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Is generalisation conservative? A study with novices in chess

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The present paper argues that generalisation is conservative. Our goal was to experimentally study the links between knowledge generalisation and the storage of contextual elements. The knowledge domain, very simple chess configurations, allowed subjects, novices in chess, to acquire micro-expertise based on the analysis of a single source problem. In the first experimental phase, subjects had to analyse a source problem. We induced two modes of source-problem encoding: In the first group, subjects were given explanations focused on the sequence of elementary solving steps; in the other group they were given the general principle relevant to the category of problems in question. Subjects had then to solve different tests (solving isomorphic problems, recall tests, similarity tests) designed to answer two questions: The first question was to test whether the experimental manipulation in the two groups had in fact generated knowledge that varied in abstractness; the second question was to determine whether generalisation is accompanied by storage of surface features of the source problem. Results show that the knowledge generalisation is conservative. Subjects who generalise their knowledge have a better memory retention of context-dependent elements than the other subjects.

Many studies have shown that problem solving by analogy is facilitated when a schema that is potentially applicable to a class of problems is constructed, i.e., when the subject builds an abstract representation structure that includes the goals and subgoals to be reached, the requirements to be met, and the strategy to implement (e.g., Cummins, 1992; Gick &

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Holyoak, 1980, 1983). In this framework, solving a new, structurally isomorphic problem by analogical reasoning consists of applying the abstract schema and instantiating it with the new problem data.

This conception of analogical problem solving, albeit the prevailing one in cognitive psychology, has turned out to be insufficient when it comes to accounting for the well-established role of surface features in reasoning by analogy. Experts as well as novices take surface cues into account when assessing the degree of similarity between problems belonging to the same class (e.g., Chi, Feltovich, & Glaser, 1981). Furthermore, it is always easier to solve a new target problem when its surface features resemble those of an already processed source problem (e.g., Holyoak & Koh, 1987; Novick & Holyoak, 1991; Reeves & Weisberg, 1993; Ross, 1987, 1989). It follows from this that specific information about previously processed problems is stored in memory, even when the subject has general knowledge about how to solve problems in that class (Reeves & Weisberg, 1994).

A hypothesis put forward by many authors (e.g., Anderson, Fincham, & Douglass, 1997; Brooks, Norman, & Allen, 1991; Gobet & Simon, 1996a, b; Pierce, Crain, Gholson, Smither, & Rabinowitz, 1996) is that several representation structures with different levels of abstraction may in fact co-exist, including special cases elaborated at a low level of abstraction, and more abstract representation structures applicable to several if not all instances of the category in question. Depending on the extent to which the to-be-solved target problem resembles the corresponding source problems, one or the other of these forms of representation will take precedence. When the target problem is recognised as familiar, an already processed case would be searched for and adapted to it. But when the problem cannot be connected to a known case, an abstract schema would be applied and instantiated (provided, of course, that such a schema exists in long-term memory). There is still little experimental data in support of this hypothesis, but it appears plausible and tempting from the standpoint of cognitive efficiency: It is less costly and faster to adapt a known case, if possible, than it is to systematically reconstruct or re-calculate the solving process by applying and instantiating an abstract schema. Moreover, this second hypothesis helps account for the fact that novices (who do not yet have an abstract schema) manage to solve problems when they are very similar to the source (e.g., Reed, 1987, 1989; Reed & Bolstad, 1991).

The study presented here was conducted in this theoretical framework and focuses on the phase during which subjects construct knowledge that can be reused later to solve new problems. Our goal was to experimentally study the links between knowledge generalisation and the storage of contextual elements. In many studies, generalisation is viewed as a "conservative" process (Blessing & Ross, 1996; for a review, see Reeves & Weisberg, 1994), i.e., abstract knowledge and contextual elements can co-exist, yet few attempts have been made to investigate the processes through which these different types of knowledge are built.

In the first phase of the experiment conducted here, we attempted to experimentally lead subjects to encode the same source problem in two different ways, one specific and one more abstract, solely by varying the explanations given to them. For one subject group, it was hypothesised that the knowledge induced by problem-specific explanations would be highly contextualised and thus not very generalisable (see Didierjean, Cauzinille-Marmèche, & Savina, 1999). In contrast, for the other subject group, the knowledge induced was more abstract, so it should be more generalisable, i.e., applicable to other problems in the same class regardless of their surface similarity to the source problem.

In the second phase, the subjects were given a test designed to answer two questions. The first was to see whether the experimental manipulation in the two subject groups had in fact generated knowledge that varied in abstractness and was thus more or less generalisable. The second—and this was the main goal of the experiment—was to determine whether knowledge generalisation is accompanied by storage of the surface features of the source problem.

The knowledge domain chosen was one that would allow subjects to acquire micro-expertise based on the analysis of a single source problem (e.g., Ahn, Brewer, & Mooney, 1992). More specifically, subjects had to find the solution to a particular chess problem: attaining "smothered mate with sacrifice" near the end of a chess game.

Here is an overall view of the successive phases of the experiment.

(1) Subjects who were chess novices were assigned to two groups matched on Chase and Simon's (1973) well-known memorization test. The subjects' first task was to analyse the source problem. One group of subjects was given an explanation of the problem that focused on the sequence of elementary solving steps. For the second group, the explanation consisted of describing the general principle behind smothered mate with sacrifice and illustrating it with the same source problem. This second experimental condition, likely to trigger self-explanations (cf., Chi, Bassok, Lewis, Reimann, & Glaser, 1989) aimed at linking the example to the general principle, was expected to promote the construction of an abstract schema (e.g., Brown & Kane, 1988).

(2) Subjects had to solve two new problems, one that was like the source problem both in its structural and perceptual features, and one that looked different on the surface but was in fact structurally isomorphic. This was used as the first measure of generalisation by subjects

in the two groups: We expected subjects given the general solving principle to solve the "unlike" problem better than subjects in the other group.

(3) After solving the two problems (like and unlike), subjects had to recall the source example as accurately as possible. This phase allowed us to determine what specific aspects of the problem were stored in long-term memory. Our hypothesis was that if knowledge generalisation is conservative, subjects who had been told the general principles underlying the solution would remember the specific aspects of the source at least as well as the other subjects.

(4) Finally, subjects had to order a set of new problems according to how much they resembled the source problem (in terms of the similarity of the solving process). The problems to rank differed from the source problem in their surface features and/or in their structure. The hypothesis was that subjects who had constructed an abstract schema would primarily use structure as a criterion for judging problem resemblance (e.g., Chi et al., 1981; Ross, 1996). This task thus gave us another measure of generalisation by subjects.

This experimental setup—in which certain measures allowed us to assess the specificity of the knowledge constructed (recall task) while others served to evaluate its generality (scores on the like and unlike problems, and ordering task)—should provide insight into the representation levels elaborated during the acquisition of micro-expertise, and their use in problem solving, and should therefore test the link between knowledge generalisation and specific-element storage.

METHOD

Subjects

Forty-four psychology students (mean age: 23 years 4 months, standard deviation: 11 months) participated in the experiment. All subjects judged themselves to be novices in chess (having played less than once a year) but were familiar with the rules.

Materials

Pre-test materials. The pre-test materials consisted of a chess board and a layout based on a real game after approximately a dozen moves (see Appendix 1).

Familiarisation materials. Two chess layouts were used for familiarisation (see Appendix 2).

Source example analysis materials. The example analysis materials included a chess board layout (see Figure 1) and the following two explanations.

The first explanation ("case explanation") described the correct procedure for solving the example problem:

> You need to put the white queen on square B8. The black king is in check. The black king can't take the white queen because she's protected by the white knight on C6. So the only possibility for the black player is to take the white queen with the black knight located on A6. The white player moves the D5 horse to C7. This puts the black king in checkmate. The black player loses.

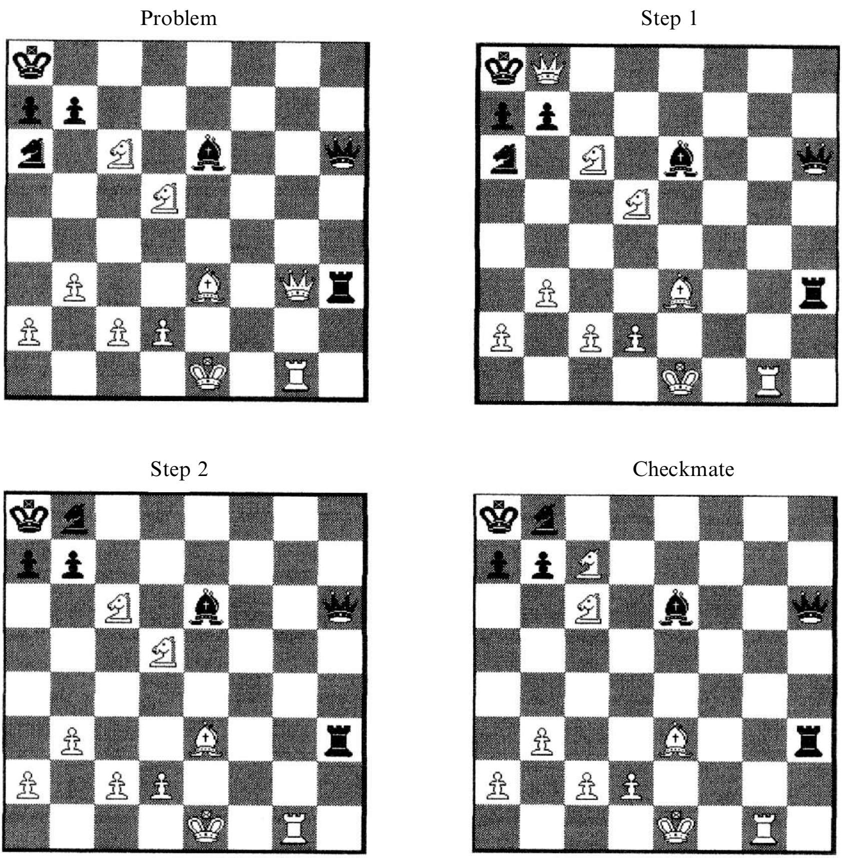


Figure 1. "Example" problem and steps to the solution.

The second explanation ("principle explanation") was a description of the principle of smothered mate with sacrifice, illustrated using the same example.

> The principle of smothered mate with sacrifice is as follows: The king is surrounded by his own men and can't move. An opposing knight then comes along and puts the king in check (see layout in Figure 1: The black knight on D5 moves to C7). Since the king is smothered by his own men, he can't get away. He is in checkmate. But to get to this arrangement, a sacrifice sometimes has to be made. There are often cases where the king can escape (show layout Figure 1). He is not completely surrounded. To surround him completely, the white player moves a piece next to the black king (here, the white queen moves from G3 to B8). This piece cannot be taken by the king because she is protected (in this case, by the white knight on C6). The queen will therefore be taken by another piece (here, the black knight on A6). She is sacrificed. Now the black king is completely surrounded by his own men. He can no longer escape. The white player threatens the black king with a knight (here, the white knight on D5, who moves to C7). The black king is in checkmate. The black player has lost.

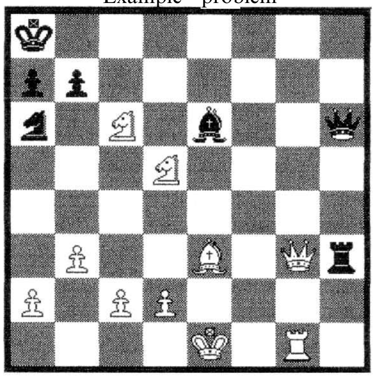
This second explanation is longer than the first one, but this is not important, since the purpose of the experimental manipulation was to induce different kinds of source problem encoding, that would lead to less-vs-more generalisation.

Target problem-solving materials. Two board layouts were used: (1) a "like" problem that closely resembled the example in both the required moves and the surface features (the remaining pieces and their positions were very similar), and (2) an "unlike" problem that required the application of the same solving principle as the example, but whose surface features were very different. The example problem, the "like" problem, and the "unlike" problem are presented in Figure 2.

Source example recall materials. The source recall phase required an empty chess board and the full set of chessmen.

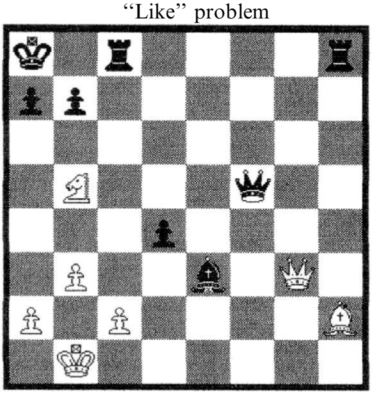
Similarity judgement materials. The similarity judgement materials were four board layouts, one of which was the example. For the other three (see Figure 3), the first (configuration a) was structurally the same and also had similar surface features to the example, the second (configuration b) resembled the example in structure only, and the third (configuration c) only had similar surface features.

"Example" problem



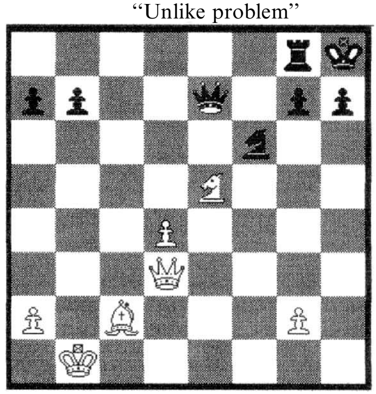
Solution:
1. Qb8–Nb8 2. Nc7 Checkmate

"Like" problem



Solution:
1. Qb8–Rb8 2.Nc7 checkmate

"Unlike problem"



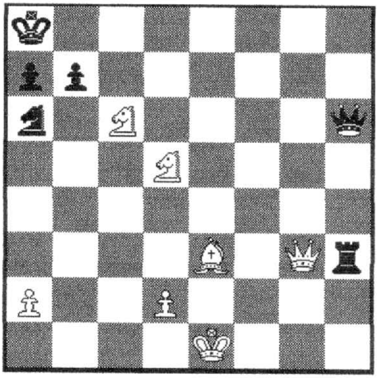
Solution:
1. Qh7–Nh7 2. Nf6 checkmate

Figure 2. Example, like and unlike problems.

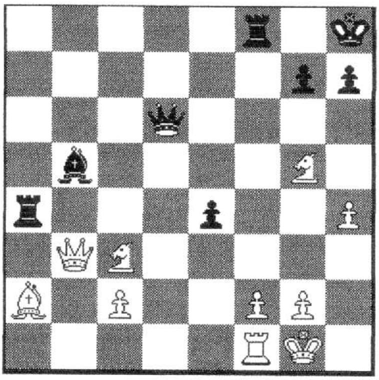
Procedure

The experiment was run in a single session lasting approximately 1 hour. Subjects were tested individually.

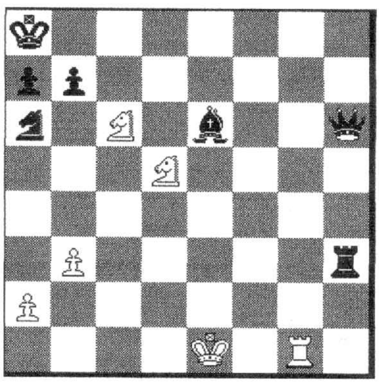
(1) Pre-test Memorisation of a board layout. The subjects were given an empty chessboard with the set of chessmen next to it. For each trial, another chessboard with pieces laid out as in a real game (Appendix 1) was placed behind the subject. The subject turned around, and his/her task was to memorise the layout within 5 seconds and then reproduce the locations of as many pieces as possible on the empty chessboard. Four



Configuration a.



Configuration b.



Configuration c.

Figure 3. Layouts used for the similarity judgement phase.

memorisation trials were allowed (mean number of correctly recalled pieces after four trials: 7.6; standard deviation: 2.7). The subjects were then assigned to two groups matched on pre-test performance: the "Principle" group and the "Case" group.

(2) Familiarisation with the game of chess. A chessboard layout was presented on paper (see Appendix 2, layout F1). The subject had to indicate the legal moves in accordance with the rules of the game, for both the white player and the black player. Then a second board layout was shown, also on paper (see Appendix 2, layout F2). The subject had to state how the white player could put the black king in checkmate by making only a few moves (it was the white player's turn). If the subject could not find the solution, it was stated and explained by the experimenter.

(3) Source example analysis phase. Subjects had to search for a solution to the example problem (see Figure 1) presented on a real chessboard, i.e., how the white player could put the black king in checkmate in a few moves. The subject was allowed to move the pieces. The experimenter prompted the subject to come back to the initial layout (which was visible on paper at all times) whenever he or she was deemed to be too far away from the solution. The time allotted to this independent searching was 1 minute. None of the subjects found a solution in the allotted time. The second step involved explaining to half of the subjects ("Case" condition) an exact solution procedure for this particular example, and to the other half ("Principle" condition), the general principle of smothered mate with sacrifice, illustrated with the example (see Materials section for the exact wording of the explanations). The subjects then had to reproduce the correct procedure on the chessboard while explaining the moves. If the subject had trouble, the experimenter repeated the initial explanation. All subjects proved to be able to reproduce and explain the correct procedure in the time allotted, which was 2 minutes in both conditions.

(4) Like and unlike target problem-solving phase. The subjects had to solve two problems, one like and one unlike the example (see Figure 2). The time limit was set at 4 minutes per problem. The Principle and Case groups were each divided into two subgroups that only differed by the order in which the two problems were solved (like then unlike, and vice versa).

(5) Source example recall. After the problem-solving phase, the subjects were given an empty chessboard and the complete set of chessmen, and were asked to recall, as fully and accurately as possible, the layout of the example initially explained by the experimenter. Subjects were not informed of this recall phase during the problem-solving phase.

(6) Similarity judgement phase. The example layout was presented to the subject, who was informed this time that it was the source example.

He or she was also given three other layouts (see Figure 3) and asked to put them in decreasing order of similarity (in terms of the required solving steps) to the example layout.

RESULTS

Measures of knowledge generalisation

Solving like and unlike target problems.[1] Table 1 gives the percentage of subjects in each experimental group (Principle and Case) who correctly solved the like and unlike problems. A problem was scored as correctly solved when the subject found the right procedure for putting the black king in checkmate.

The results showed that for both experimental groups, the problem like the example was solved better than the unlike one, sign test, $Z = 4.13$; $p^{obs} < .0001$. They also showed that although the unlike problem was correctly solved by only one subject in the Case group, a third of the group to whom the abstract solving principle had been explained succeeded on this problem.

Similarity judgements. The subjects had to state how similar three new layouts (see Figure 3) were to the example layout. They were asked to rank the three layouts in decreasing order of similarity to the example (from the standpoint of the solving procedure that had to be used). One of the three layouts looked like the example both visually and structurally (a), one resembled it only structurally (b), and one resembled it only visually and smothered mate with sacrifice was impossible (c).

Table 2 shows how the subjects in the two experimental groups ordered

TABLE 1
Percentage of subjects in each experimental group who correctly solved the like and unlike problems

	Condition	
Problem	*Principle*	*Case*
Like	77%	45%
Unlike	32%	4%

[1]Not having observed any presentation order effect for the like and unlike problems, this factor was not considered in the analyses.

TABLE 2
Similarity judgements: Percentage of subjects in the two experimental groups (Principle and Case) who stated each of the four orders

	Group	
Order	*Principle*	*Case*
1. a b c	77%	50%
2. b a c	5%	5%
3. a c b	18%	36%
4. c a b	0%	9%

the three layouts by example similarity. Four similarity orders were observed (in order of most to least similar): a b c, b a c, a c b, and c a b.

In the Principle group, the number of subjects who produced structure-based orders (orders 1 and 2) was significantly greater than the number of subjects who did not (orders 3 and 4), $\chi^2(1) = 8.91$, $p = .003$. In the Case group, structure-based ordering was not significantly more or less frequent than the other types of ordering (orders 3 and 4), $\chi^2(1) = 0.18$, n.s.

Measure of specific-feature storage: Source example recall

This phase took place after the two problems had been solved. Subjects were asked to reconstruct the layout of the source example initially explained by the experimenter.

First, note that the subjects almost never remembered the pieces that did not enter into the solution (10 of the 17 pieces in the source example), and this was true for both groups. Only 5 of the 44 subjects recalled one to three pieces that were not in the solution. The data analyses do not take into account the recall of these non-relevant pieces.

Table 3 gives the mean number of "relevant" pieces put in the correct location by subjects in the Principle and Case groups. A piece was considered to be relevant if it was part of the solving steps (pieces bKA8, bpA7, bpB7, bNA6, wQG3, wNC6, wND5).[2] The table also shows the number of additional pieces placed in an "incorrect" but "logical" location, i.e., one that did not change the solving procedure (e.g., the white queen was placed on F4 instead of G3, which is on the same diagonal).

[2] b = black, w = white, K = king, p = pawn, N = knight, Q = queen.

TABLE 3
Recall test: Mean number of relevant pieces recalled (max. 7) in the correct location, or in a different but logically correct location, for the two experimental groups (Principle and Case)

	Group	
	Principle	*Case*
Correct location	4.1	3.0
Logical location	0.9	0.3

The results showed that the subjects to whom the general solving principle had been explained remembered the specific example more accurately than the subjects in the Case group. They remembered more pieces in their exact location, $t(42) = 2.54$, $p = .007$. This shows that the contextual features of the source example were stored in memory even when abstract knowledge was constructed.

Moreover, the Principle group subjects, more often than the Case group ones, were able to place one or more pieces in a logical position that did not change the structure of the game (14 out of 22 subjects in the Principle group vs only 7 out of 22 in the Case group), $t(42) = 2.75$, $p = .004$. This is another indicator of knowledge generalisation.

DISCUSSION

Is knowledge generalisation "conservative"? In other words, do the processes implemented during knowledge generalisation lead subjects to save or forget the specific features of the source problem? In our experiment, we induced two degrees of generalisation from the analysis of a single source problem. Some subjects created a "case" (Didierjean et al., 1999) based on explanations about the specific steps needed to win in the particular case presented; others constructed an abstract schema based on explanations that relied on the general solving principle applicable to this class of problems.

Different indices were used to measure the abstractness of the knowledge built by the subjects in the two groups: (1) the subjects' transfer performance on two problems from the same class whose surface features resembled the source problem features to different degrees; (2) the subjects' performance on a problem ordering task designed to point out what structural or surface criteria they used to judge the similarity of the new problems to the source problem; and (3) the subjects' performance on a source-problem recall task, which pointed out what specific aspects of the problem they had stored in memory.

The results showed that some subjects correctly solved both types of target problems, others, only the like problem, and still others, neither problem. In line with our assumption that exposure to an abstract principle promotes generalisation (e.g., Catrambone, 1995, 1996; Clement, 1994), all subjects who succeeded on both types of problems (except one) were subjects who had been presented with the abstract solving principle. However, mere exposure to the abstract principle did not induce a knowledge level in all subjects that enabled them to solve both problems. Many subjects only succeeded on the like problem, and others, on neither problem. Subjects in the group that was only given the specific procedure for solving the example, failed on one or both problems (only one subject in this group correctly solved both problems). These results show that all subjects in the Principle group did more knowledge generalising than those in the Case group.

The ordering task results are in line with those given previously. The Principle group subjects usually used structural features to judge similarity between the new board configurations and the source example, whereas the Case group subjects rarely did so.

The recall task results showed first of all that subjects remembered only pieces that were part of the problem solution. Thus, primarily "useful" information supporting the goal "put the opponent's king in check" was retained. Bernardo (1994) obtained a comparable result in showing that only those surface features that were integrated into the problem-solving schema gave rise to a priming effect. Our results also showed that the Principle group was better at remembering the exact locations of the pieces than the Case group was. It seems, then, that constructing general knowledge does not prevent memory storage of contextual elements, on the contrary.

As a whole, these results show that the knowledge generalisation process can lead to the construction of an abstract solving schema as well as memory retention of context-dependent, surface elements that are part of the solution. These results are consistent with studies showing that the acquisition of expertise is not rooted as much in the construction of increasingly abstract knowledge, as it is in the construction and organisation of knowledge at different levels of abstraction (Gobet & Simon, 1996a, b; Kolodner, 1993).

Subjects may therefore rely on one or the other type of knowledge, depending on how similar the target is to the example (e.g., Brooks et al., 1991; Gobet & Simon, 1996a, b; Pierce et al., 1996). When the problem to be solved is perceived as being like an already learned problem, subjects can access that problem and attempt to adapt it to the solution. When the to-be-solved problem differs from the source problem in its surface features, subjects can access the abstract schema and attempt to apply it, while taking the specific features of the new problem into account. In the latter case, two hypotheses can be set out (e.g., Schunn, Reder, Nhouyvanisvong, Richards, & Sroffolino, 1997): Either (1) the subject first searches for the example and attempts to adapt it, and only when this turns out to be impossible, does he or she retrieve an abstract solving schema; or (2) the new problem is considered outright to be unfamiliar and the memory search starts directly with looking for more abstract representation structures. The experiment we conducted does not allow us to choose between these two hypotheses. For subjects who succeeded on one problem only, it was always the like problem. So these subjects must not have built an abstract schema and were thus limited to adapting the solving procedure of the example to the target problem. This was possible only when the target problem's surface features and structure were both very similar to those of the example. For subjects who failed on both problems, adaptation of the example to the target problem must not have been possible, even when the two were very similar (e.g., Reed, 1987, 1989; Reed & Bolstad, 1991).

The data we collected provide further insight into the nature of the representations constructed and used by subjects. In attempting to define the different encoding modes used in problem solving and determining how they evolve with learning, it would certainly be a gross oversimplification to distinguish only the storage of special cases and the building of abstract schemas. In line with classical theories of memory (see Jacoby & Dallas, 1981; Tulving, 1985; Tulving & Thomson, 1973; for a review, see Tiberghien, 1997), it would no doubt be more useful to hypothesise that there is co-construction and co-existence of different types of problem encoding, some more perceptual in nature, others more episodic and procedural, and still others, more semantic and conceptual.

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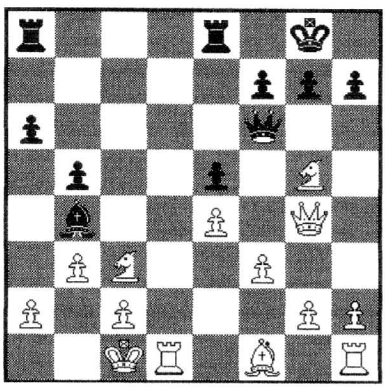
APPENDICES

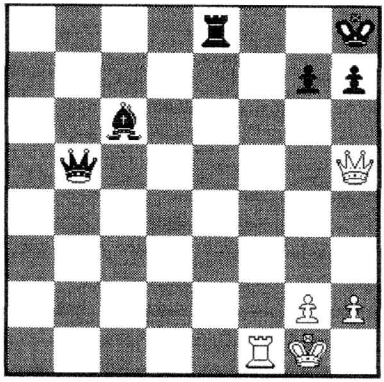
Appendix 1

Memorisation



Appendix 2

Familiarisation with game (F1)



Familiarisation with moves (F2)