Object encoding, goal similarity, and analogical transfer

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Although the importance of goal similarity and similarity of encoding are well known in analogical transfer literature, there has never been a study in which one of these factors was maintained constant and the other manipulated. This point was studied in our first experiment. The results show that the interaction between the two factors is not significant. However, the width of the credibility intervals suggests that it is difficult to conclude that there is either a presence or an absence of an interaction. The second experiment concerned more directly the impact of the encoding process on recognition of analogy. The results show that analogical transfer can be highly dependent on the way subjects interpret problems and that the encoding process can be influenced by the visual characteristics of the problems. These results can be related to a recent body of research on the importance of interpretive effects on analogy, as well as to the categorization literature.

Similarities of problem situations and of goals have been recognized as two major determinants in analogy. When both are high, spontaneous transfer can be observed (Gentner, 1983; Gick & Holyoak, 1983; Holyoak, 1985; Novick, 1988; Ross, 1984, 1987). However, there is no information about any possible interaction between these two factors. This may be due to the fact that experiments have been planned in such a way as to study the effect of one or the other factor separately. Here, our aim was to study these two factors together and in isolation, in order to verify whether both are necessary conditions for observing transfer.

For similarity of problem situations, the kind of situations that have been used are those in which subjects are asked to solve or read one or more source problems and are then asked to solve further problems whose solution requires transfer from the source problems solved earlier (Gentner, 1983; Gick & Holyoak, 1983; Ross, 1987). This research has brought out the importance of surface traits in the recognition of analogy (Holyoak & Koh, 1987; Ross, 1984). Surface traits are salient and unrelated to structure, but they influence analogical transfer. Results have shown that the transfer of solution paths from source to target problems is facilitated when surface similarities are increased or are relatively constant from one problem to the next within the same domain (Gentner & Toupin, 1986; Gick & Holyoak, 1983). For instance, in one of Gick and Holyoak's (1983) studies, the source prob-

lem was Maier's (1930) two-strings problem. Two strings are fixed far away enough from each other that it is difficult to reach one when holding the other. In order to solve the problem, subjects have to use a pincer that they attach to one of the strings, making a pendulum. In this way, they can set it in motion and catch it on an upswing while holding the other. Authors have shown that when the strings are replaced by two ribbons and the pincer by a pair of scissors (the birthday problem), transfer is very high between the two problems. The elements strings-ribbons, as well as pincer-pair-of-scissors, are surface traits that are unrelated to the structure of the problems, because they do not influence the manner in which the problem has to be solved. These objects are similar enough to facilitate recognition of analogy.

Nonetheless, the aim of a very recent body of research has been to study the impact of representations on transfer performance. In fact, as regards similarity of problem situations, a distinction needs to be made between the similarity of the objects in the situation and the similarity of the ways in which the objects are encoded. Kotovsky and Fallside (1989) have insisted on the idea that it is not the physical appearance of the objects that matters for the recognition of analogy but the internal representation of the stimuli. Bassok and Olseth (1995), as well as Bassok, Wu, and Olseth (1995), have shown how object attributes affect the way in which people represent problems and how these *interpretative effects* can affect transfer. This research has shed some light on the effect of the encoding process on the recognition of analogy, and as was mentioned by Sander and Richard (1997), it also has much in common with the categorization literature. One important aspect of the encoding process is the effect of context. It is a long-standing result that an ambiguous stimulus is perceived as belonging to the same category as the other stimuli in the context. For instance, when the letter B is briefly

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presented in a tachistoscope with a slight space between the vertical bar and the rest of the letter, it is seen either as the number 13 or as the letter B, depending on whether it is placed within a series of numbers or a series of letters (Bruner & Minturn, 1955). Schyns and Rodet (1997) have shown that categorization experience does influence the perception of subsequent category exemplars: Different unsupervised preexposures to some objects can change the features that are later used to analyze new test items. In other words, the context in which one stimulus is perceived has a great effect on the way the stimulus is encoded. As we will show later, the prior context has a great effect on the encoding process and on the recognition of analogy.

It should be noted that the aforementioned studies are limited in that the effect of similarity between source and target problems has always been studied through different problem situations. However, as the situation changes, its interpretation may also change, so it is difficult to sort out what is due to similarity of objects from what is due to interpretive effects. The exception is the Kotovsky and Fallside (1989) study, which used the same situation with two cover stories. Using isomorphs of the tower of Hanoi problem, Kotovsky and Fallside showed that transfer between two problems presenting the same stimuli (circles of three differing sizes) was not observed when the contexts of the problems were different: Subjects were told either that size could be varied (from large to small) or that the distance could be changed (from close to far). In these two situations, the stimuli were identical, so the similarity of surface traits was maintained constant. However, the cover story changed, so the encoding of the stimuli was different. This made it possible to study the effect of the encoding process on recognition of analogy while the surface traits were unchanged.

On the other hand, the effect of goal similarity on analogical transfer has almost always been studied through similarity of structure—that is, similarity of the means that permit attaining a goal (i.e., similarity of procedure)—rather than through similarity of the goal situation itself. For instance, Brown, Kane, and Echols (1986) invited subjects to read a source problem with its solution: the genie problem (Holyoak, Junn, & Billman, 1984), in which a genie who lives in a bottle rolls up his flying carpet in order to move his treasures into another bottle. After reading about this, subjects were asked to solve a structurally similar problem: An Easter rabbit needs to transport its eggs from one side of a river to the other. In order to do this, it has to roll up a carpet and roll the eggs through the carpet tube. An analysis of the results showed that the rate of successful transfer was higher for subjects who, in a recall task, emphasized goal structure and problem constraints. What we would like to underline is that what was studied in this research was more the means (goal structure) or procedure that allowed the goal to be reached than the goal state itself. The same is true for the studies of Catrambone (1994, 1995), Catrambone and Holyoak (1990), and Ross (1987, 1989), which focused more on

procedure than on the final goal. In these studies, the negative role of goal dissimilarity was studied through a dissimilarity of procedures.

As far as we know, similarity of goal has been studied directly, in problems in which the structure remained unchanged, by Gentner, Rattermann, and Forbus (1993) and by Holyoak and Koh (1987). The latter (Experiment 2) invited subjects to read two problems with surface features similar to those of the tumor problem. However, in one problem the goal remained unchanged (a cell had to be destroyed), whereas in the other it was changed (two cells had to be merged). The authors showed that when final goal situations were similar, analogical transfer increased.

We suggest that, in order to study the effect of encoding process similarity versus surface trait similarity as well as similarity of structure versus similarity of goal situation, we need to design a material that makes it possible to (1) use stimuli that can be encoded in two different ways and that are compatible with different contexts capable of eliciting one or the other encoding (in this way, the encoding context will be manipulated, whereas the appearance of the stimuli remains unchanged) and (2) change the appearance of the goal without changing the procedure (i.e., the structural features of the problem).

A situation fulfilling the constraints mentioned above is provided by problems of the passalong type. The passalong test is a test of practical intelligence developed by Alexander in 1950. The test apparatus is a kind of rickshaw game and consists of nine problems (Appendix A) composed of blue figures (located at the top of the playing board) and red figures (located at the bottom of the board). The nine problems differ as to the number, shape, size, and color of the figures. The goal for all of the problems is to move the blue figures around to the top of the board and the red ones around to the bottom and to arrange the figures in the same pattern as in the initial state. Subjects are given the final goal in the form of a graphic representation.

The problems are of increasing difficulty because solving the problems requires reaching intermediate states (subgoals) that are more and more difficult to attain.

In order to solve the first set of three problems (1, 2, and 3), all of the figures should be moved in the same direction, either clockwise or counterclockwise, directly toward their final position (Beuscart-Zéphir & Beuscart, 1989; Beuscart-Zéphir & Duhamel, 1990). There is no dead-end situation in these first problems; the turning procedure permits attaining the goal easily.

The intermediate problems (4, 5, and 6) present an added difficulty: In the course of solving the problem, some of the figures must be momentarily moved away from their final positions. A typical case can be seen in Appendix B: One of the small figures must be slid up to the top in order to make room for moving the rectangle up one space. Piaget discussed the difficulty of such situations at some length (Piaget, Cambon, & Cuaz, 1977). Richard and Zamani (1996) attributed this difficulty to

Figure 1. Initial and final states of Problems 6, 7, and 8 of the passalong test.

the fact that moving the small figure up is perceived as incompatible with the goal of moving all of the small figures to the bottom of the board. Our interpretation is that this is a typical distance-to-goal problem and calls for detour behavior.

Problems 7, 8, and 9 present a further difficulty, which is of interest to us here: Solving them requires recognizing an analogy. These problems are composed of the same figures in different arrangements (Figure 1). Solving Problem 7 requires drawing on the analogy with Problem 6—that is, that the upright rectangles in Problem 7 are analogous to the large square in Problem 6. Once this is recognized, the procedure for solving Problem 6 can be applied directly to Problem 7, as long as the rectangles are kept together (Appendix C).

Like Problem 7, Problem 8 contains two upright rectangles; however, they are not adjacent. To solve Problem 8, the rectangles must first stand one next to the other, as in the initial state of Problem 7. This done, the procedure used for Problems 6 and 7 can be used for solving Problem 8 (Appendix C). Thus, in order to get closer to the final goal in Problem 8, subjects must first satisfy a *subgoal that consists of moving the rectangles next to each other*. These rectangles must be separated again in the goal state. The structural relationship between Problems 6, 7, and 8 can be expressed like this: Problem 6 contains a

square that, in Problem 7, is replaced by two adjacent rectangles that are separated from each other in Problem 8.

The difficulty of Problem 8 is well known (Chatillon, Beziaud, Fundoni, Grellet, & Thomas, 1980). In an exploratory experiment, we observed that although transfer is easily made from Problem 6 to Problem 7 (.85 of the subjects), it is difficult between Problems 7 and 8 (about .20 of the subjects). This difficulty might be attributed to differences in surface features of the goal states—the fact that the rectangles in Problem 7's goal state are in an adjacent position, whereas in the goal state of Problem 8, they are separated (Figure 1).

Nevertheless, the surface features of the goal state in Problem 8 can be altered without changing the structural similarity between Problems 7 and 8. This can be done by making the goal states of Problems 7 and 8 identical—that is, presenting the rectangles in an adjacent position in the final state of Problem 8. Similarity of goals may then make recognition of the analogy easier. Being able to alter Problem 8's goal state without changing structural similarity makes this problem quite suitable for the study of the effect of goal similarity on analogical transfer.

As we observed casually in an exploratory experiment, another reason why subjects do not draw the analogy between Problems 7 and 8 is that the two adjacent rectangles in Problem 7 tend to be interpreted as *two halves* of

the square encountered in Problem 6. Later, when they are asked to solve Problem 8, they interpret the two non-adjacent rectangles in this problem as rectangles in their own right (and not as two halves of something else). In other words, the *actual* difference in the initial states between Problems 6 and 7 is a difference in objects (a square vs. two rectangles). The *actual* difference in initial states between Problems 7 and 8 is a difference in arrangement, not in objects (both contain rectangles, adjacent and non-adjacent, respectively). Despite the actual differences, subjects perceive Problem 7 as containing a *square* whose properties include being split in two, and they perceive Problem 8 as containing two rectangles *that are not linked to each other in any way*. Because the encoding of the rectangles is different, these objects are in fact cognitively different. What makes the 6, 7, 8 series interesting is that because of this cognitive difference, the critical encoding of the rectangles in Problem 7 can be manipulated according to whether or not Problem 6 is solved first. In this way, it is possible to study the importance of the encoding process on the recognition of analogy between Problems 7 and 8.

Thus, the passalong test makes it possible to keep the structural constraints of the problems constant while manipulating factors believed to influence analogical transfer. We propose to do this in the first part of the experiment by (1) designing two different encoding situations, in the first of which, the critical elements (the upright rectangles) are encoded in the same way in the learning problem and in the transfer problem (Problems 7 and 8, respectively), and in the second, they are encoded differently (Problems 6, 7, and 8 are solved in sequence), and (2) designing two different goal similarity situations (Problem 8 presented with or without the modified goal state; i.e., with separate or adjacent rectangles).

This design allows assessing both the individual and the combined effects of encoding similarity and goal similarity. As far as we know, there is no study in which all of these assessments have been made individually. Thus, we can make two general predictions: (1) Transfer will systematically be observed in the presence of at least one of these two factors (goal similarity or encoding similarity), and (2) there will be a combined negative effect in the absence of both factors—that is, that there will be no transfer in the different-encoding and different goal states conditions. We do not have any specific prediction concerning a possible interaction between these two factors.

Finally, we propose creating two control situations in which success in solving Problem 8 cannot be attributed to analogical transfer: solving a single problem, Problem 8 alone, without any source problem and with and without the modified goal state.

In the second part of the experiment, we investigated the conditions that enable subjects to recode situations. We did so by manipulating visual aspects and measuring the effect of the manipulation on transfer. We constructed two new experimental materials. The aim of the first was

to encourage subjects to encode the objects in the same way throughout the sequence of three problems, and the aim of the second was to encourage them to encode the objects differently. In the first material, we colored one half of the square red and the other half green; we also colored one rectangle red and the other green in both Problems 7 and 8. In order to check whether this manipulation would make the large square and the upright rectangles more salient and more similar to each other, a control condition was devised in which the rectangles and the square were uniformly red. We predicted that the red and green material would have a positive effect on performance in Problem 8 in that it would prompt subjects to (1) encode the square in Problem 6 as two contiguous rectangles, (2) encode the rectangles in Problem 7 as the rectangles of Problem 6 shown as two blocks instead of as a single one, and (3) encode the two rectangles in Problem 8 as the rectangles in Problem 7 separated by other objects. With this material, the encoding of the objects should be the same for all three problems (two rectangles in a variable pattern) and should improve performance in solving Problem 8 by facilitating recognition of analogy. This prediction is in line with Kaplan and Simon's (1990) suggestion that the benefits of recoding a situation are due to the way it enables problem solvers to take the relevant properties of a problem into consideration and thus attain a more adequate representation of the problem.

EXPERIMENT 1A

Method

Subjects. One hundred twenty volunteer students, in different disciplines at Paris 8 University, participated in the experiment. They were all in their 1st to 4th year of study and were between 18 and 25 years of age. The students were assigned to different experimental groups at random.

Material. On a computer screen, we presented problems similar to Problems 6, 7, and 8 of the passalong test (Figure 1) with respect to the shape of the figures and the constraints on the moves. A computer program checked the legality of the intended move and placed the figures in the desired positions whenever the move was legal. When it was not, nothing happened, and the subject had to attempt a new move. Every move, as well as the latency between moves, was recorded by the computer. The figures at the top of the screen were blue, and the ones at the bottom were yellow (this differed from the original passalong test, in which the figures at the bottom were red). The final state of each problem was present on the screen the entire time the subjects were solving the problem.

For this experiment, one different version of the goal state of Problem 8 was used. In this modified version, the rectangles in the problem appeared in an adjacent position (as in the goal state of Problem 7), instead of being separated as they are in the standard goal state of Problem 8 (Figure 2). It should be noticed that this modification changed neither the problem structure nor its solution and that the moves required to solve the problem remained unchanged. That is, solving Problem 8 still required joining the rectangles from the beginning of the solving process. The only change concerned the end of the procedure: The rectangles were not to be separated at the end (Appendix D). However, we assumed that this modified version would increase the recognition of an analogy between Problems 7 and 8 and would therefore decrease difficulty.

Figure 2. Experimental material used in Experiment 1A. The goal state of Problem 8 is modified, as compared with the standard material: In this material, Problem 8's goal state is the same as Problem 7's goal state.

Procedure. Experimentation took place individually in an isolated room. To familiarize the subjects with the mouse and the way the figures moved, the first item of the test provided a trial run before the actual experiment began. For each problem, the subjects were told they could stop whenever they were convinced it was genuinely impossible to solve the problem. The experimenter was present during the entire experiment and did not intervene while the subject was working on a problem.

Table 1 summarizes all of the conditions in this experiment. There were two control groups of 20 subjects each. In the first group (hereafter called 8-stand), the subjects solved only Problem 8 with the standard final state. In the second group (hereafter called 8-mod), the subjects solved only Problem 8 with the modified final state (where the rectangles are in an adjacent position).

There were four experimental groups of 20 subjects each. The first group (7/8-stand) was asked to solve Problems 7 and 8 (with the standard goals) without solving Problem 6 before. The second group (7/8-mod) also solved only Problems 7 and 8, but the goal state of Problem 8 was modified. The third group (6/7/8-stand) worked on Problems 6, 7, and 8 in the standard version. Finally, the fourth group (6/7/8-mod) solved Problems 6, 7, and 8 with the modified goal state of Problem 8. For all of the groups, both experimental and control, performance on Problem 8 provided the data to be analyzed.

Analysis method. Criteria for comparing performance (success/failure) were defined for all of the analyses in our study. Success rate is not a sufficient indicator, because success may occur after a great number of moves and a long period of trial and error, during which other uncontrolled factors related to motivation, such as perseverance, may intervene. We defined failure as not being able to solve a problem in 80 moves or less. This threshold was chosen for the following reason: The number of moves required to solve the problems by the expert path is 24 for Problem 7 and 22 for Problem 8. Rarely, however, do subjects solve the problems by the expert path. A number of different paths lead to solving the problems, and each pathway consists of a different number of moves. We set the upper limit on the number of moves high enough (four times

the expert path) that those subjects who could solve the problem would have enough time to do so and low enough that uncontrolled factors would not intervene. An a posteriori study of 60 protocols in a preparatory experiment showed that subjects who could not solve the problem usually gave up by themselves after having made an average of 70 moves. Thus, the limit on the number of moves that we set is very close to the limit subjects set for themselves. Because each move represents an attempt to discover a solution, all the variables were studied for all of the moves the subjects made. When subjects made more than 80 moves, only the first 80 were analyzed.

In Experiment 1A, we were interested both in the impact of goal configuration and in the impact of the encoding process on recognizing analogy. We therefore introduced a second criterion to measure the effect of the factors being manipulated: We examined whether or not the subjects successfully constructed and planned the relevant structure of the subgoal, even if they were unaware that the situation they had reached was the relevant subgoal situation. This subgoal consists in moving the rectangles in Problem 8 next to each other; it is the most favorable situation for solving the problem.

The dependent variables were (1) success rate as defined above, (2) the percentage of subjects who moved the rectangles into adjacent positions for Problem 8 (subgoal rate), and (3) the mean number of moves necessary to place the rectangles in the subgoal state. In order to study the latter variable, a maximum of 80 moves was counted for subjects who never joined the rectangles, even if their protocols contained more than 80 moves and they were not able to solve the problem at all. This adjustment of the data necessarily reduces differences between groups. So, the eventual significant statistical differences between groups would have been higher than those reported here.

Results and Discussion

The effect of goal state similarity on solving Problem 8. Comparison between the two control groups shows that when the rectangles were together in the goal state, the success rate increased (Fisher's exact probability value,

Table 1
Different Experimental Conditions in Experiment 1A

Effect of the Goal State	Effect of the Encoding Process		Control Groups
	Similarity of Encoding	Dissimilarity of Encoding	
Dissimilarity of goals	7/8-stand	6/7/8-stand	8-stand
Similarity of goals	7/8-mod	6/7/8-mod	8-mod

Note—Two factors were manipulated: similarity (or dissimilarity) of the encoding process and of the goal states.

Table 2
Performance on Problem 8 as a Function of the Two Main Factors
in Analogical Transfer: Similarity (or Dissimilarity) of the
Encoding Process, and Similarity (or Dissimilarity) of the Goal States

Effect of the Goal	Effect of the Encoding Process		Control Groups
	Similarity of Encoding	Dissimilarity of Encoding	
Dissimilarity of Goals	7/8-stand	6/7/8-stand	8-stand
Success rate	55	20	0
Subgoal rate	55	35	0
Number of moves to subgoal			
<i>M</i>	34	59.5	70.1
<i>SD</i>	5.6	6.7	2.23
Similarity of goals	7/8-mod	6/7/8-mod	8-mod
Success rate	70	70	35
Subgoal rate	70	75	45
Number of moves to subgoal			
<i>M</i>	34.5	28.6	47.5
<i>SD</i>	7.2	6.8	5.87

$p = .004$; Table 2). A greater number of subjects managed to move the rectangles into an adjacent position in 8-mod than in 8-stand (Fisher's exact probability value, $p = .0002$). The mean number of moves made to join the rectangles increased significantly in 8-stand, as compared with 8-mod [$t(38) = 3.59, p < .001$]. These results suggest that solving Problem 8 with the standard final goal is somewhat more difficult. There are two different possible explanations for this. The first is that it may be more difficult to conceive of the subgoal, joining the rectangles, when the goal state shows them separated. In such a case, joining the rectangles may be a move subjects avoid because it appears to be a detour (Atwood & Polson, 1976; Jeffries, Polson, Razran, & Atwood, 1977). The second possible explanation is that the modified final goal furnishes an implicit cue for constructing the subgoal. In other words, the fact that the rectangles appear together in the final goal cues moving them together to form the subgoal without any explicit thought on the matter necessarily taking place (Catrambone, 1994, 1995; Catrambone & Holyoak, 1990). Our results support either one of these interpretations.

We failed to obtain any significant difference between 7/8-stand and 7/8-mod. As we will discuss below, this can be explained by the favorable encoding context provided by the absence of Problem 6.

The comparison between 6/7/8-stand and 6/7/8-mod reveals the effect of the goal state on performance for Problem 8. The percentage of success increased when Problems 7 and 8 had similar goal states (Fisher's exact probability value, $p = .002$). A significantly greater number of subjects joined the rectangles in 6/7/8-mod (Fisher's exact probability value, $p = .02$). Likewise, the mean number of moves increased significantly in 6/7/8-stand [$t(38) = 3.22, p < .001$]. These results are interesting. In fact, as far as we know, the importance of goal similarity on analogical transfer has never been demonstrated in isolation as has been done here—that is, by modifying

only the appearance of the goal state while the structural properties of the problem remain unchanged.

Comparisons between 7/8-mod and 8-mod show that when Problem 7 was presented before modified 8, the success rate increased (Fisher's exact probability value, $p = .03$). Although a greater number of subjects in 7/8-mod managed to move the rectangles next to each other (75% vs. 45%), we failed to obtain a statistically significant difference between the two groups for the subgoal rate measure. Comparison between performances in 7/8-mod and 6/7/8-mod, as compared with 8-mod, supports the idea that there may be some beneficial effect of solving Problem 7 before Problem 8. However, it should be noted that the differences between 7/8-mod and 7/8-stand are not more important than those between 8-mod and 8-stand. That is, the effect of modifying the goal state was no larger when Problem 7 precedes Problem 8 than when Problem 7 is not presented. This is one limitation of the results.

The effect of the encoding process on solving Problem 8. A global comparison of success percentages for the four groups 7/8-stand, 7/8-mod, 6/7/8-stand, and 6/7/8-mod proved significant [$\chi^2(3, N = 80) = 13.42, p = .003$]. At a more detailed level of analysis, the success rate decreased significantly in 6/7/8-stand, in comparison with 7/8-stand (Fisher's exact probability value, $p = .02$). Although nonsignificant, the difference in the percentage of subjects in 6/7/8-stand who joined the rectangles decreased, in comparison with 7/8-stand (35% vs. 55%). The mean number of moves taken to join the rectangles decreased significantly in 6/7/8-stand, as compared with 7/8-stand [$t(38) = 2.86, p = .003$]. These results are in accordance with our prediction and point to the importance of the encoding context: Despite the fact that two problems may contain the same objects, analogy may not be recognized if there are differences in the way the problems are interpreted.

The performances of 7/8-mod and 6/7/8-mod were rather close. This result shows that when the goal states of

Problems 7 and 8 are similar, performance on Problem 8 is high, either in the presence or the absence of Problem 6. In other words, in the absence of Problem 6, performance on Problem 8 is high enough to mitigate the role played by the final state.

We obtained one combined effect for these factors—the worst performance was obtained when there was a dissimilarity of both encoding and goals (6/7/8-stand)—but we failed to obtain this combined effect for the most favorable condition, which is similarity of goals and of encoding (7/8-mod). These results prompted us to study the interaction between the two factors. We decomposed the global chi-square value: In order to study the effect of the encoding process, we calculated a global success rate for 7/8-stand + 7/8-mod, on the one hand, and for 6/7/8-stand + 6/7/8-mod, on the other. As far as this measure is concerned, the difference between the two groups was not significant [62.5% for 7/8-stand + 7/8-mod vs. 45% for 6/7/8-stand + 6/7/8-mod; $\chi^2(1, N = 80) = 2.46, p > .10$]. For the impact of the goal state, we calculated a global success rate for 7/8-stand + 6/7/8-stand, on the one hand, and for 7/8-mod + 6/7/8-mod, on the other. The difference between these two groups was significant [$\chi^2(1, N = 80) = 8.49, p < .003$]. As was explained above, the global comparison between the four groups proved significant [$\chi^2(3, N = 80) = 13.75, p = .003$]. If one subtracts the sum of the first two chi-square values (2.46 + 8.49) from the global chi-square value (13.42), the remaining value corresponds to the interaction. Interaction between the two factors was not significant [$\chi^2(1, N = 80) = 2.47, p > .10$]. The credibility interval for the interaction effect is $[-.05; .71]$, with a guarantee of .95 and an observed effect = .35. (The credibility interval given here is the Bayesian equivalent of a confidence interval. It is obtained with a noninformative Jeffreys' prior; see Bernard, 1998.)

Similar results were obtained for the subgoal rate. The global chi-square value was significant [$\chi^2(3, N = 80) = 7.99, p = .04$]. Interaction between the two factors was not significant [$\chi^2(1, N = 80) = 1.26, p > .10$]. The credibility interval for the interaction effect is $[-.16; .62]$, with a guarantee of .95, and an observed effect = .25 (i.e., 25%).

The width of the above credibility intervals suggests that the experimental precision is insufficient for determining whether or not there was an interaction.

It should be noted that for studying the transfer of procedure from Problems 6 and 7 to Problem 8, it may appear reasonable to remove the data collected from those subjects who failed to solve Problem 7 within the number of trials allowed (i.e., 80). Actually, we observed 3 subjects who failed on both Problems 7 and 8 in 6/7/8-mod, as well as two failures on both problems in 7/8-mod. Three subjects each failed on Problem 7 in 7/8-stand and in 6/7/8-stand; one of these subjects, nonetheless, solved Problem 8 in each group. Removing these data did not change the results notably. The success rate in 6/7/8-mod differed significantly from that in 6/7/8-stand (82.3% vs. 17.64%; Fisher's exact probability value, $p = .0002$).

Comparison as regards the subgoal rate also remained significant (88.2% vs. 29.4%; Fisher's exact probability value, $p = .0007$). Likewise, differences between 7/8-stand and 7/8-mod remained insignificant as regards the success rate, as well as the subgoal rate (61.1% vs. 76.4%; $p = .47$). Comparison between 7/8-mod and 6/7/8-mod remained insignificant for the success rate (82.3% vs. 76.4%) as well as for the subgoal rate (53.5% vs. 46.4%; $p > .60$). The difference between 7/8-stand and 6/7/8-stand remained significant in terms of success rate (61.1% vs. 17.6%; Fisher's exact probability value, $p = .01$). However, the difference was insignificant as regards the subgoal rate (61.1% vs. 35.2%; Fisher's exact probability value, $p = .18$).

The results obtained in the first part of this experiment are compatible with the idea that the reason why the problems are encoded differently is that the readily made analogical transfer from Problem 6 to Problem 7 (a square becomes two halves of a square) provides conflicting encoding. In other words, it is not the mere appearance of the objects that matters but, rather, the manner in which they are encoded and interpreted. Again, results are consistent with Bassok and Olseth (1995) in that they shed some light on the importance of the interpretive effects on the recognition of analogy.

In the next part of the experiment, we again studied the impact of the encoding process on the recognition of analogy. Although a variety of factors may influence the use of an analogue, the role of visual properties has more rarely been taken into account (Beveridge & Parkins, 1987; Chen, 1995; Gick & Holyoak, 1980, 1983). Kaplan and Simon (1990) showed that the relevant dimensions of a problem can be manipulated and that this manipulation may lead to a change in the encoding process. In fact, recognition of analogy may sometimes necessitate a change in the encoding process, something that can be obtained when the properties on which the analogy is based are made more salient. In the last part of this experiment (1B), we modified the visual aspect of the material to study how manipulation of the perceived characteristics of a problem can influence the way its objects are encoded and how recoding a problem affects recognizing the analogy between problems.

EXPERIMENT 1B

Method

Subjects. Forty volunteer students at Paris 8 University participated in the experiment. They were assigned to different experimental groups at random.

Material. For this experiment, we modified the test apparatus in two different ways. Both modifications concerned the visual aspect of the figures in the initial and final states of Problems 6, 7, and 8 and were aimed at modifying perception of these problems. The two new experimental materials are represented in Figure 3.

We will call the standard version *Material 1*. As was explained before, in this material, all of the figures were blue, except for the horizontal rectangle, which was yellow and remained so in the two modified versions. In the first modified version (called hereafter *Material 2*), the large square in Problem 6 and the rectangles in Prob-

Figure 3. Experimental material used in Experiment 1B. The initial and final states of Problems 6, 7, and 8 are modified, as compared with the standard material. In Material 2, the square in Problem 6 and the rectangles in Problems 7 and 8 were of the same color (red), and all of the small squares around them were blue. In Material 3, the square in Problem 6 was shown in two colors (red and green), and each colored area was in the form of an upright rectangle. In Problems 7 and 8, one of the two rectangles placed side by side.

lems 7 and 8 were all red. The small squares around them remained blue, as in the standard material. This color manipulation of the experimental material was aimed at calling attention to the square and the rectangles by making them stand out against the other figures.

In the second modified material, called hereafter *Material 3*, the square in Problem 6 was shown in two colors (red and green), and each colored area took the form of an upright rectangle. In Problems 7 and 8, one of the two rectangles was red, and the other was green (the final states were modified in the same way). This modification was aimed at making the square in Problem 6 appear as two rectangles placed side by side.

Although Materials 2 and 3 both emphasized the resemblance between the objects in Problems 6, 7, and 8, we did not expect them to have the same effects on solving Problem 8. Material 2 maintained the possibility of encoding the rectangles in Problem 7 as two halves of the square in Problem 6. In Material 3, the encoding of the objects should be the same for all three problems (two rectangles in a variable pattern). The similarity in encoding should improve recognition of the structural analogy between Items 6, 7, and 8.

Procedure. In this experiment, the control group was the third experimental group of the previous Experiment 1A (i.e., 6/7/8-stand): 20 subjects solved Problems 6, 7, and 8 with the standard version of the material (Material 1).

There were two experimental groups (20 subjects per group). The first group worked on Problems 6, 7, and 8 with Material 2, and the second group worked on the same problems with Material 3. Performance on Problem 8 was compared for all three groups.

The dependent variables for measuring performance on Problem 8 were (1) success rate, (2) number of subjects who achieved the *move the rectangles next to each other* subgoal, and (3) the number of moves required to achieve the subgoal.

Prediction. We predicted that performance on Problem 8 with Material 3 should prove significantly better than that with the other two materials. In addition, because Material 2 did not eliminate the possibility of encoding the two rectangles in Problem 7 as two halves of a square, we also predicted that differences in performance for Problem 8 between Material 2 and the standard test material (Material 1) would prove insignificant.

Results and Discussion

The experimental materials had a global effect on the success rate [$\chi^2(2, N = 60) = 9.44, p < .01$; Table 3]. However, there was no significant difference between the standard material and Material 2 ($p > .10$). In contrast, with Material 3, a greater number of subjects were able to solve the problem than with the standard material and with Material 2. Differences were statistically significant between the standard material and Material 3 (Fisher's exact probability value, $p = .005$), as well as between Material 2 and Material 3 (Fisher's exact probability value, $p = .03$). There was no significant difference between the standard material and Material 2 ($p > .10$).

Table 3
Performance on Problem 8 as a Function
of the Experimental Material Presented

Measure	Experimental Groups		
	Material 1	Material 2	Material 3
Success rate	20	30	65
Subgoal rate	35	40	65
Number of moves to subgoal			
<i>M</i>	59.5	57.6	38
<i>SD</i>	6.7	6.6	7.47

A greater number of subjects moved the rectangles next to each other with Material 3, but the differences were not significant ($p > .10$). However, the number of moves made in order to join the rectangles decreased significantly with Material 3, as compared with Material 1 [$t(38) = 1.95, p < .028$], as well as compared with Material 2 [$t(38) = 2.13, p < .01$].

The results are consistent with the hypothesis that the difficulty in solving Problem 8 stemmed from failure to recognize the analogy and that this failure was, in turn, due to a difference in the way the objects in Problem 8 and the objects in Problems 6 and 7 were encoded. Giving the square in Problem 6 and the rectangles in Problems 7 and 8 the same color, thus making them more similar, cannot be said to have facilitated recognition of the analogy, in the absence of any significant difference between Materials 1 and 2. In contrast, performance on Problem 8 with Material 3 was significantly different from performance with the other materials. These results are entirely consistent with Kaplan and Simon's (1990) findings and show that manipulating traits likely to influence perception of a problem can have an effect on mental representations and, thus, on recognition of analogy and on performance.

At the end of the experiment, we also studied the verbalizations of the subjects in the experimental groups (14 individual protocols per experimental group) and compared these with the verbalizations of the subjects in the control group. The subjects were presented with drawings of the initial and final states of Problems 6 to 8 and were invited to explain differences and/or similarities between the three problems. In our analysis, we retained the terms a subject spontaneously used to designate the objects in each problem. The results show that the term *rectangle* was frequently used to designate the objects in Problem 6 with Material 3 but was totally absent for the other materials (Fisher's exact probability value, $p = .0001$). When they worked on Material 3, the subjects used the term *rectangle*, rather than *square*, to designate the two-colored square in Problem 6. As regards the relations made between problems, the results show that for Problems 6 and 7, division relations were more frequently identified by those subjects who had worked on Materials 1 and 2 than by those who had worked on Material 3 (Fisher's exact probability value, $p = .001$). On the other hand, Material 3 prompted the subjects to perceive the same objects, differently spaced, in Problems 6 and 7. These results corroborate the hypothesis

that what constitutes the contribution of Material 3 to recognizing the analogy is that the two-colors square allows a continuity in the encoding of the objects throughout the three problems. The change in mental representations that our manipulation provoked made the objects *cognitively* similar.

GENERAL DISCUSSION

In the two experiments reported here, we studied two main factors in the recognition of analogy: similarity of goals and similarity of the encoding process. Although these two factors have both been studied in the literature, as far as we know, they have never been studied together with the same material. In the first part of the experiment (1A), we aimed at studying the role played by goal state similarity and encoding similarity on recognition of analogy. The results show that when goal states are similar between problems, recognition of analogy is made easier, independent of the context in which the problems are encoded. Similarly, when problems are encoded in the same way, analogy is recognized regardless of whether the final goals are similar. The results also show that the interaction between these two factors is statistically insignificant. However, the width of the credibility intervals suggests that the experimental precision is insufficient to determine whether or not there was any interaction.

The second part of the experiment (1B) aimed at studying more precisely the encoding process, which we believe affects recognition of the analogy between Problems 7 and 8. Our study emphasizes the role played by the visual appearance of objects on the way tasks are interpreted. The results of Experiment 1B showed that visual properties can have a positive or a negative effect on recognizing analogy. The positive effect occurs when the visual characteristics make the properties on which the analogy is based more salient.

It might be argued that the material used here is heavily visual in nature and that it differs from materials usually used in the analogical transfer literature, which are often text oriented (Gentner et al., 1993; Gick & Holyoak, 1980, 1983) or mathematical (Catrambone, 1994, 1995; Ross, 1987, 1989). However, it should be noted that we obtained the same results as those found with text-oriented materials. That is, we showed the effect of goal and of surface trait similarity on the recognition of analogy. This suggests that other results obtained here could be replicated with other kinds of materials. However, modification of the encoding process, without altering surface traits and the problem itself, would be more difficult with text-oriented materials, given that when the text is modified, the problem would also be changed. Thus, in order to study these points, the material chosen here seems to be more relevant.

These results corroborate numerous findings in the literature on both analogical transfer (Bassok & Olseth, 1995; Bassok, Wu, & Olseth, 1995; Kotovsky & Fallside, 1989) and categorization (Goldstone, 1994; Schyns & Rodet, 1997). In fact, subjects have quite a bit of freedom

in the encoding of the objects or, more precisely, in choosing properties and words by which to identify objects. The code attributed to the objects depends on the context. Our results suggest that subjects will continue to work with a given encoding as long as it appears to be compatible with the situation. This is why the problems previously solved play an important role not only as source problems for the transfer of procedures, but also, and more specifically, as sources for interpreting a new situation (Sander & Richard, 1997). This suggests that the encoding of the target problem may depend on the way the source problems have been encoded. That is, the prior context or the source problem may influence the way the target problem will be interpreted.

When the initial interpretation is inappropriate, it must be modified. This change in the representation of a situation is what Gestaltists have referred to as the phenomenon of *insight*. Our findings are also consistent with the theory developed by Ohlsson (1992), according to which restructuring is a product of a search through semantic memory. According to this author, failed attempts at solving a problem can lead to searching the semantic memory for new interpretations of the objects in the problem. Therefore, information that is present in the situation or hints provided by the experimental situation are of great importance in directing attention and in guiding the subject to a new interpretation. In accordance with a recent body of research in which visual properties were used to make analogical transfer easier (Beveridge & Parkins, 1987; Chen, 1995; Gick & Holyoak, 1980, 1983), the results we obtained here show how the semantic aspects of a problem can be activated through the visual properties selected and how manipulation of these properties can modify the interpretation of the problem.

One implication of these results concerns the distinction usually made between structural and surface traits in analogical transfer literature. Those objects of the situation that are related to surface traits of a problem are usually considered to be unrelated to the structural aspects—that is, the set of actions and subgoals that permit attaining the goal. However, the actions that may be applied to an object depend on the properties of the object. In other words, in order for an action to be applied, the object must have those properties that make the action applicable.

Indeed, the functional properties of objects are usually correlated with their physical structure—that is, with what is considered as being their surface properties. These properties may be more or less salient in a problem, given the context in which it is presented. What is important in analogical transfer is to recognize the functional similarity between the objects in two problems. Sometimes, surface properties allow accessing the relevant functional properties because they are the most salient physical properties. For instance, in the study by Gick and Holyoak (1983) presented in the introduction, a pair of scissors and a pincer share some salient properties that make them appropriate for the solution procedure (they are heavy, can be attached, etc.). Likewise,

ribbons and strings share some salient properties that are necessary for making a pendulum (they are long and flexible, they can swing, etc.). The results of Experiment 1A show that objects can be encoded in different ways, depending on the various properties taken into account and used to describe them. The effect of encoding is to make the structural similarity between problems recognizable or not. Thus, the inferred set of actions and subgoals depends on the way problems are encoded. In order to recognize the structural similarity between problems, the objects have to be encoded in the appropriate way. Consequently, the same actions may be inferred when the objects in two problems share salient properties that make these actions applicable.

We think that in order to study analogical transfer, more attention must be paid to the ways in which the characteristics of problems can influence the interpretation of the source and target problems.

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APPENDIX A

The Initial States (A) and the Final States (B) of Problems 1–9 of the Passalong Test

APPENDIX A (Continued)

APPENDIX B

The Critical State in Problem 6 of the Passalong Test, in Which the Relevant Action Consists of Moving One Small Figure to the Top in Order to Make Room for Moving the Horizontal Rectangle

Critical state and irrelevant moves

Impasse

Critical state and the relevant move

Favorable state

APPENDIX C
The Structural Similarity of Problems 6, 7, and 8 of the Passalong Test

Problem 6

Problem 7

Problem 8

APPENDIX D
The Procedure for Solving Problem 8 With the Standard and With the Modified Goal States

Problem 8

Initial state

Critical state

Standard Goal state

Problem 8

Initial state

Critical state

Modified Goal state