

## Matrix and Mnemonic Text-Processing Adjuncts: Comparing and Combining Their Components

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The comparative text-processing benefits of matrix structures, mnemonic representations, and their combination were examined in 3 experiments (1 with college students, 2 with 5th graders). The study's major findings permit the following conclusions: First, contrary to previous research on the topic, 2-dimensional matrices (whether in a verbal or pictorial format) produced only limited positive effects on students' text-learning performance, relative to either corresponding linear outlines or text alone. Second, and in contrast, appropriate mnemonic representations (whether individually presented or embedded in a matrix) did prove to be highly effective text-learning facilitators of students' memory and application in both individual- and group-testing situations, both immediately following instruction and on 1-week delayed tests. Third, relatively little advantage of the mnemonic matrix over individual mnemonic representations was detected.

Did you know that although both blacktip and nurse sharks tend to swim in large groups close to the shore line, the former have tearing teeth whereas the latter have grinding teeth? Acquiring such information is not merely a useful academic exercise, but a practically useful one as well. It could save a skin diver's life some day if he or she were aware of the *kind* of sharks in the neighborhood, rather than simply knowing that there *are* sharks in the neighborhood. That is, it is generally hoped that book-learned factual information will be more than processed and remembered "inertly" (Whitehead, 1929); instead it will be used purposefully to solve meaningful problems.

This study's goal was to assess the proposition that even

information that is both comprehensible and well-organized is not necessarily easy to remember (e.g., J. R. Levin, 1986). The study follows from two related lines of instructional-strategies research, one that has investigated spatial techniques for making to-be-learned information more compact and better organized (matrix structures—see Kiewra, 1994) and another that has investigated systematic techniques for making such information more memorable (mnemonic representations—see J. R. Levin, 1993).

### *Matrix Structures*

The typical matrix presents information verbally in a column-and-row format. Suppose, for example, that one wanted to use a matrix to display the characteristics of six different fish. The matrix in Figure 1 presents the six fish names (already organized by their usual swim depth) as column headings and four other fish characteristics (social grouping, color, size, and diet) as row headings. Details pertaining to a fish's characteristics appear in the corresponding matrix cell. Presumably, a matrix works because it is more "computationally efficient" (Larkin & Simon, 1987) than informationally equivalent text or outline formats because it (a) reduces clutter, (b) localizes related information, and (c) facilitates perceptual enhancement (Winn, 1988).

A matrix is *less cluttered* than a typical, linearly presented text or outline because it uses fewer words to convey the same ideas. For instance, even an outline equivalent to the matrix in Figure 1 must list the fish characteristics (e.g., color and size) six times (once for each fish), whereas the

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	Depth of Fish					
	200 ft		400 ft		600 ft	
<b>Fish:</b>	Lup	Hat	Arch	Bone	Scale	Tin
<b>Social Grouping:</b>	Small	Solitary	Solitary	School	School	Small
<b>Color:</b>	Black	Brown	Blue	Orange	Yellow	Tan
<b>Size:</b>	150 cm		300 cm		500 cm	
<b>Diet:</b>	Algae		Minnows		Flounder	

Figure 1. Typical verbal matrix (from Kiewra, Kauffman, Robinson, DuBois, & Staley, in press).

corresponding matrix presents characteristics one time regardless of the number of fish (or other topics) presented. Less clutter should help students attend selectively to and relate key ideas. A matrix *localizes related information* by positioning it within the same matrix row. For instance, the fish colors all appear within the same matrix row, whereas this information might appear over several text paragraphs or within successive sections of an outline interrupted by several unrelated details about diet, size, and so forth. Consequently, matrix users are more likely to make between-topic comparisons (in this case, between-fish comparisons) than are those using a linearly organized text or outline format. *Perceptual enhancement* occurs within a matrix because the big picture or overarching relationships are made readily apparent. When a matrix is examined both vertically and horizontally, the big picture can emerge with minimal computational effort and can help students discover implicit overarching relationships. For instance, several implicit relations emerge from examining the Figure 1 matrix vertically and horizontally: As fish inhabit deeper depths, their coloration lightens, their size increases, they feed on larger prey, and they tend to travel in larger social groups (though not perfectly). In contrast, considerable computational effort is necessary to assemble and recognize these relationships when reading an equivalent text or outline. Empirically, matrices have been compared with text and outlines and have generally proven more effective in helping students learn facts and relationships (e.g., Kiewra, 1994; Kiewra, Kauffman, Robinson, DuBois, & Staley, in press; Robinson & Kiewra, 1995).

### Mnemonic Representations

Concurrently, in recent years, researchers have capitalized on the memory-enhancing qualities of mnemonic techniques to improve students' acquisition of science facts and concepts (e.g., J. R. Levin, Morrison, McGivern, Mastropieri, & Scruggs, 1986). For example, in comparison with conventional figural displays (e.g., line drawings of minerals and their properties), pictorial mnemonic representations are more effective (Scruggs et al., 1985). Moreover, when botany classifications are presented in the context of a mnemonic taxonomy (or a *mnemonomy*), superior memory and problem-solving gains result relative to a conventional boxes-connected-by-lines taxonomy, both immediately following instruction and after a delay of several weeks (M. E.

Levin & Levin, 1990). The pervasiveness of associative mnemonic techniques has been amply documented (see, e.g., J. R. Levin, 1993). The power of such techniques is presumed to result from the salient encoding cues, systematic retrieval paths, and thematic connections that are created between what a learner already knows and what he or she wants to remember (see, e.g., Bellezza, 1987; Desrochers & Begg, 1987; J. R. Levin, 1983; and M. E. Levin & Levin, 1990).

### The "Mnemonatrix": A Mnemonic Matrix

The present study seeks a combination, or marriage of sorts, of these two well-researched instructional strategies, matrices and mnemonics. The marriage of the two, which is presumed to incorporate the best qualities of each, is manifested essentially in a mnemonic matrix, or what we have dubbed a *mnemonatrix*. The matrix aspect of the *mnemonatrix* is assumed to assist students' comprehension by graphically organizing information initially presented in a text format, thus making relationships among vertical and horizontal categories easier to grasp. The mnemonic aspect of the *mnemonatrix* is assumed to assist students' memory by making to-be-learned unfamiliar information more meaningful, integrated, and retrievable. A further assumption (J. R. Levin, 1986; M. E. Levin & Levin, 1990) is that students' effective use, or application, of previously presented information depends critically on that information having been initially acquired and readily accessible. As such, techniques that foster acquisition and accessibility also have the potential to foster application.

The primary focus of this study was on investigating the combined benefits of mnemonic- and matrix-embedded *pictorial* representations. Accordingly, we sought to develop a matrix format that would accommodate pictures efficiently. The resulting pictorial matrix, displayed in Figure 2, is structurally different from the typical verbal matrix of Figure 1. In particular, the Figure 2 matrix is characterized by its "two-factor" structure in that it emphasizes two primary factors, swim depth (rows) and social grouping (columns). The typical verbal matrix (Figure 1), in contrast, is characterized by its "multifactor" structure because it lists multiple attributes (e.g., size, color, diet) down its left-hand side.

The two-factor matrix seems ideal for incorporating pictures because all pictorial information about a single fish can appear within a single matrix cell. One cell in Figure 2, for example, shows the Arch fish's blue color, solitary social grouping, minnows diet, 300-cm size, and 400-ft swim depth. This same pictorial information would be cumbersome to depict in a multifactor matrix. For instance, five separate pictures appearing in five different matrix cells would be needed to depict the Arch fish's characteristics. This study, then, marks the first time that a matrix in two-factor format and containing pictures was used. It also marks the first time that both the comparative and combined benefits of matrix structures and mnemonic representations were directly assessed.

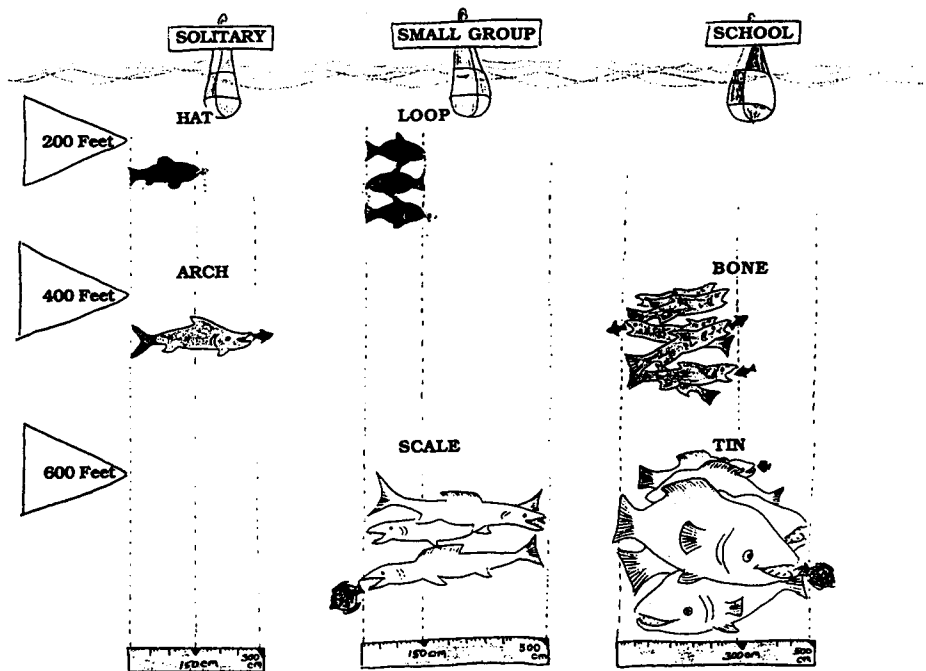


Figure 2. Conventional picture matrix used in Experiment 1. (Note that in the actual materials, the fish are shown in different colors.)

## Experiment 1

### Method

**Participants and design.** One hundred twenty-one students from two midwestern universities were randomly assigned in approximately equal numbers to one of seven experimental conditions, as defined by the factorial combination of two levels of an accompanying *structure* (outline, matrix) and three levels of its *presentation mode* (verbal, conventional picture, mnemonic picture), along with a text-only (no accompanying materials) control condition.

**Materials.** Materials included a passage about six fictitious fish adapted from Friedman and Greitzer's (1972, p. 611) article, six variations of passage-accompanying materials, and several passage-based performance measures. Also included were assessments of students' verbal ability and cognitive style. The 264-word passage follows:

#### Characteristics of Fish

Fish fall into one of three social groupings: solitary, small, or school. Solitary fish swim alone. Examples of solitary fish include the Hat and the Arch. The Hat swims at a depth of 200 feet, is brown, is 150 cm long, and eats algae. The Arch swims at a depth of 400 feet, is blue, is 300 cm long, and eats minnows.

Examples of fish in small groups (2–3 fish) include the Loop and the Scale. The Loop swims at a depth of 200 feet, is black, is 150 cm long, and eats algae. The Scale swims at a depth of 600 feet, is yellow, is 500 cm long, and eats flounders.

Examples of fish in schools (more than three fish) include the Bone and the Tin. The Bone swims at a depth of 400 feet, is orange, is 300 cm long, and eats minnows. The Tin swims at a depth of 600 feet, is tan, is 500 cm long, and eats flounders.

The passage contains 30 discrete facts, 5 about each of the 6 fish.

Its organization by social grouping was intended to obscure both the specific between-fish comparisons (e.g., that the Hat and Loop both swim at a depth of 200 ft, are darker in color, are 150 cm in length, and eat algae) and general across-fish relationships (e.g., that fish swimming at progressively deeper levels are lighter in color, are longer, and eat larger prey). The six variations in the passage-accompanying materials differed in both their structure and presentation mode.

**Outline structures** were organized by social grouping, with three main headings: solitary, small group, and school. Subsumed by each main heading were the two swim depths associated with each social group. Subsumed by each depth level was information about the fish's name, color, length, and diet. An outline structure was selected for comparison with the matrix structure because the former's listlike format encourages readers to follow a linear, top-to-bottom processing route. As noted earlier, *matrix* structures were organized by social grouping and swim depth. The column headings named the three social groupings, and the row headings named the three swim depths. Six of the nine matrix cells contained information about the corresponding fish's name, color, length, and diet. The remaining three cells were empty.

Concerning presentation mode, the *verbal* versions of the outline and matrix used printed words to describe the fish (see Figure 3 for the verbal matrix). The *pictorial* versions of the outline and matrix additionally included line drawings of the fish to illustrate their characteristics (see Figures 2 and 4 for the conventional picture matrix and mnemonic picture matrix, respectively). In the pictures, length is indicated by the relative size of the fish and by rulers drawn beneath them. Social grouping is shown by the number of fish swimming together (one, three, more than three). Diet is depicted by the food that the fish are shown eating. The fish were also pictured in different colors (not evident here). The conventional and mnemonic pictures differ in only one way: Mnemonic pictures include fish that are redrawn to resemble objects that

	<u>SOLITARY</u>	<u>SMALL GROUP</u>	<u>SCHOOL</u>
	HAT	LOOP	
200 Feet	Brown color 150 cm long Eats algae	Black color 150 cm long Eats algae	
	ARCH		BONE
400 Feet	Blue color 300 cm long Eats minnows		Orange color 300 cm long Eats minnows
		SCALE	TIN
600 Feet		Yellow color 500 cm long Eats flounders	Tan color 500 cm long Eats flounders

Figure 3. Verbal matrix used in Experiment 1.

provide a direct link to the fish's name. For example, the Hat fish looks like a hat, the Bone fish looks like a bone, and the Tin fish looks like a tin can. Figures 2 and 4 illustrate the critical "name link" difference between the conventional and mnemonic picture matrices, respectively.

Four types of performance measures were administered: factual recall, comparison, relationship, and application. The factual recall test asked students to recall the name, color, length, and food for each of the six fish, given a particular social grouping and swim depth (e.g., solitary fish at 200 ft). Two versions of this test were

constructed, one in matrix form and the other in outline form. The comparison test included 30 items, 24 of which required that students supply the names of pairs of fish (from a provided list) that shared a common attribute (e.g., swims at 200 ft). The remaining six items probed for each fish's color (hereinafter referred to as "color memory"). Although these six fish-by-fish color-memory items were administered as part of the comparison task, they do not require any between-fish comparisons, and therefore, they were extracted from that test. The relationship test included four questions that asked students to describe the relationship between the fish's swim depth and their: (a) size, (b) diet, (c) social grouping, and (d) color (there is a relationship for each of these—see Figures 1–4). The application test had students predict characteristics of a new fish discovered at 800 ft, on the basis of their knowledge of the studied fish at shallower levels. Note that neither of these latter two tests required memory for the previously learned fish names. Instead the tests assessed the degree to which students could extract a bigger picture from the fish passage.

Two brief assessments of students' ability were also made. Because neither of those measures turned out to be of any consequence to the present results and conclusions, however, they are not considered further here.

*Procedure.* Group-administered instruction and testing occurred in several different sessions, with all conditions approximately equally represented within each group. Written instructions informed all participants that they would have 10 min to study material about the characteristics of fish. All students were told to note the social grouping, swim depth, color, length, and food for each fish. Students receiving accompanying outlines or matrices were instructed to focus their study time on those structures after reading the text. They were also briefly instructed in how to read the outline vertically or the matrix vertically and horizontally. Students receiving pictures were told how to interpret them (e.g., that a picture of one fish represents a solitary social grouping).

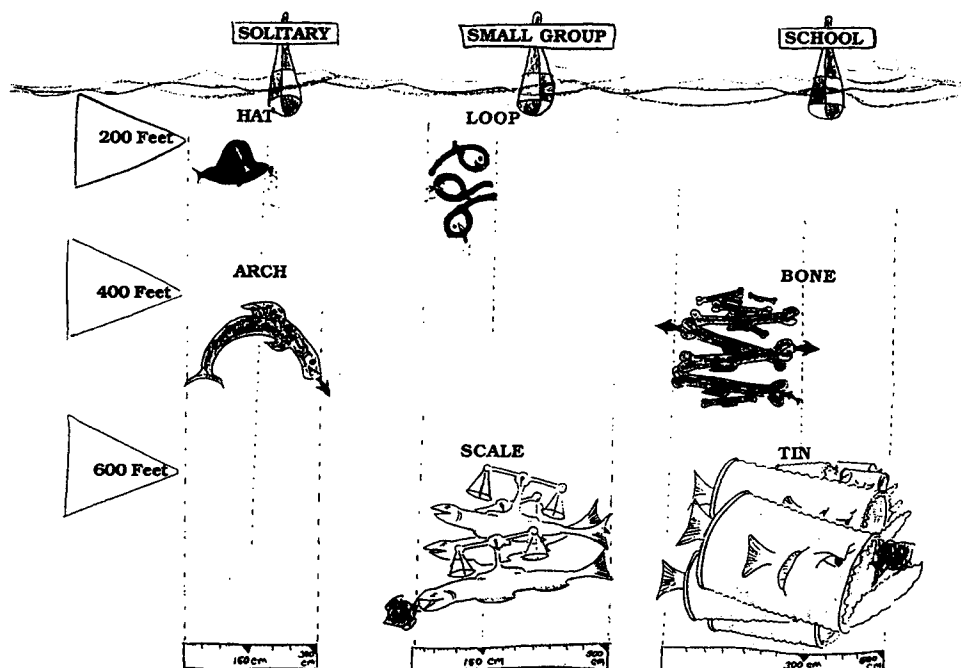


Figure 4. Mnemonic picture matrix used in Experiment 1. (Note that in the actual materials, the fish are shown in different colors.)

Students with mnemonic pictures were also told that the fish were drawn in a way that resembled the fish's names.

After instructions were read, students were given the passage and accompanying materials for 10 min. The two student-ability assessments were administered next (12.5 min), thereby constituting filler tasks to eliminate the contribution of students' short-term memory to their performance on the passage-related measures. The factual recall test followed, with participants taking both forms of it (matrix and outline). It had been planned that these two forms of the test would be administered in counterbalanced order. Because of a miscommunication, however, this did not occur at one of the two university sites (the matrix recall test was always administered first at that site). The resulting between-conditions comparisons are not compromised by this miscue, and the effects of university and recall-test order are taken into account in both the statistical analyses and the reported adjusted means. Four min were provided for each recall test. Next, students completed the application test (4 min), followed by the relationship test (6 min), and finally the comparison test (4 min). The particular test-administration order was selected to minimize the positive influence of earlier tests on subsequent tests.

## Results

Rather than analyzing the data according to the design's nominal 2 (structures)  $\times$  3 (presentation modes) factorial structure in the company of a control group, we conducted two complementary  $\alpha$ -controlled sets of more conditions-specific analyses on each dependent measure. First, comparisons between each of the six "adjunct" conditions and the text-only control condition were made using the sequential Naik-Dunnnett procedure, based on a familywise  $\alpha$  of .05 (J. R. Levin, Serlin, & Seaman, 1994). Then, comparisons among just the six adjunct conditions were conducted using the sequential Hayter-Tukey procedure, also based on a familywise  $\alpha$  of .05 (Seaman, Levin, & Serlin, 1991).

Adjusted (for university and recall-test order) mean performance on each of the outcome measures is presented in Table 1, along with between-conditions statistical differences. The major results are summarized as follows: On all

measures requiring memory for the fish names—the matrix and outline recall tests, the comparison test, and the color-memory items (not displayed in Table 1)—students provided with the mnemonic picture matrix statistically outperformed text-only control students. Additionally, (a) mnemonic picture outline students were statistically superior to text-only students on both the comparison test and the color-memory items, and (b) the performance of mnemonic picture matrix students was statistically higher than that of conventional picture matrix students on the comparison test. No statistical differences among conditions were detected on either the relationship or the application test, where making correct passage inferences and generalizations was required but was not dependent on students' memory for specific fish names. The latter nondifferences are noteworthy vis-à-vis the comparison of mnemonic picture matrix and text-only students, and particularly in juxtaposition to the above-noted benefits for the former students on the name-dependent tests. Because of the decidedly nonnormal and heterogeneous variance characteristics associated with the data in certain conditions, analyses were also conducted with nonparametric rank and Welch unequal-variance tests of means. Such analyses corroborated the just-described statistical patterns.

In a more fine-grained analysis of specific matrix benefits, and following our earlier two-factor matrix discussion, the comparison-test data were separated according to the two attributes that were directly represented by the matrix rows and columns (swim depth and social grouping, respectively; *matrix-highlighted* attributes) and the two attributes that were not (length and food; *matrix-nonhighlighted* attributes). The pattern of statistical differences between conditions on the two item types was the same: On both matrix-highlighted and matrix-nonhighlighted items, students who were presented either the mnemonic picture matrix (respective adjusted mean percentages of 100% and 98%) or the mnemonic picture outline (92% and 95%) statistically outperformed text-only students (79% and 71%).

Table 1  
*Adjusted (for University and Recall-Test Order) Mean Percentages Correct, by Experimental Condition, on the Outcome Measures of Experiment 1*

Condition	Measure				
	Factual recall		Comparison <sup>c</sup>	Relationship <sup>d</sup>	Application <sup>e</sup>
	Matrix <sup>a</sup>	Outline <sup>b</sup>			
1. Text only	71.5	71.3	74.6	82.7	61.8
2. Verbal outline	77.7	79.8	83.5	79.0	72.3
3. Conventional picture outline	79.1	77.3	87.6	75.9	79.3
4. Mnemonic picture outline	87.2	86.6	93.9 <sup>f</sup>	69.9	72.5
5. Verbal matrix	83.6	82.9	88.9	68.7	73.9
6. Conventional picture matrix	84.7	86.1	80.9	87.5	77.1
7. Mnemonic picture matrix	97.2 <sup>f</sup>	97.6 <sup>f</sup>	98.8 <sup>f,g</sup>	83.4	81.3

*Note.* There were 18 students each in Conditions 1–4, 17 students in Condition 5, and 16 students each in Conditions 6 and 7.

<sup>a</sup>MSE = 525.28. <sup>b</sup>MSE = 511.44. <sup>c</sup>MSE = 346.42. <sup>d</sup>MSE = 666.56. <sup>e</sup>MSE = 583.75. <sup>f</sup>Differs statistically from the text-only mean, based on the Naik-Dunnnett procedure (familywise  $\alpha$  = .05). <sup>g</sup>Differs statistically from the conventional picture matrix mean, based on the Hayter-Tukey procedure (familywise  $\alpha$  = .05).

At the same time, no statistical differences between the performance of students provided with a conventional matrix (in either verbal or pictorial form) and that of text-only students were detected on either item type. Thus, the present comparison test's two item types did not differentially affect matrix and nonmatrix students' information processing in a manner consistent with what might have been predicted from a consideration of the features that were and were not directly conveyed by the matrix (and the corresponding "perceptual enhancement" interpretation).

### Discussion

The results of Experiment (Exp.) 1 support and extend our knowledge about methods for enhancing students' memory for factual text content in at least two ways. First, mnemonic pictures proved superior to both text only and conventional pictures (see, e.g., J. R. Levin, 1982; J. R. Levin et al., 1986; M. E. Levin & Levin, 1990). It is notable that even though the mnemonic component applied here was restricted to name-retrieval links (e.g., the Hat fish was simply pictured as a hat) rather than to more attribute-integrating mnemonic links (e.g., J. R. Levin et al., 1986, and to be elaborated in the introduction to Exp. 2), the former links helped students in the two mnemonic picture conditions remember related attribute information about the fish as well (e.g., that the Hat fish is brown in color). Second, the results of Exp. 1 suggest that mnemonic representations may add to the power of a matrix structure. In particular, students who were shown the mnemonic picture matrix consistently outperformed text-only controls and scored near the ceiling on each memory test administered (matrix and outline recall, comparison, and color memory), whereas conventional picture matrix students did not. In addition, the performance of mnemonic picture matrix students statistically exceeded that of conventional picture matrix students on the comparison test. An alternative characterization of the present findings is that a matrix structure may add to the power of mnemonic representations, for similar reasons: The statistical benefits of mnemonic pictures in an outline format were not as pervasive as they were when the same pictures were embedded in a matrix. The issue of mnemonic versus mnemonic matrix comparative facilitation is revisited in the General Discussion.

Exp. 1 yielded three unanticipated results as well: First, the expected benefit of matrix structures over outlines did not occur. Although the verbal matrix condition generally seemed to produce somewhat better performance relative to the verbal outline condition, not one of those differences was statistically significant. It might be argued that because there were seven conditions in the present experiment, matrix benefits may have been masked because of the relative conservativeness of the statistical tests conducted. However, when the data were similarly reanalyzed with just the five nonmnemonic conditions included (i.e., in accord with earlier matrix investigations), the same conclusions held: Despite the appearances in Table 1, no statistical differences were found between either matrix condition (verbal or

conventional pictures) and the text-only control condition on any of Exp. 1's outcome measures.

Such results are contrary both to the matrix's theoretical advantages in computational efficiency and to previous empirical findings. They are most at odds with results from a recent study that incorporated the same fish content into text-only, verbal outline, and verbal matrix conditions similar to those used here (Kiewra et al., in press, Exps. 1 and 2). Findings from that study revealed that matrices were generally superior to outlines, which in turn were superior to the text alone. On the basis of our earlier two-factor versus multifactor matrix discussion, it is possible that differences between the two sets of findings may have resulted from structural differences in the matrices. The inadequacy of Exp. 1's matrix structure cannot be the whole story, however, because it must be remembered that the same structure *did* operate effectively on selected outcomes when a mnemonic component was incorporated into it. At the same time, it may be that an effective mnemonic component (also present in the mnemonic picture outline materials) helped to override the ineffective matrix structure. The potential incremental benefits of a matrix addition to a mnemonic component, and vice versa, are the primary focus of Exp. 2.

Second, it was expected that the matrix recall test would be better handled by matrix-provided participants and the outline recall test by outline-provided participants. Because of the recall-test counterbalancing problem alluded to earlier, however, that facilitation-specific question was not cleanly investigated here, and so it remains an unresolved issue.

Third, and in contrast to a major impetus for this research, students who were presented a mnemonic matrix exhibited no statistical advantage on the two problem-solving measures (viz., the relationship and application tests) relative to their counterparts in the other conditions—in spite of a sizable descriptive difference between the mnemonic picture matrix and text-only students on the application test (20%, see Table 1). As noted earlier, one possibility is that the type of mnemonic matrix developed for Exp. 1, with its name-only mnemonic links, is not optimally suited for effective problem solving. That possibility was investigated in the final two experiments.

### Experiment 2

Exp. 1 produced encouraging preliminary evidence for mnemonic matrix benefits. At the same time, even though the performance of students in the mnemonic picture matrix condition was facilitated on text-learning measures reflecting memory for individual fish names and their attributes, the mnemonic matrix did not enhance students' recognition of across-attribute relationships—contrary to what we anticipated. As just mentioned, however, close examination of the mnemonic matrix operationalization in Exp. 1 reveals that it fell considerably short of its theoretical conceptualization. As seen in Figure 4, that particular matrix capitalized on mnemonic techniques only to relate fish names to their individual attributes and not to indicate across-fish similarities or across-attribute relationships and generalizations.

Insofar as thematic integrations facilitate remembering through the production of dependable retrieval cues (e.g., Desrochers & Begg, 1987; J. R. Levin, 1981), the full power of mnemonic techniques may not yet have been brought to bear on the mnematrix design. With the benefit of hindsight, then, from a "transfer-appropriate-processing" perspective (J. R. Levin, 1989; Morris, Bransford, & Franks, 1977)—namely, that anticipated cognitive outcomes ought to be conceptually related to learners' previous cognitive-processing activities and manipulations—it is not surprising that generalization and relationship benefits did not materialize in Exp. 1. In Exps. 2 and 3, we attempted to remediate the indicated deficit in the mnemonic matrix representation, and it is this improved, more veridical operationalization of a mnemonic matrix that we explore here. Of specific interest was the effect that mnemonic matrix use has on students' (in this case, grade-school students') ability to remember and apply what they have learned, both immediately and after a delay of several days.

Let us summarize and elaborate on the preceding arguments. A dual-component mnemonic matrix has the potential to solve three learning problems: understanding, remembering, and applying complex information presented in text (J. R. Levin, 1986). In Exps. 2 and 3, we reassessed the power of the mnemonic matrix, but with some important modifications. First, we developed a text containing information about true, rather than fictitious, marine animals (viz., real sharks rather than the fictional fish of Exp. 1). Second, and most importantly, we constructed pictorial mnemonic materials that afforded multiple name-attribute links through the use of thematic integrations. In these materials, the mnemonic illustration for each shark was integrated with a set of symbolically represented shark attributes. The thematic integrations were specifically designed to facilitate students' identification of and memory for across-topic relationships. Of specific interest was the effect of four different kinds of instructional material on (a) students' memory for specific details included in the text; and (b) students' application of the learned information in recognizing across-topic relationships and in solving novel problems. As we mentioned previously, because our primary interest was in the potential of *pictorial* mnemonic and matrix supplements, the corresponding verbal materials of Exp. 1 were not included here. Finally, we chose elementary school children as participants for whom the shark content and illustrations would be not just appropriate and interesting, but also of relevance to their school science curriculum.

## Method

**Participants and design.** Eighty-eight fifth graders from a midwestern community were asked to study a passage about nine different sharks. Participants were randomly assigned in equal numbers ( $n = 22$ ) to one of four experimental conditions: (a) text plus conventional pictures, where students used their own devices in the company of a conventional textbook illustration for each shark; (b) a conventional picture matrix, where a rows-and-columns organizer with accompanying conventional illustrations was provided, as in Exp. 1; (c) mnemonic pictures, where individually integrated mnemonic illustrations were provided; and

(d) a mnemonic picture matrix, which combined the just-mentioned mnemonic and matrix features. After studying the text passage, students were tested on their memory for and application of the science facts and concepts.

**Materials.** Materials included a text, illustrations in the form of realistic line drawings, a pictorial matrix, mnemonic illustrations, a pictorial mnemonic matrix, and performance measures. The text was a factual 874-word passage describing four attributes of nine real sharks (namely, their typical social grouping, type of teeth, distance from shore, and swim depth). Information contained in the text passage was compiled from two prominent sources on sharks (Castro, 1983; Last & Stevens, 1994). Because there were four attributes associated with each of nine sharks, the passage contained a total of 36 discrete facts. Also, each shark's name can be considered an additional distinguishing feature, thereby increasing to 45 separate facts the total amount of passage information to be remembered.

The passage began with a general introductory paragraph, followed by four more introductory paragraphs indicating the shark attributes (e.g., group size) and their specific levels (e.g., alone, small group, large group). The main body of the passage was written in a shark-by-shark fashion (presented in alphabetical order) and did not explicitly describe the intershark similarities and interattribute relationships (e.g., that sharks that swim at deeper levels of the ocean tend to have grinding, rather than tearing, teeth; that sharks that swim closer to the shore tend to travel in larger groups). For example, the passage information about the first two sharks discussed was as follows:

First let me tell you about the *angel* shark. The *angel* shark is found in open water, far from shore, and it swims at the bottom of the ocean. It has grinding teeth and travels alone.

Next there is the *blacktip* shark. The *blacktip* shark is found near shore and it swims at the surface of the ocean. It has tearing teeth and travels in large groups.

Corresponding attributes of each subsequently discussed shark were presented in the same temporal order.

For each of the nine sharks, a line drawing of the shark's actual appearance was constructed, along with a set of pictorially represented symbolic attributes. These illustrations therefore included both physical resemblances and symbolic representations of each shark. Specifically, the symbolic representations conveyed either of two teeth types (tearing or grinding) and one of three group sizes in which the shark typically travels (alone, represented by a single shark; in small groups, represented by a pair of sharks; or in large groups, represented by five sharks). Additionally, the actual characteristics corresponding to each of these representations were printed below each picture.

The conventional picture matrix was organized according to two spatially relevant shark characteristics: distance from shore and swim depth. Three categorized distances from shore (near the shore, represented by a beach; in between the shore and open water, represented by a pier; and open water, represented by just water and the sun) were placed atop the columns, and three swim-depth categories (on the surface, midwater, and near the bottom) were placed at the beginning of each row, forming a nine-cell matrix. The previously described illustrations for each shark were reduced in size and placed in the cell that corresponded to that particular shark's swim depth and distance from shore.

The mnemonic pictures were constructed in a similar fashion. As with the conventional pictures, the distance-from-shore and group-size attributes appeared as symbolic representations in each of the mnemonic pictures. The mnemonic illustrations were also based on symbolic representations of the teeth-type attribute (a saw for tearing teeth and a grinding machine for grinding teeth) and the

shark's name. However, the critical difference between the conventional and mnemonic pictures involved the use of thematic integrations in the latter. Each shark picture was formed from a thematic integration involving the shark's name, distance from shore, swim depth (represented by a sailboat for on the surface, a submarine for midwater, or plant life for near the bottom), teeth type and group-size attributes, along with a captioned description of the integrated scene. Figure 5 highlights the critical difference between the dogfish shark's conventional (top) and mnemonic (bottom) illustrations. Note that although the two illustrations differ in the ways just described, the two are informationally equivalent.

As with the conventional picture matrix, the mnemonic picture matrix columns defined the three distances from shore, and the rows defined the three swimming depths. Also as with the conventional picture matrix, a reduced mnemonic picture of each shark was placed according to its appropriate row and column location within the spatial array (see Figures 6 and 7 for a comparison of the conventional and mnemonic picture matrices, respectively).

Two randomized versions of two tests, attribute *identification* and shark *classification*, were developed, along with reasonably parallel forms of a third task (*problem solving*). For the identification test, children had to pick out the four specific attributes associated with a given shark's name (from an organized list of all possible attributes). The classification test consisted of 11 statements (e.g., "travels in small groups"), each of which required the student to group together sharks that share a particular characteristic. The problem-solving task was a four-item test designed to assess students' ability to apply in an inferential fashion the information that they had learned in the passage. For two of the items (Items 1 and 3), students needed to remember specific shark names to solve the problem correctly (name-related items), and for two items (Items 2 and 4) memory for shark names was not necessary (name-unrelated items). For example, Item 1 was "A mysterious disease has killed off most of the shellfish in the ocean (for example, crabs and lobsters). Which of the sharks you studied are also likely to be killed from this situation? Why?" and Item 2 was "If you caught sharks for a living and you wanted to catch as many as you could at one time, where would you fish: open water, in between, or near shore? Why?" On the basis of a transfer-appropriate-processing assessment of the two tasks' requisites, mnemonic benefits were more anticipated on the name-related items than on the name-unrelated items.

A 45-item scrambled word filler task was also developed to eliminate the contribution of students' short-term memory to their performance. Finally, a 5-item questionnaire was constructed to assess students' prior knowledge of sharks (2 items), as well as the degree to which students considered the passage and accompanying materials useful (1 item) and enjoyable (1 item) and students' receptiveness to using similar study materials again (1 item).

**Procedure.** The participants were seen on an individual basis by one of two experimenters, with experimenters counterbalanced across conditions. For all experimental conditions, the initial session was 60 min, with approximately 20 min allotted to each of three phases: instruction, study, and testing. During the instruction phase, the experimenter read the passage aloud while the participants followed along silently. As the passage was read, students in the text plus conventional pictures and the conventional picture matrix conditions were shown representational and symbolic picture "keys" for the corresponding text information and were told how to interpret them (i.e., for distance from shore, that a beach scene represented "near shore," the end of a wooden pier represented "in between the shore and open water," and just the water line with the sun above represented "open water"). As each key was introduced, experimenter questioning and feedback fol-

lowed, to assure that students understood the proper interpretation. Participants in the mnemonic pictures and mnemonic picture matrix conditions were shown analogous symbolic and mnemonic picture keys.

Immediately following instruction, pictures of the nine sharks and their attributes were introduced in the same order that they had been presented in the passage, while the experimenter read the verbal descriptions below them (see Figure 5) and directed the students' attention to the critical information in each picture. After all nine pictures were presented, the experimenter reminded the students to pay close attention to the various attributes associated with each shark, including swim depth, distance from shore, type of teeth, and group size. That portion of the study phase took approximately 10 min. Then, students were provided with either 5 in.  $\times$  8 in. index cards containing the individual sharks (text plus conventional pictures and mnemonic pictures) or a corresponding matrix (conventional picture matrix and mnemonic picture matrix) and were allowed an additional 10 min to study the materials.

After the study time had expired, a scrambled word filler test was administered, followed by the three performance measures: identification, classification, and problem solving. Students were then thanked for participating and asked not to discuss the specifics of the study with their classmates. Seven days after the initial session, the experimenters returned unannounced and administered a delayed version of the three performance measures to all students in their regular classrooms. In-class testing was decided on for reasons of both experimenter convenience and student-teacher nondisruption.

**Scoring.** Students' immediate and 7-day delayed protocols were scored by individuals who were unaware of students' assigned conditions. For both the identification and classification tests, 36 points were possible. On the latter test, incorrect selections were subtracted from correct selections to determine a student's total score (there were no omissions). For the problem-solving test, points were awarded in relation to the completeness of the student's answer. For example, scoring for Item 1 presented earlier was based on supplying the names of three specific sharks (1 point for each), along with the corresponding justification (0–2 points, with 0 indicating *no justification* or a *completely incorrect one*, 2 indicating a *completely correct justification*, and 1 indicating a *partially correct justification*). Separate scores were calculated for the two problem-solving subtests, name related and name unrelated, and were then converted to proportions because of the unequal number of points possible for each.

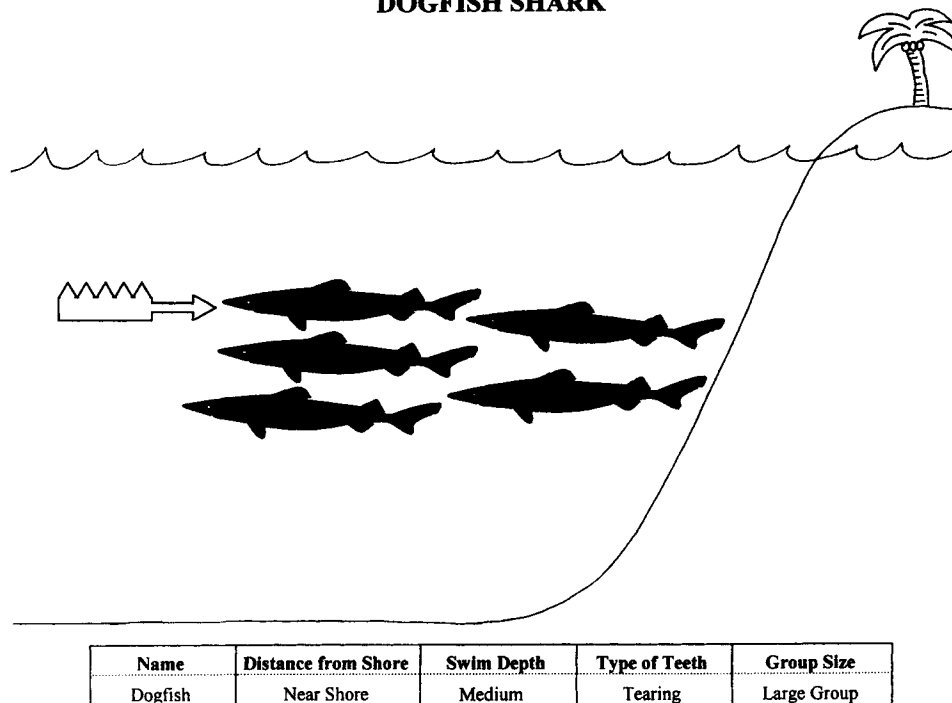
## Results and Discussion

All statistical tests were conducted on adjusted means that had experimenter variance (associated with both the main effect and the interaction with conditions) removed from them. These adjusted means (expressed as percentages correct) are presented in Table 2. It should be noted that the values associated with the classification measure are not truly percentages in that points were subtracted for incorrect responses, and thus, negative scores are possible. Differences among the adjusted condition means, summarized in Table 2, were again assessed by the sequential Hayter–Tukey procedure based on a familywise  $\alpha$  of .05.

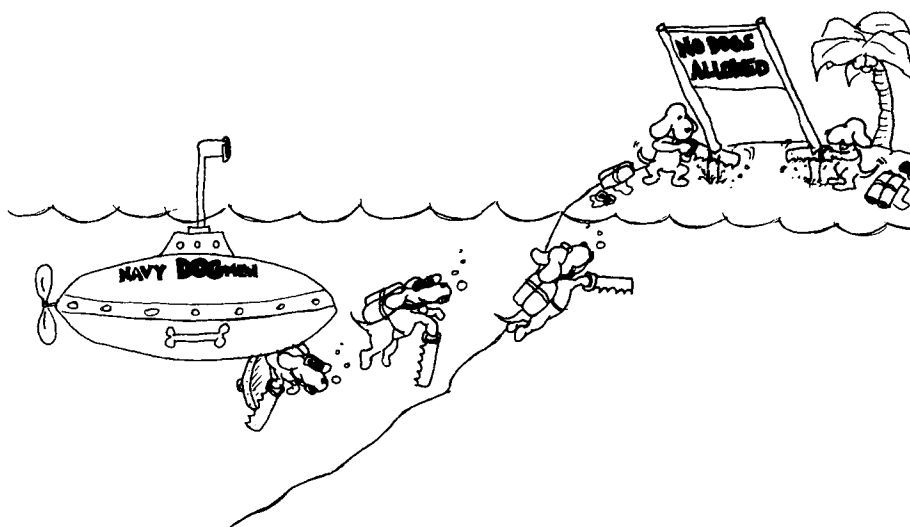
For immediate identification, Hayter–Tukey comparisons revealed that students in the three adjunct conditions (mnemonic picture matrix, mnemonic pictures, and conventional picture matrix) all identified more shark attributes than did students in the text plus conventional pictures condition. In



## DOGFISH SHARK



## DOGFISH SHARK



A **submarine** filled with navy **dogmen** notice a sign on the **beach** saying "No Dogs Allowed." A **group** of angry dogs decides to swim to shore armed with **saws** to cut down the sign.

Figure 5. Conventional (top) and mnemonic (bottom) illustrations for the dogfish shark, used in Experiments 2 and 3.

addition, students in the two mnemonic conditions were statistically superior to their peers in the conventional picture matrix condition on this measure. For the delayed identification test, a similar statistical pattern of mean

differences emerged, with one exception: Conventional picture matrix and text plus pictures participants were not statistically different.

For both the immediate and delayed classification tests,

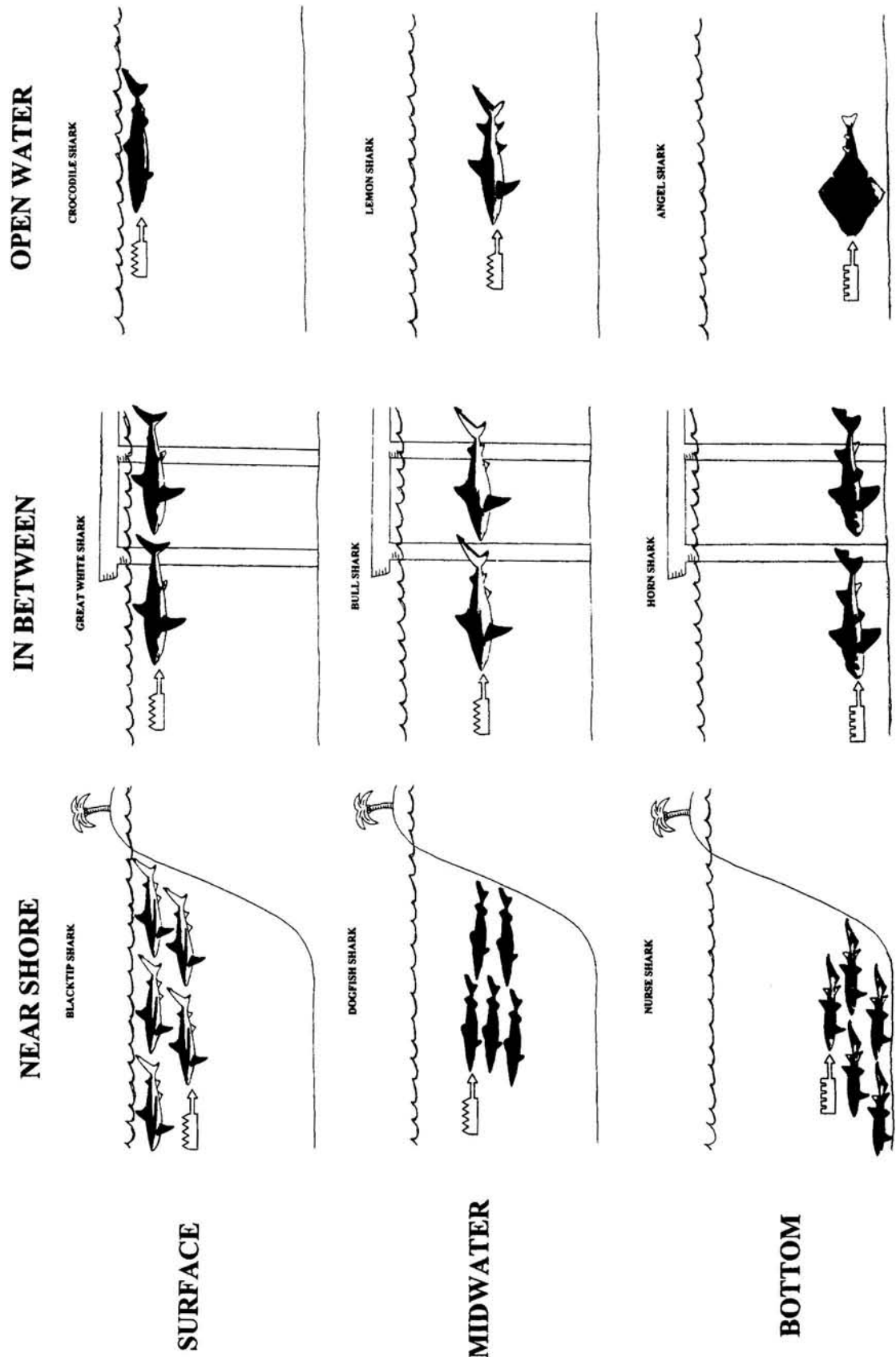


Figure 6. Conventional picture matrix used in Experiments 2 and 3.

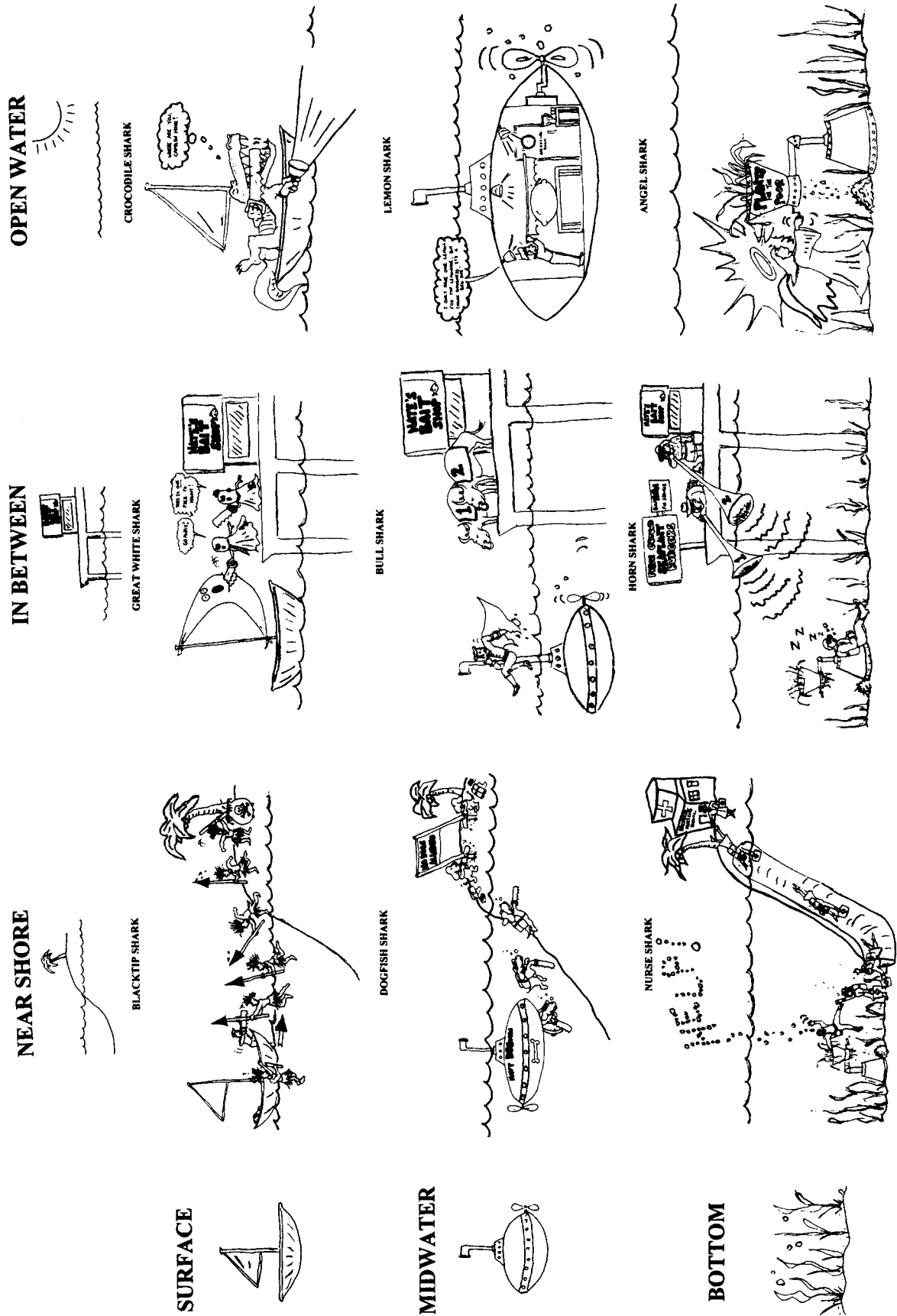


Figure 7. Mnemonic picture matrix used in Experiments 2 and 3.

Table 2  
Adjusted (for Experimenter) Mean Percentages Correct, by Experimental Condition, on the Outcome Measures of Experiment 2

Measure	Condition			
	Text + conventional pictures	Conventional picture matrix	Mnemonic pictures	Mnemonic picture matrix
Identification				
Immediate <sup>a</sup>	59.6	69.4 <sup>i</sup>	95.2 <sup>ij</sup>	90.2 <sup>ij</sup>
Delayed <sup>b</sup>	55.7	63.9	95.3 <sup>ij</sup>	91.5 <sup>ij</sup>
Classification				
Immediate <sup>c</sup>	21.1	25.5	86.3 <sup>ij</sup>	80.6 <sup>ij</sup>
Delayed <sup>d</sup>	17.3	26.0	84.3 <sup>ij</sup>	80.7 <sup>ij</sup>
Name-related problem solving				
Immediate <sup>e</sup>	26.7	47.8 <sup>i</sup>	56.0 <sup>i</sup>	69.3 <sup>ij</sup>
Delayed <sup>f</sup>	20.0	47.5 <sup>i</sup>	62.7 <sup>i</sup>	59.3 <sup>i</sup>
Name-unrelated problem solving				
Immediate <sup>g</sup>	50.3	68.2	59.8	64.0
Delayed <sup>h</sup>	36.1	53.2	57.0 <sup>i</sup>	54.7 <sup>i</sup>

Note. There were 22 students per condition. The values associated with the classification measure are not true percentages because points were subtracted for incorrect responses.

<sup>a</sup>MSE = 139.3. <sup>b</sup>MSE = 170.6. <sup>c</sup>MSE = 475.2. <sup>d</sup>MSE = 486.7. <sup>e</sup>MSE = 878.1. <sup>f</sup>MSE = 886.8. <sup>g</sup>MSE = 841.3. <sup>h</sup>MSE = 573.9. <sup>i</sup>Differs statistically from the text + conventional pictures mean, based on the Hayter-Tukey procedure (familywise  $\alpha = .05$ ). <sup>j</sup>Differs statistically from the conventional picture matrix mean, based on the Hayter-Tukey procedure (familywise  $\alpha = .05$ ).

Hayter-Tukey comparisons indicated that mnemonic picture matrix and mnemonic pictures students each outperformed students in the conventional picture matrix and the text plus conventional pictures conditions, with no differences between the former two or between the latter two groups of students. For immediate name-related problem-solving performance, mnemonic picture matrix, mnemonic pictures, and conventional picture matrix students each exhibited statistically higher performance relative to their text plus conventional pictures counterparts. In addition, mnemonic picture matrix students statistically outperformed conventional picture matrix students (whereas mnemonic pictures students did not). On the delayed name-related problem-solving subtest, students in the three adjunct conditions again scored statistically higher relative to students in the text plus conventional pictures condition, and this time there were no statistical differences among the three adjunct variations. Although no conditions-associated differences were detected on the immediate name-unrelated subtest (where, as was noted earlier, performance benefits of the mnemonic pictures were not specifically expected), after a 1-week delay, students in both the mnemonic picture matrix and mnemonic pictures conditions were statistically superior to students in the text plus conventional pictures condition, with no difference between the former two. When the data were reanalyzed with the scrambled-word test added as a covariate, the just-described pattern of statistical conclusions was identical, with one exception: The difference between conventional picture matrix and text plus conventional pictures students was not statistically significant.

As in Exp. 1, supplementary analyses were also conducted separately for identification- and classification-test items tapping information that either was or was not directly represented in the matrix (matrix highlighted = swim depth

and distance from shore vs. matrix nonhighlighted = type of teeth and social grouping, respectively). On the immediate identification test, and consistent with the previously discussed "perceptual enhancement" interpretation, the previously reported statistical difference between conventional picture matrix and text plus conventional pictures students was localized in the matrix-highlighted items (i.e., no corresponding difference was found for matrix-unrelated items). All other reported statistical differences and nondifferences were duplicated on both the immediate and delayed versions of that test, as well as for both versions of the classification test.

Between-conditions statistical differences (familywise  $\alpha = .05$ ) were detected on two of the three questionnaire items that were analyzed. The two prior-knowledge items indicated that almost all students were previously unfamiliar with the information presented, and so no additional analyses were conducted on those items. When asked how helpful the passage-accompanying materials were, students who were provided with the mnemonic picture matrix rated it as more helpful (adjusted  $M = 3.8$  out of 4) than did students who were provided with the conventional picture matrix (adjusted  $M = 3.3$ ). When asked whether they would use such materials again if they were provided with them, mnemonic picture matrix students' adjusted mean rating of 3.4 (between *probably yes* and *definitely yes*) was somewhat, though statistically, lower than the 3.8 adjusted mean rating of mnemonic pictures students. In that regard, even text plus conventional pictures students perceived the provided shark pictures to be helpful and indicated that they would use such pictures again, as evidenced by their comments and respective adjusted mean ratings of 3.6 and 3.5. It is interesting to note that no conditions-related differences were detected on the "enjoyable" item (adjusted  $M$ s = 3.5–3.7), suggesting

that students in all conditions were comparably engaged by the task.

The results of Exp. 2 permit four unmistakable conclusions. First, mnemonic pictures benefitted students' performance more than did conventional pictures. Students presented with either the integrated mnemonic matrix or the individual mnemonic pictures statistically outperformed students who were presented with individual conventional pictures on all six of the mnemonic-relevant performance measures (i.e., all those except the name-unrelated problem-solving items). Second, mnemonic pictures—whether matrix embedded or individual—also proved to be superior to conventional picture matrices. This was true statistically for mnemonic matrix pictures on five out of six mnemonic-relevant measures and for individual mnemonic pictures on four of those measures. Third, although we expected the partnership of mnemonics and matrices to provide the greatest facilitation of student performance, that partnering seemingly played a limited role. On all eight performance measures, processing individual mnemonic illustrations was statistically as effective as processing an integrated mnemonic matrix. This "equivalence" finding is reconsidered in the General Discussion. Finally, students presented with the conventional picture matrices experienced limited performance benefits relative to text plus conventional pictures students, on three measures: the immediate identification task ("perceptually enhanced" matrix-highlighted items only) and both the immediate and delayed name-related problem-solving tasks. As was noted in relation to the Exp. 1 results, such restricted facilitation may be a function of the specific matrix operationalization used here. We also return to that issue in the General Discussion.

### Experiment 3

Experiment 3 replicated the basic operations of two of Exp. 2's conditions, conventional picture matrix and mnemonic picture matrix. We considered both economy of resources and statistical power in deciding to include only these two conditions. The latter consideration was especially relevant to an additional, extending feature of Exp. 3: We incorporated group, as opposed to individual, administration of the instructional materials. That is, rather than students being instructed and tested individually as in Exp. 2, in Exp. 3 they were instructed and tested in large groups—an extension that is a nontrivial one both substantively and methodologically. Regarding the former, it is well-documented that strategies that may be effectively implemented with individual students are not necessarily effectively implemented in a group context (e.g., J. R. Levin, 1993). Regarding the latter, claims of successful group-administered treatment effects are often unjustified because the supporting evidence is based on inappropriate statistical models (e.g., J. R. Levin, 1992).

### Method

*Participants and design.* One hundred fifty-eight fifth graders from a midwestern university community participated in the study.

They were drawn from eight classrooms located at four different schools. Within each classroom, students were randomly assigned in approximately equal numbers to one of the two experimental conditions: conventional picture matrix or mnemonic picture matrix.

*Materials, procedure, and scoring.* Materials paralleled those of the conventional picture matrix and mnemonic picture matrix conditions in Exp. 2.

The initial instruction and testing phase consisted of a single session approximately 1 hr long. For each experimental session, students from two classrooms were selected and combined. About half the students in each classroom were randomly assigned to each experimental condition. All students in one condition were instructed and tested in one of the classrooms by one experimenter while all students in the other condition were instructed and tested in the other classroom by another experimenter (with experimenters and conditions counterbalanced in that regard). This procedure resulted in four instructional groups per condition, with each instructional group containing approximately 20 students.

Students were asked to listen to a lesson about sharks and were encouraged to ask questions if necessary. The experimenter began by reading the passage aloud to the group. This was followed by the introduction of booklets containing condition-specific materials that were distributed to each student in the group. As in Exp. 2, students were shown picture keys appropriate for their condition and were instructed in how to interpret the individual pictures for each shark. Each student then received an individual copy of the conventional picture matrix or mnemonic picture matrix, depending on the condition, and was given 5 min to study the materials on his or her own.

After the study time had expired, the materials were collected and the scrambled word test was administered to all students (approximately 3 min). This was immediately followed by distribution of the three performance tasks administered in the following order (each for approximately 10 min): attribute identification, shark classification, and problem solving. Students were asked to work independently and at their own pace. The questionnaire described in Exp. 2 was distributed after all tests were completed. Seven days after the initial phase of the study, the experimenters returned unannounced and administered the alternate forms of the three performance measures to all students in their own classrooms, without any additional instruction. Each student's protocol was scored by individuals who were unaware of students' assigned conditions, according to the procedures described in Exp. 2.

### Results and Discussion

For each dependent measure, the means of the two classroom subgroups in each session were averaged. Because subgroup sizes were approximately equal in all cases, a simple unweighted averaging procedure was applied. The resulting eight instructional group means (four apiece in the matrix and mnematrix conditions) comprised the units of analysis. Mean performance, by condition, is presented in Table 3.

As was found in both previous experiments, students in the mnemonic picture matrix condition statistically and substantially outperformed those in the conventional picture matrix condition with respect to remembering explicit factual information that was covered in the passage: identification task,  $t(6) = 7.81$ ; classification test,  $t(6) = 14.41$ ; both  $ps < .001$ . Similar mnemonic benefits were found on these two factual recall measures after a 1-week delay:

Table 3  
Mean Percentages Correct, by Experimental Condition, on  
the Outcome Measures of Experiment 3

Measure	Condition	
	Conventional picture matrix	Mnemonic picture matrix
Identification		
Immediate <sup>a</sup>	67.3	88.3 <sup>i</sup>
Delayed <sup>b</sup>	61.2	88.1 <sup>i</sup>
Classification		
Immediate <sup>c</sup>	29.1	72.6 <sup>i</sup>
Delayed <sup>d</sup>	25.3	71.3 <sup>i</sup>
Name-related problem solving		
Immediate <sup>e</sup>	30.5	49.2 <sup>i</sup>
Delayed <sup>f</sup>	37.1	55.6 <sup>i</sup>
Name-unrelated problem solving		
Immediate <sup>g</sup>	71.3	57.9
Delayed <sup>h</sup>	58.9	62.5

Note. There were four groups of about 20 students each per condition. The values associated with the classification measure are not true percentages because points were subtracted for incorrect responses.

<sup>a</sup>MSE = 14.3. <sup>b</sup>MSE = 11.2. <sup>c</sup>MSE = 18.2. <sup>d</sup>MSE = 27.1. <sup>e</sup>MSE = 64.1. <sup>f</sup>MSE = 73.1. <sup>g</sup>MSE = 171.1. <sup>h</sup>MSE = 53.2. <sup>i</sup>Differs statistically from the pictorial matrix mean ( $\alpha = .05$ ).

identification task,  $t(6) = 11.38$ ; classification task,  $t(6) = 12.51$ ; both  $ps < .001$ . Importantly, and in contrast to what was found in the initial two experiments, mnemonic picture matrix students also outperformed conventional picture matrix students on the name-related problem-solving subtest, both immediately and after a 1-week delay: respective  $ts(6) = 3.30$  and  $3.06$ , both  $ps < .025$ . At the same time, and consistent with the transfer-appropriate-processing perspective, mnemonic picture matrix students did not differ statistically from their conventional picture matrix counterparts on either the immediate or delayed name-unrelated problem-solving subtest: immediate subtest,  $t(6) = 1.45$ ,  $p = .20$ ; delayed subtest,  $|t| < 1$ .

When the identification and classification tests were subdivided into matrix-highlighted and matrix-nonhighlighted items and analyzed separately (as in Exps. 1 and 2), mnemonic picture matrix students statistically outperformed conventional picture matrix students on all eight resulting measures: 2 Tests (identification and classification)  $\times$  2 Item Types (matrix highlighted and matrix nonhighlighted)  $\times$  2 Test Times (immediate and delayed).

Although the mean ratings of the questionnaire items were uniformly lower than those of Exp. 2, statistical differences favoring mnemonic picture matrix over conventional picture matrix students were found on the three items that were analyzed: helpfulness (respective  $Ms = 3.4$  and  $2.9$ ), enjoyableness (respective  $Ms = 3.0$  and  $2.7$ ), and receptiveness to future use (respective  $Ms = 3.2$  and  $2.9$ ).

With one minor exception, all statistical conclusions were corroborated on the basis of small-sample exact permutation tests. That exception was the delayed name-related problem-solving measure, for which  $p$  was .058.

## General Discussion

The present study reexamined the effectiveness of two previously well-researched text-processing supplements: matrix structures and mnemonic representations. In addition, this study marked the first time that the two supplements have been combined into mnemonic matrices—and what hereinafter we refer to as “mnematrices”—with the aim of extracting the best of what each component has to offer. Here we discuss how matrices and mnemonics fared, both individually and in combination.

### Matrix Structures

Previous text-processing research has shown that students who are provided with typical verbal matrices generally outperform those provided with either an outline or the text alone (Kiewra, 1994; Kiewra et al., in press). Theoretically, matrices are thought to be more computationally efficient than outlines or text because of their reduced clutter, localization, and perceptual enhancement properties. In terms of clutter, matrices contain fewer words than texts or outlines. They also present heading labels (such as “diet”) once rather than multiple times. In terms of localization, matrices position related information closer together than linearly organized outlines or text, making it easier to draw relationships across a particular category (such as the food that fish eat). In terms of perceptual enhancement, the matrix’s two-dimensional structure permits students to view vertical and horizontal dimensions concurrently and thereby recognize overarching relationships that may exist (e.g., that fish swimming at progressively deeper depths eat progressively larger food). Outlines, because of their linear structure, obscure overarching relationships. Typical linear text presentations also obscure such relationships, unless they are explicitly pointed out to the reader.

Yet, and in contrast to what had been anticipated on the basis of both such theory and previous research, the matrix benefits observed here were either nil (Exp. 1) or limited in their size and scope (Exp. 2). This was true whether the matrix was presented in an all-verbal form or whether it was accompanied by conventional or symbolic picture supplements (see Figures 2 and 3). The relatively modest positive effects produced by these matrices might be attributable to the matrix structures developed for the fish and shark passages of the present study. As was previously noted in the introductory section and in relation to the Exp. 1 findings, the matrices developed for the present study differed structurally from those used in other research (e.g., Kiewra et al., in press).

The two matrix types appear to differ in the same important ways that distinguish among the computational efficiency of matrices, outlines, and text: clutter, localization, and perceptual enhancement. In the present distinction, each works to support the multifactor over the two-factor matrix structure. To illustrate, we briefly compare the two fish matrices in Figures 1 and 3. First, the Figure 3 (two-factor) matrix is more cluttered. Because certain factors such as color, diet, and size do not appear as part of the

matrix framework, they must appear within the matrix cells. In contrast, in the Figure 1 (multifactor) matrix these factors are listed down the matrix's left-hand side. The two-factor matrix also repeats certain details. For instance, the algae diet of the Hat and Loop fish appears twice in the two-factor matrix but only once in the multifactor matrix.

Second, the Figure 1 (multifactor) matrix localizes relevant information better than does the Figure 3 (two-factor) matrix. Information about fish color, for example, appears within a single row in the former but is spread across three rows in the latter. Reducing clutter and improving localization lead to greater perceptual enhancement of the multifactor matrix. At a glance, readers can, for example, examine the size within each depth level to perceive the overarching relationship that as depth increases, so does size. In the two-factor matrix, this same relationship must be built much more slowly by examining all three rows and columns and by mentally (or physically) repositioning the related information.

Additional research is needed in which matrix structure and its associated clutter, localization, and perceptual enhancement properties are varied systematically to isolate their posited effects on different performance measures. As was witnessed here in relation to the next-discussed mnemonic supplements, greater perceptual enhancement and localization are presumably what resulted from transforming an unintegrated mnemonic matrix with its limited (i.e., memory) performance benefits in Exp. 1 into an integrated one with much more pervasive (i.e., memory plus application and problem solving) benefits in Exps. 2 and 3.

### *Mnemonic and Mnematrix Representations*

Mnemonic pictorial representations have been repeatedly found to improve learning more than pictorial representations without a mnemonic component (e.g., J. R. Levin, 1993, 1995). The findings from the present study clearly support and extend those conclusions. The most basic evidential support occurred in Exp. 2, where studying individual mnemonic pictures resulted in statistically and substantially higher performance than studying conventional pictures on all six mnemonic-relevant measures, as well as on one of the two mnemonic-irrelevant measures (delayed name-unrelated problem solving).

Our results also speak to the value of individually presented mnemonic pictures relative to conventional picture matrices, which were compared head to head in Exp. 2. The former proved more effective on both the immediate and the delayed identification and classification tests. These findings suggest that the memory-enhancing properties of mnemonic techniques may be more crucial than the computational-efficiency properties of matrices with respect to performing well on tasks (at least unspeeded tasks) requiring memory for previously studied factual information, including the organization and manipulation of that information.

Other evidence demonstrating the power of mnemonic representations comes primarily from Exp. 3, where students provided with a mnematrix statistically outperformed students provided with a conventional picture matrix on all six of the mnemonic-relevant measures. Similar findings oc-

curred in Exp. 2, where mnematrix students were superior on five of the six mnemonic-relevant measures. Even in Exp. 1, where the mnemonic picture matrix did not thematically integrate its individual elements, students who received it performed better than conventional picture matrix students on the matching test. In addition, relative to a conventional picture matrix, a mnematrix produced higher student ratings of helpfulness (Exps. 2 and 3), enjoyableness (Exp. 3), and the likelihood of future use (Exp. 3).

These new findings lend support to our initial speculations that the theoretical benefits of matrices can be augmented by incorporating a mnemonic component. Unlike the Exp. 1 operationalization, the mnematrix developed for Exps. 2 and 3 enhanced students' performance on a variety of cognitive outcomes. With essentially one critical structural modification of the former version of the mnematrix—namely, the incorporation of thematic integrations of the target attributes—the present mnematrix was able to demonstrate both powerful and pervasive learning effects that were not previously captured. Such effects include similar performance benefits on 1-week delayed tests, which bolsters recent arguments concerning the enduring quality of mnemonically acquired information (cf. Carney & Levin, 1998b; Wang & Thomas, 1995).

*Mnematrix or mnemonic?* Because of the present study's findings that matrix-embedded mnemonic illustrations were generally superior to conventional picture matrices, it might be tempting to conclude that mnemonic representations add something to a matrix structure. At the same time, because of the present study's findings that equivalent benefits were generally produced by the two different mnemonic illustration formats (matrix-embedded and individual), it might be tempting to conclude that a matrix structure does not add much to a mnemonic representation. (Recall, however, that with Exp. 1's name-only mnemonic pictures, adding a matrix structure did produce more pervasive text-learning benefits than did simply incorporating the mnemonic pictures into an outline format.) We believe that such conclusions are premature, however, until more, and more sensitive, measures of students' performance are assessed. That is, additional research is needed to separate out the *unique* facilitative cognitive components of matrix-embedded mnemonic illustrations (mnematrices) from stand-alone mnemonic illustrations (Atkinson, Levin, Beitzel, & Glover, 1999).

### *Concluding Comments*

What we do know from this study, however, is that once again mnemonic techniques have been demonstrated to be more than simple memory aids. In Exps. 2 and 3, students provided with mnemonic pictures outperformed text plus conventional pictures and conventional picture matrix students even on measures thought to be the matrix's strong suit, such as interconcept identification and problem solving. That the list of outcomes facilitated by mnemonic pictures includes indicators of information manipulation and inferential thinking provides strong counterargument to those who criticize the instructional potential of mnemonic strategies, namely that (a) their cognitive benefits are restricted to tasks

requiring the deployment of lower level, verbatim memory processes, and (b) because of that, mnemonic-strategy use hampers students' ability to perform higher level cognitive tasks. Not only did the present mnemonic pictures *not* hamper students' application and problem solving, but as has been observed in the past (e.g., Carney & Levin, 1998a; M. E. Levin & Levin, 1990), they helped students better organize, and solve problems with, the information they learned relative to students who acquired the material through nonmnemonic means. Recently collected data indicate that mnemonic techniques can be similarly adapted to improve students' acquisition and application of categorizable information (Glover, Beitzel, Levin, & Carney, 1999). As the argument has gone and continues to go, reasoning and thinking critically presuppose having reliable access to the critical factual information that enables reasoning and thinking critically (e.g., J. R. Levin, 1986, 1995). Mnemonic representations can hasten the cementing of that reliable access.

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