—Previous computer experience was coded using the categories described in Table 2. The everyday life complexity scale (Kohn & Schooler, 1983) has a minimum of 1 and a maximum of 7.

to use the drawing program to solve problems in multiple ways.

METHOD

Subjects and Design

One hundred fifty-one subjects were recruited through a local newspaper announcement, flyers displayed at local stores, and a National Institutes of Health newsletter circulated to NIH employees. Twenty-three individuals failed the training posttest, leaving a total of 128 subjects—76 females and 52 males. All subjects had high school degrees or the equivalent, 91 had undergraduate degrees, and 32 had graduate degrees. None of the subjects had had any prior experience working with microcomputer drawing programs. In ac-

cordance with NIH guidelines, the subjects were paid \$56.50 if their participation was divided over two sessions (one pretesting session, one experimental session), and \$40.75 if their participation was completed in one session. Background characteristics of these 128 subjects are presented in Table 1.

The subjects were randomly assigned to the 16 cells of the 2 (training organization: organized order, random order) $\times$ 2 (training analogical model: present, absent) $\times$ 2 (practice trial visual complexity: simple, complex) $\times$ 2 (practice trial logical complexity: simple, complex) design.

Apparatus

The subjects were trained to use some aspects of the commercial drawing program Fullpaint (Ann Arbor Softworks, 1986) on either a Macintosh Plus or a Macintosh SE microcomputer. Fullpaint is a mouse-operated "painting" program. Users select the tool they want to use from a palette depicted on the left side of the screen; each tool is used to create a particular type of figure or image, or to modify one. The "icons" by which the tools are represented on the screen are designed to be mnemonically useful. For example, the tools that apply patterns are depicted as a paint can, a spray-paint can, and a paintbrush; a tool that draws freehand lines is depicted as a pencil; the tools that draw rectangles are themselves rectangles; and so forth. A second palette depicted along the bottom of the screen portrays 38 patterns that a user may select to fill in objects that have been or will be drawn. The Macintosh screen as it appears for Fullpaint, including tool icons and Fullpaint's patterns, is depicted in Figure 1.

Figure 1. A completed practice trial from the visually complex condition, shown on the Macintosh screen (in actuality, the picture took up less of the screen). "Tools" are depicted in the palette on the left of the screen; patterns are depicted in the palette along the bottom of the screen. In the logically complex condition, the starting picture for this trial included only the large white circle. In the logically simple condition, the starting picture included the large white circle and the patterned, rounded rectangle shown in the same relative positions as indicated in the figure.

Procedure and Materials

The subjects participated in a pretesting session and a multistage experimental session. The pretest lasted approximately 1 h; the experimental session lasted from 1.75 to 6 h, depending on the rate at which the subject completed the experimental tasks.

Pretesting Session

During this session, a structured interview was used to obtain information about the subjects' educational level and experience, and about the amount and kinds of computer experience they had had. In addition, information about the nature of their jobs was collected. Following the structured interview, the subjects were administered the WAIS Vocabulary and Block Design subtests. Information from the interview and the WAIS subtests were used as covariates in the multivariate analyses of covariance to control background variables.

Everyday life complexity was scored using Kohn and Schooler's (1983) criteria for occupational complexity. Previous computer knowledge and experience were coded to take account of the subject's computer-related background (descriptive information appears in Table 2; see Table 1 for distributions).

Experimental Session

During this session, the subjects completed the training and practice trials and tests designed to evaluate the subject's knowledge. Subjects were tested individually, and completed all tasks at their own pace. The experimenter remained in the testing room with them to answer questions and to run the computer during all tasks except the paper-and-pencil tasks. Tasks are listed below in the order in which they were completed, with the exception that the order in which the two multiple-choice tests (problem-solution evaluation and outcome-prediction tests) were administered was counter-balanced across subjects.

Training trials. The subjects were told:

This notebook is the training manual you will use to learn Fullpaint, a drawing program for Macintosh computers. On the first few pages, you'll find some basic information you'll need to familiarize yourself with the computer. The following pages will show you how to do different things with the program. Each page will teach you how to draw something new. As you reach each page, follow its instructions. Any questions?

For subjects in the model condition, the experimenter pointed out that a second picture of the model was in view on the desk. The model was removed at the end of the training trials.

Training books consisted of an introductory page that depicted a Macintosh computer and labeled the parts to which later instructions would refer, and a page of instructions describing the use of the mouse. These two pages were followed by an additional 20

pages, each of which provided instructions on how to use one of Fullpaint's tools to make a particular kind of drawing. Instructions described each of the 17 tools the subjects would need to master to complete the experimental session; because two of the tools were particularly versatile, the subjects received instructions on how to use each of these tools in multiple ways. A picture of the relevant tool was provided at the top of each page of instructions. Four types of training books were prepared, corresponding to the four cells resulting from the training manipulations of organization and analogical model.

No model/random order. In this condition, training books consisted only of the materials described above. The 20 pages of instructions for tool usage were presented in a randomized order.

Model/random order. In this condition, training books were similar in most respects to those in the no model/random order condition. However, following the page of instructions about the mouse, a "model page" was presented (see Figure 2). The analogical model was similar to those used by other investigators who have studied the acquisition of computer-related skill (e.g., Mayer, 1975, 1976, 1979; Rumelhart & Norman, 1981). The model page, entitled "A view of the tools on your desk," began with the sentence, "You can think of the tools you will learn on the Macintosh as tools you might find on your desk." Below this sentence was a picture of a pencil holder, a T square, a stencils box, a paint box, and a box for scissors and blades. Each of these were depicted containing some Fullpaint tools; each tool the subjects were to learn was depicted in one container. The model's containers were based on conceptual distinctions among the tools. The pencil holder contained tools that draw freehand lines, the T square container contained a tool that draws straight lines and right angles, the stencils box contained tools that draw shapes, the paint box contained tools that apply patterns, and the box for scissors and blades contained tools used to move shapes or parts of shapes.

No model/organized order. In this condition, the pages were presented in the following organized order: tools for making shapes, tools for applying patterns, tools for drawing freehand lines, a tool for drawing straight lines, and tools for moving drawings or parts of drawings. No mention was made of the model at any point in the book, and the sections of the training book were not labeled for the subjects in any way. The references to the model categories here are solely for the reader's convenience.

Model/organized order. In this condition, the picture of the model was presented after the mouse instructions page, and the tool instruction pages were presented in the organized order just described. Each section of tool instructions was headed with a reference to the part of the model that was relevant to that set of tools (e.g., "Using the tools in the stencils box").

Training posttest. After completing the training trials, the subjects were administered a posttest, which was introduced with the following instructions:

I'm going to show you a series of pictures on the screen one at a time. After I've shown you each picture, I'd like you to draw a duplicate of that picture. You'll get several chances to draw the picture.

The format for the last three trials of the posttest was different from that of the first seven trials; therefore, the instructions for the last three trials were,

Now I'm going to show you a series of incomplete pictures on the screen, one at a time, along with a printed version of what each completed picture should look like. I'd like you to do whatever you need to do to the picture on the screen to make it look like the picture that's printed out.

Each of the 10 trials could be "passed" by the use of a single tool. However, since many of the trials could be successfully completed by the use of several tools, or by the use of another tool, these alternative solutions were counted as correct responses. The subjects were given three opportunities to solve each problem on their own. If they had not successfully completed the trial on the

Table 2
Previous Computer Experience Categories

Code	Criteria
5	Employed in full-time computer programming or data analysis
4	Programming or data analysis (excluding data entry, alphabetical sorting by computer, etc.) is a major job requirement
3	Word processing is a major job requirement
2	At least 2-3 months' experience in programming and/or data analysis, or more than 6 months' experience in word processing
1	Less than 2 months of programming or data analysis experience, or less than 6 months' word-processing experience
0	No previous computer experience, or experience limited to computer games

A VIEW OF THE TOOLS ON YOUR DESK

You can think of the tools you will learn on the Macintosh as tools you might find on your desk:

Figure 2. The analogical model.

third attempt, they were administered the following sequence of hints: (1) "Can you think of a way to _____?" where the experimenter identified the nature of the difficulty, (2) Can you think of a tool that _____s?" where the experimenter again identified the difficulty, and (3) "Try each of the tools one at a time, starting at the top of the palette." After each hint, the subjects were required to try to duplicate or complete the picture before the next hint was given. Hints and opportunities were provided until the subject had correctly drawn or completed the picture.

On each trial, the experimenter recorded whether the subject had chosen the correct pattern and had responded correctly, the sequence of tools used on each attempt, the hints given, and the number of attempts. A subject was considered to have passed the posttest if eight of the trials were successfully completed in three or fewer attempts.

Practice trials. During this part of the experimental session, the subjects were instructed,

For the next part of the session, we're going to continue doing the same kind of thing you've just been doing. I'll show you incomplete pictures on the screen. This notebook has pictures of what the completed pictures should look like. I'll show you one unfinished picture at a time, along with the printed finished picture. I'd like you to do whatever you have to do to make the picture on the screen look like the printed picture.

There were 15 practice trials. The subjects were allowed to start over on a given problem as many times as they wished. If they were unable to complete the picture, the experimenter proceeded through the same sequence and procedure of hints used during the posttest. An example of a completed practice-trial picture is shown in Figure 1.

Two different kinds of complexity were manipulated during practice. Both were based on Schooler's (1984) definition of complexity:

The more diverse the stimuli, the greater the number of decisions required, the greater the number of considerations to be taken into account in making these decisions, and the more ill-defined and apparently contradictory the contingencies, the more complex the environment.

One type of complexity manipulation—the visual complexity manipulation—involved varying the degree of stimulus diversity. The second complexity manipulation—the logical complexity manipulation—involved varying the number of decisions required by the task and the number of considerations to be taken into account in making those decisions.

In the visually simple condition, only two patterns were used to fill in shapes in the completed pictures. In the visually complex condition, 16 patterns were used. The stimuli for the two conditions were otherwise identical.

The logical complexity conditions differed in terms of the minimum number of steps required to complete the picture presented on the screen; each use of a tool was counted as a step. The logically complex trials required a mean of 2.33 steps, and the logically simple trials required a mean of 1.27 steps. In addition, the number of choices available to the subject varied in the two logical complexity conditions. To measure the number of choices for each trial, we constructed a decision tree consisting of the more likely ways of solving the problem. For each node in the tree where there was more than one branch, we counted the number of branches leading down from the node, and subtracted 1. This value was considered the number of choices available at that node. Then, we added the number of choices across the entire tree (if a problem had more

than 100 choices, we assigned it the value 100). The mean number of choices across trials in the logically simple condition was 1.33; the mean number in the logically complex condition was 19.73. The subjects in the logically simple and logically complex conditions all received the same target pictures; only the unfinished pictures presented on the computer screen differed between the two conditions.

On each trial, the experimenter recorded the number of attempts the subject used to complete the trial, the number of tools used, the number of incorrect patterns chosen, and the hints that were given.

Paper-and-pencil tests. Two multiple-choice paper-and-pencil assessments were used to assess the subjects' understanding of the program and their ability to evaluate possible problem solutions.

Test of problem-solution evaluation. This test was designed to assess the subjects' evaluations of possible problem solutions. The subjects were instructed,

Imagine that you are starting out with the picture labeled as "Before" above, and want to turn it into the picture labeled as "After." Which of the following tools would be the best one to use to finish the picture?

For some of the problems, the following sentence replaced the last one: "Which of the following sequences of steps would work?" The subjects then chose the appropriate tool or sequence of steps from the four options provided. There were seven problems on the problem-solution evaluation test.

Test of outcome-prediction accuracy. This test required the subjects to predict the outcomes of a series of Fullpaint operations, and assessed their accuracy. The subjects were presented with a hypothetical situation, presented both pictorially and in written form. The actions of an imaginary user were then described, and the subject was asked, "Which of the following will the resulting picture look like?" The subjects then chose their responses from the four pictures provided. There were 10 problems on the outcome-prediction test.

Flexibility test. The flexibility test was designed to test the subjects' ability to solve Fullpaint problems in multiple ways. In this task, the subjects were asked to reproduce each of three pictures in eight different ways. Each way was defined by providing the subjects with the set of tools that was to be used; sets contained from one to five tools. Although there were frequently multiple ways of solving each problem with a given set of tools, the eight sets forced the subjects to solve each problem eight different ways. The instructions for the task were:

Reproduce the picture above, using the following combinations of tools. You don't have to use the tools in the order presented, and you may use each of the tools as often as you need to. I'll give you three opportunities to use each set of tools to reproduce the picture. If you haven't gotten it by the third try, we'll just go to the next one. Remember, you must use all of the tools given to duplicate the picture.

Target pictures and tool sets were supplied in test booklets.

On each trial, and for each of the three possible attempts, the experimenter recorded whether the subjects had chosen the correct pattern, and whether they had duplicated the picture using all of the tools.

RESULTS

Four multivariate analyses of covariance were conducted on data from the 128 subjects who passed the posttest (completed eight or more of the 10 trials in three or fewer attempts). Each analysis was performed on the data from one major phase of the experimental session: (1) posttest, (2) practice trials, (3) paper-and-pencil knowledge measures, and (4) flexibility test. In each analysis,

the covariates were: (1) age, (2) sex, (3) everyday life complexity, (4) raw score on the WAIS Vocabulary subtest, (5) raw score on the WAIS Block Design subtest, and (6) degree of previous computer knowledge and experience. We report first the effects of experimental variables on performance during the learning period (posttest and practice-trial performance), and then the effects on our final measures of Fullpaint knowledge and problem solving. Unless otherwise indicated, only the results that were significant at the $p < .05$ level are reported.

Performance During Training and Practice

Posttest Results

In this analysis, we investigated the effects of order of tool presentation and of the analogical model during training trials on the subjects' performance on the posttest. The dependent measures were (1) number of posttest trials passed in three or fewer attempts and (2) total number of attempts across all posttest trials. Neither of these main effects, nor their interaction, was significant on any multivariate or univariate test.

Practice-Trial Results

In this analysis, the dependent measures were (1) total number of attempts on all practice trials and (2) total number of tools used on all practice trials. The experimental factors were organization (random or organized), presence or absence of the model, visual complexity (simple or complex), and logical complexity (simple or complex).

Clearly, the logical complexity manipulation was effective [multivariate test, $F(2,105) = 232.73$]. Practice trials in the logically complex condition required more tools to complete ($M = 57.87$) than did those in the logically simple condition ($M = 22.75$) [univariate $F(1,106) = 261.21$, $MS_e = 98.78$]. In addition, the logically complex condition appears to have been more difficult; the subjects required more attempts to successfully complete trials in this condition ($M = 25.50$) than in the logically simple condition ($M = 17.38$) [$F(1,106) = 29.15$, $MS_e = 22.17$]. No other main effects or interactions, either multivariate or univariate, were significant.

Final Measures of Representation and Performance

In the analyses reported below, we tested the hypothesis that the subjects' ultimate competence using the software package would depend both on whether they received initial instruction that was rule-based (i.e., involving organization or the analogical model), and on the complexity of their subsequent practice experiences. We predicted that performance would be best when rule-based training had been combined with complex practice, and when non-rule-based training had been combined with simple practice. Finally, we asked whether paper-and-pencil tests and the flexibility test would be affected by different sets of variables. In particular, we examined whether visual complexity had its major effect on flexibility-

Table 3
Mean Performance on the Problem-Solution Evaluation Test, the Outcome-Prediction Accuracy Test,
and the Flexibility Test as a Function of Organization, Model, Visual Complexity, and Logical Complexity

Test	Random				Organized			
	No Model		Model		No Model		Model	
	Visually Simple	Visually Complex	Visually Simple	Visually Complex	Visually Simple	Visually Complex	Visually Simple	Visually Complex
Logically Simple								
Problem Solution	4.62	5.62	4.88	4.25	5.62	5.25	5.25	5.00
Outcome Prediction	6.38	6.38	5.62	5.62	6.00	6.00	5.00	6.50
Flexibility test trials	23.75	22.62	22.75	23.00	23.25	23.50	21.75	23.50
Flexibility test attempts	32.12	37.38	37.12	36.38	36.62	33.25	40.50	31.62
Logically Complex								
Problem Solution	4.75	5.38	5.25	4.75	4.38	4.75	5.38	5.38
Outcome Prediction	5.50	5.50	6.12	6.12	5.25	5.00	5.75	6.38
Flexibility test trials	22.38	22.62	23.25	23.25	21.62	22.88	23.50	23.50
Flexibility test attempts	38.62	40.38	37.12	35.80	44.88	36.75	34.50	34.38
Mean Across Logical Complexity Conditions								
Problem Solution	4.69	5.50	5.06	4.50	5.00	5.00	5.31	5.19
Outcome Prediction	5.94	5.94	5.88	5.88	5.62	5.50	5.38	6.44
Flexibility test trials	23.06	22.62	23.00	23.12	22.44	23.19	22.62	23.50
Flexibility test attempts	35.38	38.88	37.12	36.12	40.75	35.00	37.50	33.00

Note—"Flexibility test trials" refers to the number of flexibility test trials passed, "Flexibility test attempts" refers to the number of attempts summed across trials.

test performance, whereas logical complexity affected both paper-and-pencil and flexibility-test performance. A summary of these data is presented in Table 3.

Paper-and-Pencil Test Results

The dependent measures for the paper-and-pencil tests were the number of correct responses on the problem-solution evaluation test and on the outcome-prediction test. In all other respects, this analysis was identical in design to the one performed on the practice-trial data.

As predicted, a significant interaction between model and logical complexity [multivariate $F(2,105) = 3.53$] reflected the fact that performance was best in the model/logically complex and the no-model/logically simple cells (see Figures 3a and 3b). The interaction was significant for both the problem-solution evaluation test [$F(1,106) = 4.77$, $MS_e = 1.22$; see Figure 3a] and the outcome-prediction test [$F(1,106) = 3.97$, $MS_e = 3.20$; see Figure 3b]. None of the simple-effects followups of these univariate interactions was significant.

Flexibility-Test Results

The dependent measures for the flexibility test were total number of trials passed in three or fewer attempts and total number of attempts across trials (for the latter measure, subjects who failed to complete a trial in the allotted three attempts were assigned a score of 5). This analysis was otherwise identical in design to those performed on the practice-trial and paper-and-pencil data.

As predicted, and as was the case for the paper-and-pencil tests, there was a significant interaction between model and logical complexity [multivariate $F(2,105) = 5.84$], again indicating that performance was best in the

model/logically complex and no-model/logically simple cells (see Figures 3c and 3d). The interaction was significant for both number of trials passed [$F(1,106) = 11.64$, $MS_e = 2.00$; see Figure 3c] and number of attempts [$F(1,106) = 8.40$, $MS_e = 47.08$; see Figure 3d].

Follow-up tests of these univariate interactions revealed that in the logically simple condition, the number of trials passed was lower in the model than in the no-model condition [$F(1,106) = 4.15$]; the reverse was true in the logically complex condition [$F(1,106) = 7.50$]. Although there was no effect of model on number of attempts in the logically simple condition, the model condition led to fewer attempts than did the no-model condition in the logically complex condition [$F(1,106) = 7.76$].

In addition, in contrast with the results from the paper-and-pencil tests, there was a significant interaction between organization and visual complexity [$F(2,105) = 4.11$]. Performance was best for the visually simple condition when training included randomly ordered instructions; in contrast, for the visually complex condition, performance was best when training had included organized instructions (see Figure 4). This interaction was significant both for number of trials passed [$F(1,106) = 5.72$; see Figure 4a] and number of attempts [$F(1,106) = 8.16$; see Figure 4b]. Follow-up analyses of these univariate interactions revealed that for number of trials passed, performance in the visually simple condition was better in the random presentation condition than in the organized condition [$F(1,106) = 4.09$]; in the visually complex condition, there was no significant effect of model. For number of attempts, performance in the visually simple condition was better following random than following organized training [$F(1,106) = 4.68$]; the reverse was true

Figure 3. Performance on paper-and-pencil measures and the flexibility test as a function of logical complexity and model condition. The maximum possible score was 7 for the problem-solution evaluation test, 10 for the outcome-prediction accuracy test, and 24 for number of trials passed on the flexibility test.

in the visually complex condition [$F(1,106) = 3.92$]. No other multivariate main effects or interactions were significant.

DISCUSSION

Summary of Results

In this study, we tested the hypothesis that our manipulations (i.e., organization of training, training models, complexity of practice) would affect whether subjects developed rule-based or episode-based representations of a new domain. We expected that the principles of transfer-appropriate processing would affect those representations, as well as subjects' problem-solving skill in actually using the computer drawing package. The results supported these hypotheses. When logically complex practice had been provided, the subjects performed better following model-based instruction than following no-model instruction, both on paper-and-pencil tests and on a problem-solving task. In contrast, when logically simple practice had been provided, the reverse was true: performance was better after no-model instruction than after model-based instruction. In addition, organization of instructions inter-

acted with visual complexity only for problem-solving measures: when practice had been visually complex, performance on the flexibility test was best when instructions had been organized; however, when practice had been visually simple, performance was best when the instructions had been presented in random order.

Theoretical Implications

The pattern of our findings indicates that, as posited in the introduction, two factors appear to underlie subjects' performance and knowledge regarding the newly learned domain. The first factor is the way in which the subjects retrieved declarative information about previous experience with the package. Retrieval of relevant declarative information is assumed to underlie performance both on measures of knowledge of the system (outcome-prediction and problem-solution evaluation tests) and on measures of actual hands-on problem solving (the flexibility test). The second factor is the procedural knowledge involved in actually working with the package. This knowledge includes information about both motor sequences (e.g., that which is involved in using a mouse) and other aspects of perceptual-motor performance. This

Figure 4. Performance on the flexibility test as a function of training stimulus organization and visual complexity.

procedural knowledge is assumed to affect only subjects' performance when solving real problems on the computer, not their understanding of the system.

Factors Affecting Retrieval of Declarative Information

The results of this study support the distinction between rule- and episode-based representations, as well as the version of transfer-appropriate processing presented in the introduction. According to the principles of transfer-appropriate processing, performance should be best when training and practice conditions encourage the same sort of processing (i.e., when both encourage either episode-based or rule-based processing). This was, in fact, the case for the model and logical complexity manipulations.

Following Brooks (1987; see also Schooler, 1989), we propose that because of the amount of effort involved in rule abstraction, people prefer to use episode-based representations. Various environmental conditions can, however, differentially encourage the use of either rule- or episode-based processing. Therefore, following the training period, the subjects approached the posttest having encoded their experiences either with greater reference to rules (in the case of the model condition, which

encourages such encoding), or with minimal reference to rules (in the case of the no-model condition, which discourages such encoding). Since either of these two modes of processing would have been adequate to support good performance on the relatively simple problems that comprised the posttest, the two conditions did not yield differences in posttest performance.

The model predicts, however, that during the practice trials, all other things being equal, people would tend to revert to episode-based retrieval, the generally preferred retrieval mode. However, whether returning to episode-based retrieval was useful depended on the complexity of the practice trials. As discussed in the introduction, episode-based retrieval would work well when the practice trials were simple, since later retrieval of such holistically encoded problems and solutions would frequently yield useful analogies. However, such similarity-based retrieval of complex problems would frequently yield retrieval of misleading or inappropriate problems; therefore, complex practice experience should have encouraged the subjects to switch to rule-based processing. Accordingly, performance on later practice trials should have been better when the encoding of a later event was of the same mode as that used for an earlier event. Unfortunately, because the nature and difficulty of practice trials could not be equated, any analysis investigating the effects of the model and logical complexity for individual trials would be meaningless.²

In any case, data from our final measures of representation and performance indicate that subjects can become quite proficient in a fairly sophisticated domain by using either episode-based or rule-based processing. The subjects could apparently do well even on the relatively demanding flexibility test by retrieving holistically similar previous problems from training, practice, and previous flexibility-test trials, and applying their previously effective solutions to new problems. Such performance would be consistent with Brooks's (1987) claim that many kinds of tasks that seem to require abstraction-based reasoning can actually be performed by using episode-based retrieval and processing. However, according to the model presented here, high degrees of proficiency depend on whether all training conditions encouraged the same kind of processing. Under such consistent-encoding conditions, the information that is encoded during learning is relatively easy to retrieve and use later. However, if some experiences encourage episode-based encoding while others encourage rule-based encoding, then later retrieval is impaired, and ultimate proficiency suffers.

Not all of our predictions regarding retrieval, however, were supported. First, we had originally predicted that organization, like the analogical model, would encourage the subjects to induce the rules that underlie the software package. Therefore, performance on even the paper-and-pencil tasks should have been better following organized than following random training, when the practice trials had been complex. However, this was not the case. Although our conclusions are speculative, we suggest that

the model was more effective in encouraging abstraction and aiding retrieval (at least when combined with logically complex practice) because it provided links between new information and previous knowledge, which itself provided useful concepts and retrieval cues. Although some ties between old and new information would have been established as a result of organization, the model was far more explicit than organization alone in suggesting mnemonically useful parallels between the characteristics of real drawing tools and those of the software package. Second, we found no effects of visual complexity on paper-and-pencil measures. However, since visual complexity affected only visual and motor aspects of actual solution of a problem (i.e., the selection of a pattern), but not the underlying logic of its solution, it might be expected to have little effect on paper-and-pencil measures. Instead, one might expect it to affect actual hands-on performance, as it indeed did.

Factors Affecting the Acquisition of Procedural Knowledge

The interaction between the analogical model and logical complexity described above was obtained for both paper-and-pencil measures and flexibility-test measures. However, we also found that the factors that influence the actual use of the software package differ somewhat from those that affect only subjects' declarative representations of it. An additional interaction between visual complexity and organization of training affected only the two measures of actual problem-solving skill (i.e., the two flexibility-test measures). For both flexibility-test measures, organization yielded better performance than did random training following visually complex practice, whereas the reverse was true following visually simple practice.

Although this interaction bears some similarity to the interaction between the model and logical complexity, it occurred only in flexibility-test performance. Therefore, this finding seems to reflect the development of appropriate procedures for the execution of problem solutions. Two principles of skill learning may have been involved (see Anderson, 1983). First, the subjects developed procedures appropriate to the types of choices presented in practice trials, particularly choices involved in selecting patterns. With experience, they developed individual procedures to select each pattern. Presumably, the subjects in the visually simple condition developed fewer such productions than did the subjects in the visually complex condition. Second, we propose that previous exposure to organized training facilitated the development of composite procedures during training trials, by making the goal structure of a problem more transparent. According to Anderson (1983), individual productions may be combined into composite productions when the original productions are included in the same goal structure. Such composite productions have advantages and disadvantages. On the one hand, they speed up performance on the problems to which they are relevant. On the other

hand, they increase the rigidity of behavior by "locking" several previously independent, more general productions into a unit. It should be noted that this explanation treats practice trials as a period during which procedures are compiled. Therefore, as we observed, the effects of visual complexity and organization should not appear until many, if not all, practice trials have been completed.

How would these two factors have affected flexibility-test performance? Consider first the subjects who had experienced visually simple practice. If they had also received organized training, they would have been more likely to have combined their pattern-selection procedures into composites. The rigidity of these composites would have impaired their performance on the flexibility test, which required the use of a greater variety of patterns than did the practice trials. In contrast, the subjects who received visually simple practice without previous organized training would have been less likely to have formed composite procedures; their general, simple procedures would have been of use in at least some aspects of the flexibility test. Therefore, the rigidity of composite productions created in the organized condition would have created particular difficulties for the subjects who experienced visually simple practice and organized training.

A different picture emerges for the subjects in the visually complex condition. For these subjects, the wide variety of patterns encountered during practice would have been very similar to those involved in the flexibility test. Consequently, composite procedures would have been an advantage to these subjects, since they would have increased the probability of having developed an appropriate, efficient response. On the other hand, the subjects in the visually complex condition who had not received organized training would have been less likely to have formed composite procedures, and would have relied on more general, less efficient procedures during the flexibility test.

Methodological and Theoretical Limitations

The results of the present study should be interpreted in the light of several limitations. First, we assessed the effect of only one organizational scheme and one related analogical model. It is possible that different organizations and models would have yielded different findings. However, the organization and model used in the present study were similar to those used by other investigators who have studied the acquisition of computer-related skills (e.g., Mayer, 1975, 1976; Rumelhart & Norman, 1981), so it seems likely that some degree of generalization is warranted. Even if one is conservative in generalizing from these findings, however, the present study still demonstrates that under at least some conditions, the effects of analogical models depend on how complex a person's learning experience is. Similarly, the learning experience we provided lasted for a particular length of time, which for most subjects involved several hours, and application followed immediately afterward. It is possible that people's reliance on either rule-based or episode-

based processing might be different if longer or shorter learning periods are involved, or if a longer period elapses between learning and testing.

In addition, in contrast with most studies of transfer-appropriate processing, we did not design two separate criterion tasks to independently assess episode- and rule-based representations. This was because, unlike most studies, the focus of this investigation was on demonstrating that effects of combinations of training experiences could affect subjects' general competence in dealing with the software package. Therefore, we framed our assessments not in terms of retrieval measures for episodes and rules per se, but in terms of how well subjects performed on hypothetical and actual problems in the domain.

It should also be noted that the "organization" provided during training differed somewhat between the model and no-model conditions. In the model condition, the parallel between the organization and the model was made explicit, whereas this could not have been the case in the no-model condition. We constructed the training stimuli for the model/organized condition in this way in order to make the instructions as ecologically valid as possible. Although this decision may have created a methodological problem, our results do not reveal any resulting difficulties; in particular, we see no significant evidence of any interaction between model and organization, or of any higher order interactions including these two factors.

Throughout this paper, we have assumed that the major difference between the flexibility test and the paper-and-pencil tests lies in the degree to which their performance relies on procedural knowledge, and that the organization of training materials had its major effect on the acquisition of procedural knowledge. Although this approach has been theoretically useful, there are, of course, other ways in which these tasks differ. These other distinctions may, in fact, be responsible for the dissociation we observed. Further research is obviously needed to ascertain the exact nature of the task differences involved.

In fact, throughout this paper, we have discussed a number of distinctions as though they were true dichotomies: episode-based versus rule-based, declarative versus procedural. Such a characterization is clearly simplistic, and we know relatively little about the nature of these distinctions. Some may involve dimensions rather than discrete categories. For some distinctions, the two types of processing or representation might be mutually exclusive; alternatively, they may be independent—that is, they may be required either alone or in combination in a given task. For example, people may use both procedural and declarative knowledge in many, if not all, tasks. In describing the requirements of our paper-and-pencil tasks and the flexibility test, we have assumed that it is the relative amount of the two kinds of processing that matters: given the nature of the tasks, the flexibility test seems to require more procedural knowledge than do the paper-and-pencil tasks. Similarly, we have referred to episode-based and rule-based processing as "modes" of processing. This should not be interpreted to mean that an event is neces-

sarily encoded exclusively in either an episode or a rule mode. Instead, our major point is that some environmental conditions encourage people to emphasize one or the other of these two kinds of information in encoding and retrieval.

Conclusions

The results of this experiment demonstrate that whether or not a model helps in mastering a new domain depends not just on the fit between model and domain, but also on the complexity of the training and learning experience. More generally, learning experiences that are congruent in emphasis on either rule-abstraction processes or on episodic, analogy-based, encoding will lead to better performance than those that are not. Previous discussions of the effects of providing an analogical model have focused on the degree to which the model is appropriate to the domain (e.g., Rumelhart & Norman, 1981). However, the presentation not only of appropriate models, but also of organized learning and complex practice have been demonstrated to lead to improved performance. Our results indicate that none of these factors alone is always helpful. Instead, their usefulness is a function of the learning experiences in which they are embedded.

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NOTES

1. The way in which the term "analogical" is used here is different from the sense used in the above discussion of analogy-based problem solving. In the earlier discussion, the term "analogy" implied a structurally similar specific experience. Here, however, the term "analogical model" refers to a model of a novel domain that explicitly compares the new domain to some other known domain.
2. As was the case for the posttest problems, simple practice-trial problems could have been solved by retrieving either rules or previous episodes. However, because episode-based processing is assumed to be the "default" strategy, and because simple practice trials did not encourage rule-based processing in any way, we suggest that the simple practice problems were generally solved by retrieving previous problems rather than rules. In addition, we have tentative evidence that the interaction between model and logical complexity shown in the final measures began to appear during practice trials. There was a statistically unreliable tendency for the subjects in the logically complex (but not in the logically simple) condition to use fewer tools on practice trials when the model had been provided ($p = .07$).

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