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Revising the Visualizer–Verbalizer Dimension: Evidence for Two Types of Visualizers

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Sixty participants were administered spatial ability tests, a verbal ability test, and a visualizer–verbalizer cognitive style questionnaire. Although verbalizers tended to be a homogeneous group with an intermediate level of spatial ability, there were 2 groups of visualizers, 1 with high spatial ability (the spatial type) and another with low spatial ability (the iconic type). To compare the use of mental images by the 2 types of visualizers in solving problems, interviews with 8 high-spatial visualizers and 9 low-spatial visualizers were conducted. The students were presented with graphs of motion and were asked to visualize and interpret the motion of an object. Whereas low-spatial visualizers interpreted the graphs as pictures and mostly relied on visual (iconic) imagery, high-spatial visualizers constructed more schematic images and manipulated them spatially. In addition, we compared problem-solving strategies used by verbalizers to those of visualizers. In contrast to visualizers, verbalizers of low and high spatial ability did not have any clearly marked preference to use visual or spatial imagery.

The visualizer–verbalizer cognitive style is described by “individual preferences for attending to and processing visual versus verbal information” (Jonassen & Grabowski, 1993, p. 191). *Visualizers* are those individuals who rely primarily on imagery processes when attempting to perform cognitive tasks; *verbalizers* prefer to process information by verbal-logical means. In this study, we proposed and tested a revision of the visualizer–verbalizer cognitive style dimension.

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Psychologists and educators have long debated the value of the visualizer–verbalizer classification. Disagreement on this classification seems to result from the tendency to equate the visualizer–verbalizer classification with individual differences in imagery, that is, describing visualizers as those of high-imagery ability and verbalizers as those of low-imagery ability (e.g., Hollenberg, 1970; Jonassen & Grabowski, 1993; Richardson, 1999). However, research has failed to establish a clear relation between individuals' preferences to process information visually and their performance on imagery tasks. Educational researchers have found that visualizers' performance on spatial ability tests is no better than that of verbalizers (e.g., Lean & Clements, 1981). Similarly, clinical psychologists have failed to establish a relation between individuals' preferences to process information visually and their scores on imagery vividness questionnaires (see Hiscock, 1978, for a review). They concluded that "it is tenuous to equate a vivid imager with a visualizer and vice versa … since in all probability, the two are separate issues" (Strosahl & Ascough, 1981, p. 429). These results have cast some doubt on the usefulness of the visualizer–verbalizer distinction, and as a consequence the number of studies regarding visualizer–verbalizer cognitive style has declined over the past decade. However, in recent years, with increasing research on multimedia and hypermedia instructional effects, the concept of learner's cognitive style has attracted renewed attention (e.g., Andris, 1996; Plass, Chun, Mayer, & Leutner, 1998; Stenning, Cox, & Oberlander, 1995). This raises the question of whether the visualizer–verbalizer cognitive style is a valid dimension and there is a demand for further elaboration of this concept.

The hypothesis of this research is that the visualizer–verbalizer dimension is not a unitary construct but involves two qualitatively different types of visualizers who process visual-spatial information, generate mental images, and solve visually presented problems in different ways. This hypothesis is consistent with recent findings in cognitive psychology and neuroscience research suggesting that imagery is not general and undifferentiated but composed of different, relatively independent visual and spatial components (e.g., Baddeley, 1992; Farah, Hammond, Levine, & Calvanio, 1988; Kosslyn, 1994; Logie, 1995). *Visual imagery* refers to a representation of the visual appearance of an object, such as its shape, size, color, or brightness. *Spatial imagery* refers to a representation of the spatial relations between parts of an object, the location of objects in space, and their movements and is not limited to the visual modality (i.e., one could have an auditory or tactile spatial image). We suggest that the dissociation between visual and spatial imagery also exists in individual differences in imagery. That is, some individuals may construct vivid, concrete, and detailed images of individual objects in a situation, whereas others create images that represent the spatial relations between objects that facilitate the imagination of spatial transformations such as mental rotation. We refer to these groups as the *iconic type* and the *spatial type,* respectively.

In this research, we also examined whether the iconic type and the spatial type generate different mental images when presented with the same visual input. Specifically, we examined the ability of iconic and spatial types to generate and use mental images while solving problems in kinematics that required them to visualize and interpret the motion of an object from a graph. We expect that visualizers of the spatial type are more likely to construct schematic images while visualizing the motion of an object from a graph. In contrast, visualizers of the iconic type are more likely to construct pictorial images and give pictorial interpretations of a graph. We relate individual differences in mental imagery to a common misconception in interpretation of kinematics graphs in which students interpret the graph as a picture of the phenomenon depicted, rather than an abstract representation.

THEORETICAL BACKGROUND

Evidence for Two Types of Imagery

Neurophysiological and neuroimaging data provide evidence that higher level visual areas of the brain can be divided into two functionally and anatomically independent perceptual systems: one concerned with the appearance of individual objects and the other with spatial relations between objects (Jonides & Smith, 1997; Kosslyn & Koenig, 1992). For instance, Ungerleider and Mishkin (1982) found that monkeys with lesions in the parietal cortex were severely impaired in tasks that required assessing an object's spatial relations, but not in tasks that required visual discriminations between different forms, patterns, and objects. In contrast, monkeys with lesions in the inferior temporal cortex were impaired at learning to discriminate the visual appearance of objects but not in the spatial tasks.

It has been argued that the dissociation between the representation of visual appearance and spatial relations exists not only in perception but also in mental imagery (e.g., Farah et al., 1988; Levine, Warach, & Farah, 1985; Milner & Goodale, 1995). For example, Levine et al. demonstrated that following brain lesions in the temporal cortex, patients can be extremely impaired in tasks tapping visual aspects of imagery although showing normal performance on tests of spatial imagery (see also Farah et al., 1988). In contrast, parietal damage leads to impairment in spatial imagery skills, such as mental rotation or maze learning. Accordingly, Farah et al. (1988) concluded that "imagery researchers have been misled by the use of a common term 'imagery' to label what are in fact two distinct types of representations" (p. 443).

Similarly, in neuroimaging studies, spatial and visual imagery tasks led to very different patterns of brain activity (Jonides & Smith, 1997; Kosslyn & Koenig, 1992, chap. 3; Smith et al., 1995). For instance, Uhl, Goldenberg, Lang, and Lindinger (1990) found that when participants visualized a route on a map that they had memorized prior to the experiment, brain activation was observed in the parietal lobes. In contrast, when participants imagined faces and colors, there was a substantial activation of the temporal lobe.

A distinction between visual and spatial processing has also been proposed in the working memory literature. According to a current conception (Baddeley, 1992; Baddeley & Lieberman, 1980), working memory consists of a central executive and two specialized subsystems: a phonological loop and a visuospatial sketchpad. The *central executive* controls attention and coordinates the activities of the other parts, the *phonological loop* is specialized for processing verbal information, and the *visuospatial sketchpad* is specialized for processing visual-spatial information. Dual-task studies (Baddeley & Lieberman, 1980; Logie, 1995) suggest that the visual-spatial sketchpad needs to be further divided into visual and spatial components. Baddeley and Lieberman (1980) found that spatial tasks (e.g., tracking a light while blindfolded with only auditory feedback) interfere with other spatial tasks more than with purely visual tasks (e.g., discriminating the brightness of two lights). Logie (1985) also showed that visual tasks are impaired by concurrently viewing irrelevant pictures but not by arm movements, whereas spatial tasks are impaired by arm movements but not by irrelevant pictures.

Cognitive Style and Individual Differences in Imagery

Research on the role of cognitive style in mathematics problem solving began to appear at the end of the 1970s. Based on clinical methods, Krutetskii (1976) concluded that individuals could be classified into groups according to how they process mathematical information. The first group, the *analytic type,* consists of people who prefer verbal-logical modes when attempting to solve problems. The second group, the *geometric type,* involves those who prefer to use imagery. The third group, the *harmonic type,* consists of individuals who have no tendency one way or the other and use both images and verbal codes equally.

Following the Krutetskii (1976) approach, Moses (1980), Suwarsono (as cited in Lean & Clements, 1981), and Presmeg (1986a, 1986b) proposed that individuals could be placed on a continuum, called *degree of visuality,* with regard to their preference for using imagery while solving mathematical problems. An instrument called the Mathematical Processing Instrument was developed by Suwarsono (as cited in Lean & Clements, 1981) to measure an individual's degree of visuality and has been used extensively in research on imagery in mathematical problem solving.

These studies, however, failed to establish any clear relation between the degree of visuality and students' levels of spatial ability. Moreover, there was a tendency for students who preferred to process information by verbal-logical means to outperform more visual students on both spatial and mathematical tasks (Lean & Clements, 1981). The findings appear to be in conflict with the idea that imagery has a functional role in performance on spatial and mathematical tasks. Several educational studies concluded that "it is inappropriate to continue to identify spatial ability with visual processing" (Gorgorio, 1998, p. 227) and that high-spatial students are actually more flexible in selecting verbal strategies when these are more efficient (Stenning & Monaghan, 1998).

Another explanation of the inconsistencies in cognitive style research is elaborated further in our research. Because imagery ability is not all-or-none but composed of distinct visual and spatial components (Kosslyn, 1995), a given individual can not be classified as high or low in imagery ability generally, but as high or low in visual imagery and spatial imagery, respectively. The idea that imagery may involve different types of representations has appeared in only a few educational studies (Johnson, 1987; Krutetskii, 1976; Presmeg, 1986a, 1986b). For instance, Presmeg (1986a, 1986b) identified different kinds of imagery used by high school students while solving mathematical problems, such as concrete pictorial imagery, pattern imagery, kinesthetic and dynamic imagery, and memory for formulas. She ascribed the most important role in mathematical problem solving to *pattern imagery,* in which concrete details are disregarded and pure relations are depicted. In contrast, *concrete pictorial imagery* may focus the reasoning on irrelevant details and thus make it difficult to formulate the necessary abstractions. Recently, Hegarty and Kozhevnikov (1999) found that visual-spatial representations used by elementary school children while solving mathematical problems can be reliably classified as primarily schematic or primarily pictorial. Moreover, they found that although the use of schematic spatial representations was associated with success in mathematical problem solving, the use of pictorial representations was negatively correlated with success. Use of schematic representations was also significantly correlated with students' spatial visualization ability.

Our research used both quantitative and protocol analysis research methods and includes three studies. In the first study, we examined the quantitative relation between students' cognitive styles and their spatial abilities to identify two types of visualizers. In the second study, we compared how these two types of visualizers interpreted and solved kinematics problems involving graphs of motion. In the third study, we compared the performance of visualizers and verbalizers on kinematics problems involving graphs.

STUDY 1

Method

Participants. The participants were 60 undergraduate psychology students recruited from the psychology participant pool at the University of California, Santa Barbara.

Materials. The materials consisted of a pretest questionnaire, two spatial relations tests, two spatial visualization tests, a verbal ability test, and a Visualizer–Verbalizer Cognitive Style Questionnaire. The pretest questionnaire included questions about students' high school physics background, age, and gender, and asked students to report their Scholastic Aptitude Test (SAT) Quantitative scores.

Students' levels of spatial relations were assessed using the Card Rotation Test and the Cube Comparison Test (Ekstrom, French, & Harman, 1976). *Spatial relations tests* measure the ability to rapidly judge whether two stimuli show the same figure rotated to different positions in space (Ekstrom et al., 1976; Lohman, 1988). The Card Rotation Test consists of 10 items that require participants to view a two-dimensional target figure and judge which of the five alternative test figures are planar rotations of the target figure (as opposed to its mirror image) as quickly and as accurately as possible. The internal reliability of this test is .80. The Cube Comparison Test consists of 21 items. Each item presents two drawings of cubes with letters and numbers printed on their sides. Participants must judge whether the two drawings could show the same cube from different orientations. The internal reliability of this test is .84.

Spatial visualization abilities were assessed by the Paper Folding Test and the Form Board Test (Ekstrom et al., 1976). *Spatial visualization tests* measure processes of apprehending, encoding, and mentally manipulating spatial forms (Lohman, 1988). The Paper Folding Test consists of 10 items. Each item shows successive drawings of two or three folds made in a square sheet of paper. The final drawing shows a hole being punched in the folded paper. The participant is to select one of five drawings to show how the punched sheet would appear when fully opened. Internal reliability of the Paper Folding Test is .84. The Form Board Test consists of 24 items. Each item of the Form Board Test presents five shaded drawings of pieces, some or all of which can be put together to form a figure presented in outline form. The task is to indicate which of the pieces, when fitted together, would form the outline figure. The internal reliability of this test is .81.

Participants' verbal ability was measured by means of the Advanced Vocabulary Test, which measures the "availability and flexibility in the use of multiple meanings of words" (Ekstrom et al., 1976, p. 163). It consists of 18 items, each of which presents five numbered words. The task is to indicate which of these words has the same or nearly the same meaning as the word above the numbered words. The internal reliability of the test is .83.

The students were also presented with a Visualizer–Verbalizer Cognitive Style Questionnaire, which measured their preference to use imagery as opposed to verbal-logical codes when attempting to solve problems.[1] As in previous measures of

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[1] According to most previous psychology and educational studies, students who consistently gave visual solutions to different cognitive tasks were called *visualizers,* and those who gave nonvisual solutions were called *verbalizers.* It might be more appropriate to describe students who preferred nonvisual solutions to the Visualizer–Verbalizer Cognitive Style Questionnaire as "nonvisual" or "verbal-analytical" students rather than verbalizers, but we use the term *verbalizer* throughout this article for consistency with the rest of the literature.

visualizer–verbalizer cognitive style (Lean & Clements, 1981), the cognitive style test included two parts. Part I of the test contained five written mathematics problems that could be solved either by visual or nonvisual methods. These problems were taken either from previous studies (Hegarty & Kozhevnikov, 1999; Lean & Clements, 1981) or composed specifically for this study. A pilot study had determined that these problems were of appropriate difficulty for the students and that students used a variety of strategies to solve them. In Part II, the students were presented with different solutions for the problems included in Part I and were asked which solutions they had used to solve the problems. Students were given the opportunity to state if they used more than one type of solution (e.g., both visual and nonvisual methods), and space was provided for them to describe alternative methods that were not listed. A score of 2 was given for each visual solution and a score of 0 was given for each nonvisual solution, irrespective of whether the answer was right or wrong. A combination of methods was given an intermediate score of 1. The internal reliability of the questionnaire is .80.

Procedure. The tests were administered as part of a larger study, which also included qualitative kinematics problems and mechanical reasoning questionnaires (results reported in Kozhevnikov, 1998). Each participant was seated in an individual booth that contained a desk with partitions on both sides. The participants were tested in small groups of up to 6 students per session. After completing a pretest questionnaire, the participants were administered the Visualizer–Verbalizer Cognitive Style Questionnaire, which took approximately 10 to 15 min to complete (the participants were not placed under any time restriction). Then they completed the Card Rotation Test, the Cube Comparison Test, and the Paper Folding Test, in that order. Each of these tests was preceded by the standard instructions for that test and took 3 min to complete. Then, participants were given the Form Board Test, which took 8 min, followed by the Advanced Vocabulary Test, which took 4 min.

Results

Descriptive statistics. Descriptive statistics are given in Table 1. Male students performed better than female students on the Cube Comparisons test, $t(58) = 2.41$, $p < .05$, but there were no sex differences on any of the other variables measured.

Relation between spatial ability and cognitive style. The correlations among the spatial ability tests, verbal ability, and the Visualizer–Verbalizer Cognitive Style Questionnaire are presented in Table 2. The spatial ability tests correlated highly with each other. Other analyses (reported by Kozhevnikov, Hegarty, & Mayer, 2002) indicated that the four spatial tests used (the Paper Folding Test,

TABLE 1
Distribution Characteristics (Minimal and Maximal Score, Mean, and Standard Deviation) for Each Test of the Cognitive Factors

Test	*Minimum*	*Maximum*	*M*	*SD*
Paper Folding	1.25	10	6.04	2.25
Form Board	2	18	11.02	3.77
Card Rotations	12	80	57.57	18.30
Cube Comparison	0	19	9.29	4.89
Verbal ability	1	11	6.49	2.41
Cognitive style	0	10	5.86	1.95

TABLE 2
Pearson Product–Moment Correlation Coefficients Among Six Measures

Measure	*Cognitive Style*	*Paper Foldin g*	*Form Board*	*Card Rotation*	*Cube Comparison*	*Verbal Ability*
Cognitive style	1.00	0.07	0.13	0.16	0.14	–0.21
Paper Folding		1.00	0.44*	0.46*	0.43*	0.20
Form Board			1.00	0.49*	0.44*	0.15
Card Rotation				1.00	0.34*	0.25
Cube Comparison					1.00	–0.04
Verbal ability						1.00

*Correlation is significant at the $p < .01$ level, two-tailed.

Form Board Test, Card Rotation Test, and Cube Comparison Test) loaded on a single spatial factor.[2] Therefore, we created a composite spatial ability score for each student by averaging his or her standard scores (z score) for the Paper Folding Test, Form Board Test, Card Rotation Test, and Cube Comparison Test.

As can be seen also from Table 2, the cognitive style questionnaire did not correlate with any of the spatial ability tests. These results are consistent with previous research (e.g., Hegarty & Kozhevnikov, 1999; Lean & Clements, 1981; Moses, 1980) showing that no positive correlation exists between visualizer–verbalizer style and spatial ability tests.

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[2] Although there is evidence for dissociation between tests of spatial visualization and spatial relations in the psychometric literature (Carroll, 1993), a number of tests of each type must be included in analysis for these abilities to emerge as separate factors. In this study, we were not concerned with the dissociation between spatial visualization and spatial relations, so we did not include enough tests for spatial visualization and spatial relations to consider them separately.

We further examined this apparent lack of relation as follows. First, we classified students as either visualizers or verbalizers on the basis of a median split on their score on the cognitive style questionnaire. The mean score was 4.56 (*SD* = .31) for verbalizers and was 7.40 (*SD* = 1.13) for visualizers. Second, the participants were classified as low (bottom 25% of the distribution), average (middle 50%), or high spatial ability (top 25%) based on their composite spatial ability scores. Figure 1 presents the percentage of visualizers and verbalizers who scored low, average, and high on spatial ability.

As shown in Figure 1, the majority of verbalizers are of average spatial ability. In contrast to verbalizers, visualizers are not a homogeneous group with respect to their spatial ability. There are two contrasting groups—visualizers of high spatial ability and visualizers of low spatial ability (see Figure 1), with only a small number of visualizers of average spatial ability.[3] A chi-square test revealed that the distribution of low, average, and high spatial visualization ability was significantly different for visualizers and verbalizers, $\chi^2(2, N = 60) = 10.6, p < .01$. A one-way analysis of variance (ANOVA) revealed that there was no significant difference between low-spatial visualizers, high-spatial visualizers, and verbalizers on the SAT Quantitative test, $F(1, 59) = 0.52, p = .59$.

Verbal ability and cognitive style. As shown in Figure 2, the majority of verbalizers and visualizers are of average verbal ability. A chi-square test revealed that the distribution of low, average, and high verbal ability students with respect to their verbal ability was not significantly different for visualizers and verbalizers, $\chi^2(2, N = 60) = 0.12, p = .94$.

Discussion

The results of this quantitative study demonstrate that, in contrast to verbalizers, visualizers are not a homogeneous group with respect to their spatial ability. There appear to be two different groups—visualizers of high spatial ability and visualizers of low spatial ability.

Sixty-nine percent of participants with high spatial ability were visualizers. Preference for visual strategies, however, does not imply a high level of spatial ability. Fifty-nine percent of all students of low spatial ability were also visualizers. These results help to explain the apparent lack of correlation between visualizer–verbalizer cognitive style and spatial ability. Other researchers have not taken into account the fact that the relation between use of visual strategies and spatial ability is not linear. This has led them to the misleading conclusion that verbalizers

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[3] More recent data (Kozhevnikov & Kosslyn, 2000) based on 130 participants support the finding that the distribution of visualizers is not flat but bimodal.

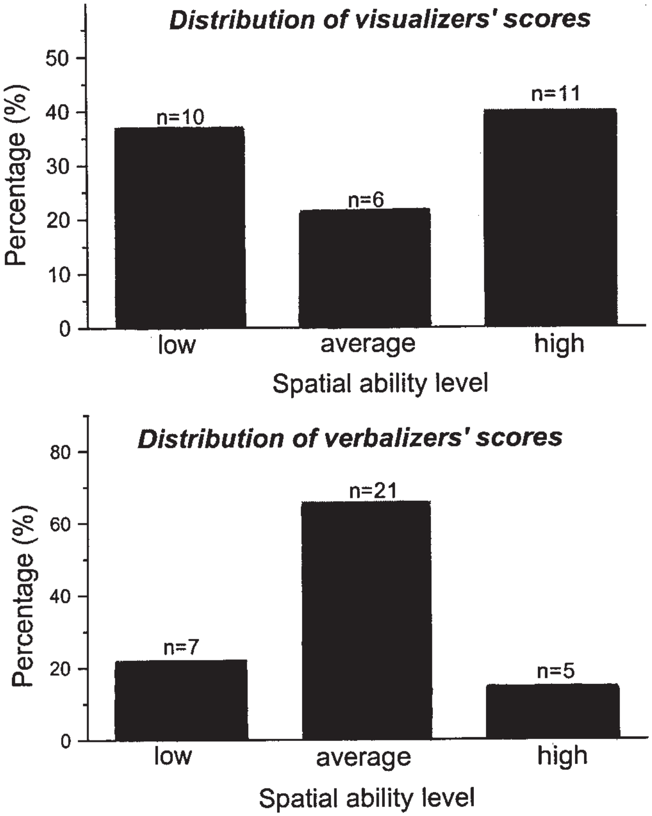

FIGURE 1 Percentage of visualizers and verbalizers who scored low, average, and high on spatial ability tests.

"outperform more visual students on both mathematical and spatial tests" (Lean & Clements, 1981, p. 296).

Hegarty and Kozhevnikov (1999) also identified two types of visualizers that differed in their spatial ability—those who generated schematic spatial representations of word problems and tended to have high spatial ability and those who generated pictorial visual representations of word problems and tended to have low spatial ability. This suggests that there may be qualitative differences in problem-solving strategies between visualizers of low and high spatial ability. A protocol study (Study 2) was designed to examine differences between visual-spatial representations and problem-solving strategies used by visualizers of different spatial ability levels while solving kinematics problems that involved interpreting graphs of motion.

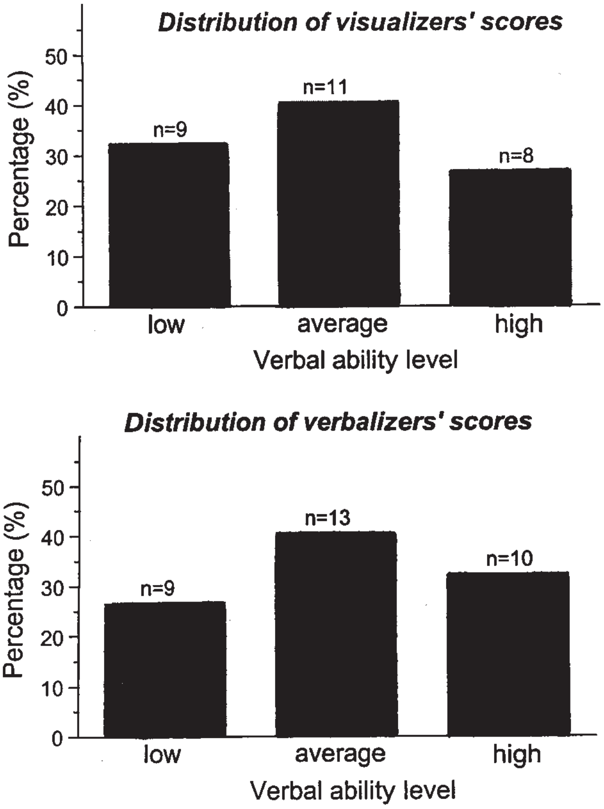

FIGURE 2 Percentage of verbalizers and visualizers who scored low, average, and high on verbal ability test.

STUDY 2

In Study 2, we tested the hypothesis that the differences between low-spatial and high-spatial visualizers reflect the dissociation between visual and spatial imagery, such that visualizers of high and low spatial ability generate different mental images when presented with the same visual input.[4] Specifically, we proposed that low-spatial visualizers are more likely to rely on visual imagery and therefore generate pictorial images, whereas high-spatial visualizers are more likely to rely on spatial imagery and therefore construct schematic images. To test whether the two

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[4] In this context, the term *mental image* is used to refer to representations constructed during perception of immediate sensory input and not only in the absence of visual stimuli (Kosslyn, 1995).

types of visualizers generate different types of mental images of the same visual input, we presented students with kinematics problems that required them to visualize and interpret the motion of an object from a graph.

Educational studies have revealed that students have a consistent set of difficulties with kinematics graphs (e.g., Beichner, 1994; Bell & Janvier, 1981; Kerslake, 1981; McDermott, Rosenquist, & van Zee, 1987; Mokros & Tinker, 1987; Preece, 1983). Even students who can comprehend and construct graphs in a mathematics classroom are often unable to access this knowledge in the interpretation of real data (Leinhardt, Zaslavsky, & Stein, 1990) or apply these skills to kinematics tasks (McDermott et al., 1987). The most frequently reported graph misinterpretation is the *graph-as-picture* misinterpretation in which students expect the graph to be a picture of the phenomenon (e.g., a hump on a graph is perceived as a bicycle rider climbing a hill) regardless of what the graph ordinate shows (i.e., position, velocity, or acceleration). McDermott et al. (1987) reported that students have "trouble separating the shape of the graph from the path of the motion" (p. 509). Mokros and Tinker (1987) found that middle school students can easily interpret graphs that resemble pictures of the phenomena, but they have more trouble when the graphs do not resemble a picture. Beichner (1994) reported that nearly a quarter of all postinstruction students tend to indicate a graph of identical shape when they are asked to translate from one kinematics graph to another (e.g., from a velocity graph to an acceleration graph). The belief that kinematics graphs are like photographs of the situation leads students to the conclusion that the graph's appearance has no reason to change simply because one changes variables on the vertical axis. Similarly, Janvier (1981) found that students had much difficulty on tasks that required them to coordinate a graph with several motion tracks, particularly with the need to consider the graph symbolically and disregard pictorial resemblance with elements on the track. Janvier (1981) suggested that for many students "the vivid memories and/or strong mental images which support their thinking conflict with the more basic abstract aspects of the problem" (p. 119).

In this study, we examined the susceptibility to the graph-as-picture misinterpretation of low-spatial and high-spatial visualizers. If low-spatial visualizers tend to construct pictorial visual images, then we would expect low-spatial visualizers to be more susceptible to the graph-as-picture misconception.

Method

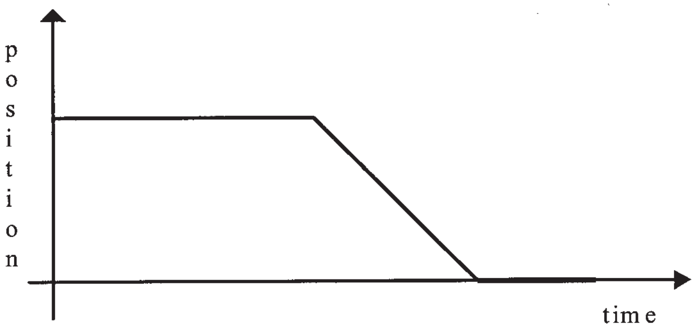
Participants. The participants were 17 undergraduate students at the University of California, Santa Barbara. They were selected from a larger group of 49 participants on the basis of their scores on tests of spatial ability (Paper Folding, Form Board, Cube Comparison, and Card Rotation) and on the Visualizer–Verbalizer Cognitive Style Questionnaire. Each participant's composite standard score on all spatial ability tests was calculated. Students selected for the interviews were all high visualizers (i.e., they showed a strong preference for the visual processing mode on the cognitive style questionnaire), but they differed in their spatial ability level. Eight were high-spatial visualizers (from the top 25% of the distribution for composite spatial ability score; 6 male students and 2 female students), and 9 were low-spatial visualizers (from the bottom 25% of the distribution; 4 male students and 5 female students).

To eliminate any possible effect of physics background on the results of this study, we chose only those students who had not taken any physics courses at the college or high school levels. To control for visualizers' quantitative ability level, we compared the scores of low- and high-spatial visualizers on the SAT Quantitative test. A one-way ANOVA revealed that there was no significant difference between the two groups of visualizers on this test, $F(1, 15) = 1.77$, $p = .20$.

Materials. We used the same pretest questionnaire, Paper Folding Test, Form Board Test, Cube Comparison Test, Card Rotation Test, and Visualizer–Verbalizer Cognitive Style Questionnaire as in Study 1. In addition, the materials included two kinematics problems.

In the first problem, the students were presented with a graph of motion (see Figure 3) and asked to visualize and describe a real situation depicted on the graph. A correct description is that the object at first does not move, then moves at a constant velocity, and later comes to a stop. In the second problem (see Figure 4a), students were asked to draw a graph of velocity versus time on the basis of a graph of position versus time. The correct solution to this problem (velocity vs. time graph) is presented in Figure 4b. The object moves with constant velocity at the first interval (from 0–2), does not move at the second interval (from 2–4), then it moves with constant velocity in the opposite direction (from 4–5) and later comes to a stop.

Procedure. On the first day, the pretest questionnaire, spatial ability tests, and cognitive style questionnaire were administered in group sessions as in Study



Here is a graph of an object's motion. Imagine some real situation depicted on the graph.

FIGURE 3 Example of a graph problem (relating a graph to a real world situation).

1. On another day, the two kinematics graph problems were presented and students were interviewed individually concerning their solution methods. Participants were first told to think aloud while solving the problem, and this was followed by specific questions about whether they considered what happened at the different intervals shown on the graphs.

In addition to recording the participants' verbalizations, we videotaped participants' hand movements and drawings. An instruction to describe a visual-spatial scene verbally requires translation of the message to a verbal representation, a process involving additional processing that could interfere with task performance (Ericsson & Simon, 1980). Hand movements, gestures, and students' drawings collected concurrently with verbal protocols can provide an effective way to study imagery processes more directly (Clement, 1994). Two independent raters analyzed the videotapes. Their agreement regarding the type of imagery (visual or spatial) used when interpreting a graph was .97.

Results

Problem 1: Pictorial interpretations of the graph by low-spatial visualizers. All nine low-spatial visualizers interpreted the graph in Problem 1 as a pictorial illustration of a situation. None of the students succeeded in solving the problem correctly or interpreting the graph as an abstract schematic representation. They expected the shape of the graph to resemble the path of the actual motion.

While visualizing the situation depicted on the graph, these students reported spontaneously generated pictorial images of concrete objects (e.g., a hill, ball, car, elevation, bullet, or table). The following are typical answers of low-spatial visualizers:

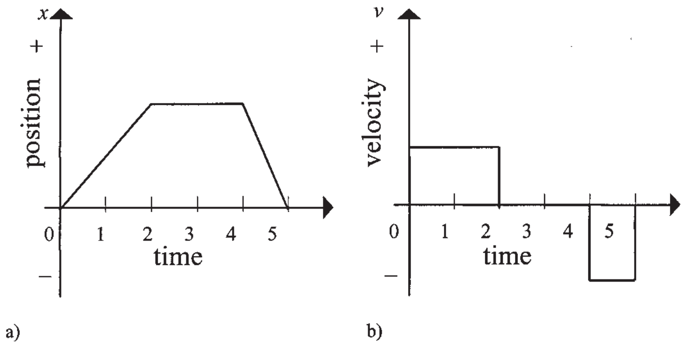


FIGURE 4 Example of a graph problem (relating one type of graph to another): (a) A position versus time graph for which the students must produce a velocity versus time graph and (b) a correct velocity versus time graph.

- “Could it just be elevation or height? And then a hill?”
- “I think it is moving like bullet that is fired and eventually that is going down, not exactly like this curve but it will go down like this …”
- “The car goes constantly and then goes downhill. … It does not change its direction … It goes downhill … This is a hill …”
- “This is a small ball that rolls on the table and then falls down …”

As is apparent from the preceding transcripts, no attempts were made to break the graph down into smaller intervals that had different characteristics of motion. Even when asked by the interviewer to visualize the motion of an object at each interval successively and describe the changes in the object’s velocity from one interval to another, low-spatial visualizers encountered serious difficulties in generating their mental images as directed. For example, the following transcript demonstrates persistence and inflexibility regarding the image of a ball going downhill:

Participant: I imagine a ball goes downhill …

Interviewer: Could you visualize the motion of an object at the first interval? At the second? How does its velocity change from the first interval to the second?

Participant: It’s moving at a constant speed at first, then it’s slowing down and finally comes to a stop … but I can not really imagine this … For example, ball … It is definitely a ball going downhill … or uphill? [shows on the graph how a ball is moving uphill in reverse direction from right to the left side of the graph].

In this transcript, it appears that a concrete pictorial image of a ball rolling downhill suppresses the student’s attempts to concentrate on visualizing the changes in the object’s velocity at each interval. Although the image of a ball rolling downhill is inconsistent with the student’s first statement that the object is slowing down at the second interval, the student does not make any attempts to restructure his image, but only proposes a reverse pattern, that is, “the ball goes uphill.”

Problem 1: Schematic interpretations of the graph by high-spatial visualizers. All high-spatial visualizers gave descriptions of the situation that were primarily schematic and usually did not ascribe concrete features to the object. In many cases, they stated that “something” is moving and did not mention a specific object. The following transcript illustrates typical high-spatial visualizers’ solutions: “At the first interval of time the position is the same: It can not move … it has a constant velocity at the second interval … it is moving constantly at a constant speed …”

Seven high-spatial visualizers were able to interpret the motion correctly. The other high-spatial visualizer incorrectly assumed that at the last interval the object would come back to its original place: "At first, something was not moving, just staying. Then it begins to move … Say it's a car … It was staying some period of time and then, going back with a constant velocity to its original place …"

None of the high-spatial visualizers referred to the graph as a concrete duplication of the motion event. Instead, they broke the graph down into smaller intervals, and their mental transformations were mostly focused on visualizing how the object's velocity changes from interval to interval.

Problem 2: Pictorial interpretations of graphs by low-spatial visualizers. All nine low-spatial participants believed that switching the ordinate variable from position to velocity would not change the appearance of the graph. In attempting to relate one type of graph to another, these students were unable to ignore the shape of the original graph. They failed to separate the shape of a graph line from the path of the motion. As in Problem 1, low-spatial visualizers failed to form an abstract visual representation that reflects changes in objects' velocity. These are typical answers of low-spatial visualizers while solving Problem 2: "It will be similar to the graph of position … the same thing … Yes, I would say this is the same thing …" and "It should be the same … it should not be different …"

One of the low-spatial visualizers applied a mathematical strategy to solve this problem, but was confused by the fact that the graph derived by the mathematical formula was different from the original graph:

> Velocity versus time is always the derivative of the position [mathematically calculates the derivative for each interval and draws the correct graph for velocity vs. time]. Hmm, I am really surprised … I thought I knew calculus … this should be the same graph as position versus time, but mathematically I got a different one …

As the preceding transcript demonstrates, the student was able to solve this problem mathematically, although he gave more credibility to his visual solution. Interestingly, the student broke the graph down into intervals to calculate a derivative at each interval, but he made no attempts to restructure his image and visualize the object's velocity at each interval successively.

Problem 2: Interpretations of graphs by high-spatial visualizers. All eight high-spatial visualizers believed that changing the ordinate variable from position to velocity would change the appearance of the graph. This indicates that in contrast to low-spatial visualizers they interpreted the graph as an abstract representation of a variable over time, which would change if the variable on the ordinate changed.

However, only two of the high-spatial visualizers solved this problem by applying a purely visual-spatial strategy. This is an example of one of their answers:

> It seems it has pretty constant velocity at the first interval … At the second interval the position is the same, it cannot move … It is constantly moving at the third interval … It is just moving at a constant speed …

The other six high-spatial visualizers used analytical strategies. Five of these participants calculated the derivative of position over time and plotted the results to create a velocity-versus-time graph. This might be a more efficient strategy for them than visualizing how the velocity of the object changes because the problem could be solved with less effort by using calculus. However, 3 high-spatial participants did not derive the correct solution because they used the incorrect formula $v = s/t$ instead of $v = \frac{\Delta s}{\Delta t}$. For instance, this is an example of such an answer: "I suppose to draw graph velocity versus time? Velocity equals distance over time? [writes $v = s/t$, then calculates mathematically]. I don't think this is soluble …"

The remaining high-spatial visualizer produced the wrong graph by applying an incorrect formula but noticed that the results were inconsistent with his visual representation:

> Velocity equals distance over time [calculates mathematically and gets the wrong graph]. I don't know, it seems strange … Because I know that from 2 to 3 it should not move, from 1 to 2 it moves with a constant velocity … from 3 to 4 it's the same …

As the previous transcript demonstrates, the student is much more confident in his visual solution compared to his analytical solution ("It seems strange … Because I know that …").

Discussion

Study 2 indicates that the two types of visualizers identified in Study 1 (the iconic type, or visualizers with low spatial ability, and the spatial type, or visualizers with high spatial ability) interpret motion graphs differently. Iconic types generate pictorial concrete images and interpret graphs as showing a concrete situation that would match the shape of the graph. Spatial types generate mostly schematic images and interpret graphs as an abstract representation.

Another important difference between the iconic and spatial types is their flexibility in using images. Iconic types tend to generate images by activating their visual memories, that is, by looking for a pattern with a closest match to the stimulus input (e.g., the shape of a hill or path of downward motion). Their visual (iconic) image is encoded as a single unit that is not easily transformable. In contrast, spatial types visualize overall motion by breaking the graph down into intervals and visualizing changes in the object's velocity from one interval to another successively.

Analysis of low- and high-spatial visualizers' responses to Problem 2 showed that the choice of verbal-analytical versus imagery strategies may depend not only on an individual's preference to process information but also on the nature of the task and a person's prior knowledge about a topic. Some visualizers from both the low- and high-spatial groups were able to solve this problem successfully by analytical methods, presumably because this problem could be solved with less effort based on their knowledge of calculus. However, when the analytical solution was inconsistent with their visual representation, both low- and high-spatial visualizers gave more credibility to the visual one.

STUDY 3

In Study 2 we found that low- and high-spatial visualizers interpreted kinematics graphs differently and we proposed that this difference reflects the dissociation between visual and spatial imagery. Could any factors other than the dissociation between visual and spatial imagery provide an alternative explanation for the previous results?

In Study 2 we controlled participants' background in physics by choosing only those visualizers who had not taken physics courses either at high school or college level. Therefore, prior physics experience could not be an alternative explanation for the results obtained in Study 2. Also, it seemed unlikely that students' experience with graphs and calculus or students' general quantitative ability could account for the differences between iconic and spatial types. First, the low- and high-spatial visualizers interviewed in Study 2 did not differ in their SAT Quantitative scores. Second, there is evidence from educational research that failure to interpret kinematics graphs is not necessarily related to students' mathematical background and "there must be other factors, distinct from mathematical background, that are responsible" (McDermott et al., 1987, p. 503). Frequently students who are skillful in plotting graphs and computing slopes cannot apply what they have learned about graphs from their study of mathematics to real data (Leinhardt et al., 1990; McDermott et al., 1987).

However, there is still a possibility that the differences between the low- and high-spatial visualizers in interpreting kinematics graphs found in Study 2 were due to differences in general intelligence level or use of metacogitive strategies rather than visual versus spatial imagery. That is, students of high spatial ability might also have higher general intelligence or more metacognitive awareness of their strategies in comparison to low-spatial students. Thus, they might be able to carry out more complex cognitive activities as well as to choose the best strategy to solve any kind of problem.

To exclude this possibility, we designed Study 3 in which we included not only visualizers of low and high spatial ability, but also verbalizers of low and high spatial ability. If the processing differences observed in Study 2 were unique for visualizers (and thus could be attributed to the differences in visual vs. spatial imagery), no differences should be observed between verbalizers of high and low spatial ability. Alternatively, if we found that high- and low- spatial verbalizers differ in their processes of graph interpretations exactly in the same way as spatial and iconic types, then the differences between spatial and iconic types found in Study 2 could not be attributed solely to individual differences in visual versus spatial imagery but also to other factors (general intelligence, the use of metacognitive strategies, etc.).

Method

Participants. The participants were 25 undergraduate students at Harvard University who had not taken any physics courses either at the high school or college level.

Materials. We used the same spatial ability tests and Visualizer–Verbalizer Cognitive Style Questionnaire as in Studies 1 and 2. In addition, the materials included a questionnaire consisting of three kinematics problems (see Appendix). In all three problems, the participants were presented with a graph of motion and asked to visualize and describe a real situation depicted on the graph without applying any mathematical strategies. We asked students not to use any mathematical strategy to eliminate any possibility of an effect of mathematical background on the results of this study.

The first problem of the kinematics questionnaire was identical to Problem 1 presented to students in Study 2. In the second problem, a graph of velocity versus time was presented to students. A correct description is that the object at first moves at a constant velocity, then does not move, then moves at a constant velocity in the opposite direction. The third problem presented students with a graph of acceleration versus time. A correct description is that the object at first moves at a constant velocity (acceleration is zero), then it accelerates with a steady rate, and later it accelerates with a higher steady rate than at the second interval.

Procedure. Students were tested individually. First, the spatial ability tests and cognitive style questionnaire were administered. Then, the kinematics questionnaire was presented and students were asked to visualize and then write down a story that described a real situation depicted on each of the graphs.

Results

First, we classified students as either visualizers or verbalizers on the basis of a median split on their score on the cognitive style questionnaire. The mean score was 4.52 (*SD* = 0.28) for verbalizers and 7.60 (*SD* = 0.78) for visualizers. Second, each participant's composite standard score on all spatial ability tests was calculated, and on the basis of a median split, each participant was classified as either low or high spatial. Thus, every student was assigned to one of the four groups: six visualizers of low spatial ability (four male students and two female students), seven visualizers of high spatial ability (four male students and three female students), six verbalizers of low spatial ability (four female students and two male students), and six verbalizers of high spatial ability (five male students and one female student).

Students' answers on the kinematics questionnaire were categorized according to the strategies they used to solve the problems. Three categories of strategies were identified: (a) *pictorial interpretation* in which a student interpreted the graph literally as a pictorial illustration of a situation; (b) *irrelevant interpretation* in which a student interpreted the graph incorrectly, visualizing an irrelevant (but not literal) real-world situation to that depicted on the graph; and (c) *schematic interpretation* in which a student referred to the graph as an abstract schematic representation and gave a generally correct description of the object's motion. For each participant, we calculated the number of his or her responses falling into each of the aforementioned categories (pictorial, irrelevant, or schematic) on all three kinematics problems.

For instance, examples of students' responses to Problem 1 that were categorized as pictorial are "a ball rolled along a level surface then down a ramp onto another level surface," or "an airplane is flying at the same height, and then gradually landing." Examples of students' responses that were categorized as irrelevant interpretations are "a little girl pushed a cart along a street, and then leaves it there," or "a toy plane is gliding into the air," or "an object is moving constantly in a circle." Examples of students' responses that were categorized as schematic are "object is still and moves at the second interval and stops again," or "I am standing at the hall near my office talking with someone, then I walk back to my office and sit down."

Two independent raters analyzed the students' answers on the kinematics questionnaire, and the interrater reliability was .96. Discrepancies were decided by consensus of the two raters.

We classified each participant's response to each question as falling into one of the previous categories (pictorial, irrelevant, or schematic). The results for Problem 1 are presented in Figure 5a and 5b for visualizers and verbalizers, respectively. As can be seen from Figure 5a, all low-spatial visualizers gave exclusively pictorial graph-as-picture interpretations to this problem, and all high-spatial visualizers interpreted the graph as an abstract schematic representation. In contrast, as can be seen from Figure 5b, verbalizers of high spatial ability gave the same number of pictorial answers as verbalizers of low spatial ability. In contrast to visualizers, they gave responses falling into the category of irrelevant answers. That is, only verbalizers visualized irrelevant (but not literal) situations to the information depicted on the graph. The pattern of responses for Problems 2 and 3 are not shown because they were very similar. The statistical analysis, following, was based on the data for all three problems.

To analyze the results statistically, we conducted a two-way ANOVA with cognitive style (visualizer, verbalizer) and spatial ability level (low, high) as the factors and the number of schematic responses given by a student to the three kinematics questions as a dependent measure. The analysis revealed a significant

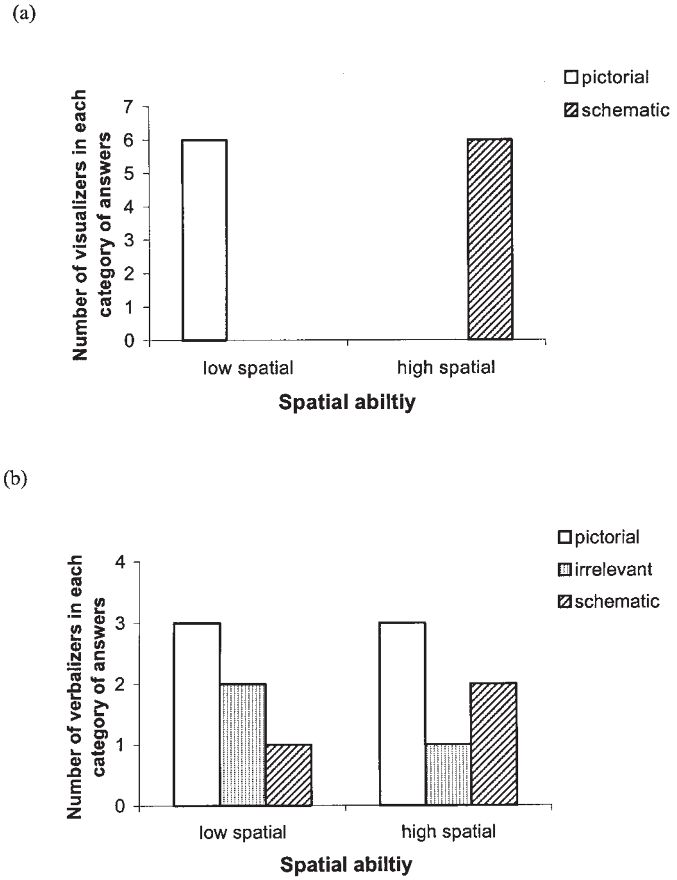


FIGURE 5 The number of low- and high-spatial visualizers (Figure 5a) and verbalizers (Figure 5b) who gave pictorial, irrelevant, and schematic interpretations for Problem 1 in Study 3.

effect of spatial ability, $F(1, 20) = 35.09$, $p < .001$, and a nonsignificant effect of cognitive style, $F(1, 20) = 0.29$, $p = .59$. The interaction of spatial ability with cognitive style was significant, $F(1, 20) = 14.21$, $p < .001$, such that the number of schematic answers given by high-spatial verbalizers ($M = 1.66$; $SD = 1.21$) was not significantly different from the number of schematic answers given by low-spatial verbalizers ($M = 1.00$, $SD = 1.00$). This is in contrast to high-spatial visualizers who gave only schematic answers for all kinematics problems ($M = 3.00$, $SD = 0.00$) and low-spatial visualizers who did not give schematic answers at all ($M = 0.00$, $SD = 0.00$).

Similarly, we conducted a two-way ANOVA with cognitive style and spatial ability level as the factors, and the number of pictorial responses given by a student to the 3 kinematics questions as a dependent measure. The analysis revealed a significant effect of spatial ability, $F(1, 20) = 57.78$, $p < .001$, and a nonsignificant effect of cognitive style, $F(1, 20) = 0.27$, $p = .61$. The interaction of spatial ability with cognitive style was significant, $F(1, 20) = 32.29$, $p < .001$: Low-spatial verbalizers ($M = 1.60$, $SD = 1.00$) did not differ significantly in the number of pictorial answers from high-spatial verbalizers ($M = 1.16$, $SD = 0.55$). This is in contrast to low-spatial visualizers who gave only pictorial answers to all kinematics problems ($M = 3.00$, $SD = 0.00$), and high-spatial visualizers who did not give any pictorial answers at all ($M = 0.00$, $SD = 0.00$).

Discussion

The results of Study 3 provide evidence that the distinction between low-spatial visualizers and high-spatial visualizers is due to differences in visual versus spatial imagery and not due to other factors such as mathematical background, general intelligence, or the use of metacognitive strategies. Verbalizers in Study 3 are matched with visualizers on all parameters except their degree of visuality: They had similar levels of spatial ability, no prior physics background, and were not allowed to use any mathematical strategies. The results show that verbalizers of both low and high spatial ability did not have any clearly marked preference to use visual or spatial imagery; some of them interpreted graphs pictorially and some of them interpreted graphs schematically. In contrast, low-spatial visualizers showed a consistent preference to use visual-pictorial imagery and high-spatial visualizers showed a consistent preference to use spatial-schematic imagery.

The relation between visualizers' level of understanding of the graphical problems and their spatial ability level cannot be interpreted as a simple correlation. That is, we did not find a gradual increase in correct schematic answers with an increase of visualizers' level of spatial ability. All visualizers from the low-spatial group consistently perceived all three graphical problems as pictures independently of the variation in their level of spatial ability. Similarly, all high-spatial visualizers, independently of their specific score on spatial ability tests, consistently perceived all three graphical problems as abstract spatial representations.

Why might some of the high-spatial verbalizers interpret a graph literally? There are many different strategies used to solve psychometric spatial tests (e.g., Carpenter & Just, 1986) and sometimes students gifted in verbal-analytical ability can solve spatial tests effectively by nonspatial strategies. It is possible that when these students are presented with a spatial task, which cannot be solved by any verbal-analytical strategy (or as in Study 3, are asked explicitly not to use any verbal-analytical strategies), they are not able to perform the task.

GENERAL DISCUSSION

Recent research in both working memory and cognitive neuroscience has suggested a dissociation between pictorial imagery and spatial imagery. Our research suggests that the visualizer–verbalizer cognitive style dimension needs to be revised to include two types of visualizers—those whose imagery is primarily pictorial and those whose imagery is primarily spatial. First, Study 1 indicated that visualizers were not a homogenous group with respect to their spatial ability. Some visualizers have high spatial ability and others have low spatial ability. Second, Studies 2 and 3 indicated that these two types of visualizers interpreted kinematics graphs very differently. High-spatial visualizers interpreted graphs correctly as abstract representations, whereas low-spatial visualizers interpreted graphs as pictures. We therefore characterized high-spatial visualizers (spatial type) as those who engage the spatial-schematic imagery system in solving problems, and low-spatial visualizers (iconic type) as those who engage the visual-pictorial imagery system in solving problems.

These results help clarify why previous studies (e.g., Krutetskii, 1976; Lean & Clements, 1981; Presmeg, 1986a, 1986b, 1992) found no relation between use of visual-spatial representations and problem solving. The results are also consistent with research by Hegarty and Kozhevnikov (1999) showing that high-spatial visualizers tend to construct schematic spatial representations, whereas low-spatial visualizers tend to construct pictorial representations of the information presented in an arithmetic word problem. Our study shows that this characterization is also true of how adult problem solvers comprehend visual-spatial representations in the domain of kinematics.

How might we account for the differences between the two types of visualizers in terms of current theories of working memory or neuroscience findings? Logie (1995) argued that there is dissociation between visual and spatial processes in visual-spatial working memory (see also Baddeley & Lieberman, 1980). One possibility is that visualizers can be divided into those who prefer to process information via abstract spatial images versus those who prefer to process information via concrete pictorial images. The data presented in this study support this possibility. The results of this research show that visualizers of low-spatial ability showed a consistent preference to use visual-pictorial imagery and visualizers of high-spatial ability showed a consistent preference to use spatial-schematic imagery while interpreting graph problems.

Another possibility is that the difference between visual and spatial types is in the operation of the central executive, that is, the component of working memory that controls attention and coordinates the activities of verbal and visual-spatial working memory (Baddeley, 1992). The central executive might be involved in allocating either visual or spatial resources to solving a given problem. Another role of the central executive is in suppressing information that is irrelevant to the current task (Engle, Kane, & Tuholski, 1999; O'Reilly, Braver, & Cohen, 1999). A difference between visualizers of the spatial and iconic types might be that for iconic types, the central executive is unable to suppress pictorial details irrelevant to solving the problem. However, the results of Study 3 do not support this possibility. If all the differences between iconic and spatial types were in their central executive processes, the differences between low- and high-spatial verbalizers would be similar to the differences between iconic and spatial types. However, no such differences were found between verbalizers of low and high spatial ability.

From a neuroscience perspective, there is evidence that although there are separate spatial and visual imagery subsystems, the information from both systems is integrated in a topographically mapped area of the brain, called "the visual buffer" (Kosslyn, 1994, 1995). The visual buffer is the place where the image itself is generated. In this buffer, we can generate an image that both involves a number of concrete individual objects (input from the visual imagery subsystem) and represents their locations in space (input from the spatial imagery subsystems). The visual buffer, however, has limited capacity. It is possible that in a complex task, visual and spatial aspects of an image compete for this limited capacity. In other words, keeping all the details of an image while manipulating the image spatially may overload the visual buffer capacity. Visualizers of the spatial type might tend not to maintain a lot of pictorial detail in their images to develop efficient spatial transformations, thus preventing large and unnecessary demands on the visual buffer. Similarly, visualizers of the iconic type might tend to generate pictorial images of high vividness and detail, which might prevent efficient spatial transformations. This might explain why visualizers of the iconic type have poor performance on spatial ability tests, especially tests of spatial visualization, which involve complex transformations of visual images.

Further research involving neuroimaging techniques is needed to examine the preceding hypothesis about the existence of two types of visualizers. If two different types of visualizers exist, different patterns of brain activation should be identified during their performance on visual-spatial problem-solving tasks. Spatial types should show more activation in the dorsal system while solving these tasks, whereas iconic types should show more activation in the ventral pathway.

The problem-solving task studied in this article was one that required students to interpret a visual-spatial representation as abstract so that pictorial representations hindered success in this task. Although pictorial images may hinder interpreting graph problems or performance on other tasks that require spatial transformations, they may be useful for other cognitive processes. For example, pictorial images have been found to have mnemonic advantages (e.g., Paivio, 1971; Presmeg, 1986a, 1986b, 1992) and to be highly correlated with visual memory measures (e.g., Marks, 1973, 1983). Luria's (1982) case study, "The Mind of Mnemonist," describes an extraordinary mnemonist who was able to generate images of exceptional vividness and concreteness (his main mnemonic technique was to put different items to be memorized in places alongside Moscow's streets he knew well and then take an imaginary walk along these landmarks). However Luria (1982, p. 388) reported that these vivid images were not helpful for the mnemonist in dealing with other types of tasks.

> Thinking of images was fraught with even greater danger. Inasmuch as S's images were particularly vivid and stable and recurred thousand of times, they soon became the dominant element in his awareness uncontrollably coming to the surface whenever he touched upon something that was linked to them even in the most general way.

Similarly, Aspinwall, Shaw, and Presmeg (1997) found that vivid concrete images may become uncontrollable while solving mathematical problems, "and the power of these images may do more to obscure than to explain" (p. 301). Therefore, it is plausible that iconic types are especially good in generating vivid pictorial images that may help them succeed in other cognitive tasks such as memory tasks, drawing, or painting, but hinder success on other tasks. Indeed, there is research showing that whereas engineers, physicists, and mathematicians have high levels of spatial ability, visual artists have much lower than average spatial ability but high scores on visual memory tests (Casey, Winner, Brabeck, & Sullivan, 1990).

Recent results of Kozhevnikov and Kosslyn (2000) give some support to the preceding hypothesis. They found that visualizers of high spatial ability were more successful than visualizers of low spatial ability on spatial imagery tasks that require image inspection and image transformation. In contrast, visualizers of low spatial ability were significantly more successful than visualizers of high spatial ability on visual imagery tasks relying on image resolution and image interpretation abilities. This reverse pattern for visualizers of low spatial ability provides corroborating evidence for a dissociation in individual differences in visual versus spatial imagery.

Our study was focused more on the relation between visualizer–verbalizer cognitive style and spatial ability rather than its relation to verbal abilities. The only verbal test given to students in this study was a vocabulary test. Further research is needed to examine more thoroughly the relationship between students' preferences to process information via language symbols and their ability to process abstract verbal information.

Implications for Education

Numerous studies have been carried out to understand the role of visual-spatial representations in learning (e.g., Larkin & Simon, 1987; Mandl & Levin, 1989; Plass et al., 1998; Winn, Li, & Schill, 1991). However, most studies investigating the effect of mental imagery on learning have treated imagery as a general and undifferentiated skill. Our research provides evidence that imagery might rely on different types of representations, and different people might have a strong preference for one type or another.

It is remarkable that a significant group of college students, visualizers of the iconic type, had difficulty interpreting graphs as abstract schematic representations and instead interpreted them as pictorial representations. These students will clearly have difficulty solving science and mathematics problems that involve graphs. How might we best teach these students to represent and solve science and mathematical problems? One possible approach is to teach iconic visualizers to represent and solve science and mathematics problems by using verbal-analytical strategies rather than spatial strategies that might be dependent on spatial working memory resources that they do not have. For example, Witkin, Moore, Goodenough, and Cox (1977) found that it was possible to induce field-dependent learners to use analytical techniques by providing specific directions as to how to proceed. *Field-dependent learners* are described as those who tend to accept the visual presentation as it is presented without analyzing or restructuring the visual components and are therefore very similar to the iconic type identified in this study.

Another possible way of teaching iconic types is to give them explicit instruction on how visual, schematic, and verbal representations relate to each other. For example, interactive computer simulations (e.g., White, 1993) that include verbal representations, schematic graphics, and iconic representations, might be effective for these students. Having all these types of representations available and demonstrating how each of them translates into the others might help students of the iconic type translate concrete pictorial representations into a more schematic spatial form. Furthermore, instruction could be aimed explicitly at teaching students to construct and interpret different types of representations and to translate between different representations of the same phenomenon. For instance, microcomputer-based learning (MBL)[5] technologies were designed specifically to pair physical events with their graphical representations in real time and thus provide students with the possibility of exploring connections between them. Students immediately see the graph made by a moving object with the results appearing instantly on the graph with each move made by the object. Researchers found a significant change in students' ability to interpret kinematics graphs and overcome graph-as-picture misconceptions after MBL intervention (e.g., Linn, Layman, & Nachmias, 1987; Mokros & Tinker, 1987; Thornton & Sokoloff, 1990).

However, we must note that although visual-pictorial images do not contribute to mathematics problem solving, this type of imagery has been found to be very useful for enhancing memory (Presmeg, 1986a), as well as in social studies classes (Danzer & Newman, 1992). Such images provide a quick means of recall and can help to illuminate the subject. Thus, the utility of a particular type of imagery depends in part on the task; it is not likely that any type of imagery is necessarily or universally superior to any other type.

In summary, the results highlight the need for research that characterizes which type of imagery facilitates learning and reasoning in specific domains. We propose that not only can instructional strategies be designed to teach students to construct and interpret different types of visual-spatial representations, but different students can be taught strategies for translating material to representations that are compatible with their own preferred cognitive style.

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[5] MBLs involve a sensor that detects the distance between the sensor and the nearest object, usually a student. The sensor is attached to a computer, which creates a graph of the student's distance from the sensor over a period of time. The graph is displayed in real time as the motion progresses.

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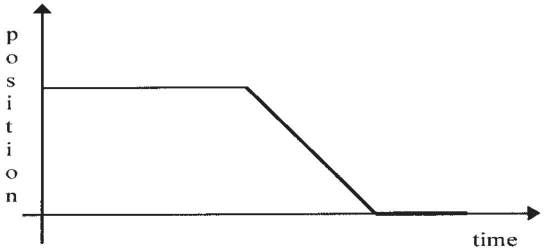
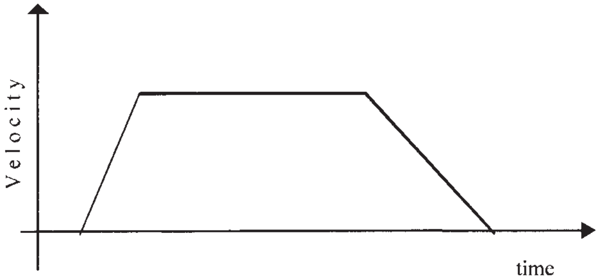
APPENDIX
Kinematics Questionnaire

Please look at the graphs below. For each graph, visualize a real situation depicted on the graph *without* applying any mathematical strategies. Please write a story about what happened with an object in each of these graphs.

Problem 1:



Problem 2:



Problem 3: