Prioritizing the New: Insight Creates Set for Familiar Problems

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Abstract

The present study sought to determine whether finding new solutions to problems after changing the initial representation of them ("insightful" solutions), create a set for familiar solutions to similar problems. To this end, problem solvers worked on a number of set problems that required them to repeatedly carry out new moves that were only available after they had changed their initial representation of the problem. The results demonstrated that this manipulation made it harder to solve similar problems having familiar solutions. This effect was especially strong, when the same new move was carried out repeatedly. This might suggest that newly discovered moves are "prioritized" relative to familiar moves. Such a prioritizing might serve to enhance the availability of new solutions to problems.

Insight and Set

Some problems are difficult because they require the problem solver to find the right sequence of steps in a vast space of alternative step sequences (Newell & Simon, 1972). The main resources for solving such problems are search heuristics and memories of prior problem solving episodes, both of which help constrain the search. In contrast, other problems, traditionally called insight problems (Duncker, 1945; Wertheimer, 1959), quickly generate the impression that they are unsolvable (Ohlsson, 1992). Instead of floundering in a myriad of possibilities, problem solvers cannot think of any useful step to take. Similar phenomena are observed in experiments that address set effects (Lovett & Anderson, 1996; Luchins & Luchins, 1959; Ohlsson, 1992). Here, participants often have difficulties finding the solution to simple problems, after having solved a number of problems with a more complex sequence of moves. Despite this similarity, different principles have been formulated to explain set effects and insight.

The study reported in this paper is part of a larger research project that investigates whether different cognitive processes need to be postulated to explain insight and set, or whether the same processes underlie both phenomena (e.g. Smith, 1995). Our main interest in the current study was whether newly discovered moves that follow a change in the problem representation create set effects for familiar solutions to similar problems. Such a "prioritizing" of new moves could provide a principle to explain the strong transfer effects observed in insight problem solving (Knoblich, Ohlsson, Haider, & Rhenius, 1999). We start with a short review of some prior research on set and insight.

Set

In their classical water-jar studies Luchins and Luchins (1959) typically compared a set group and a control group. The participants in the set group received a number of problems that could only be solved by repeatedly carrying out the same sequence of two moves, before solving a problem that could either be solved by carrying out the more complex two-step sequence or a simple single move. The control group received the same ambiguous problem after solving unrelated problems or a number of ambiguous problems. Almost all of the participants in the set group continued to use the more complex procedure, despite the availability of a much simpler solution. Participants in the control group almost always found the simple solution. Additionally, participants in the set group were often unable to solve problems that could only be solved by the simple move. Luchins & Luchins (1959) explained this effect in Gestalt terms: they claimed that the set group had been fixated on the more complex method.

Modern cognitive accounts postulate that set effects are due to the repeated activation of the same solution procedure (Lovett & Anderson, 1996; Ohlsson, 1992) or the same knowledge element in declarative memory (Smith, 1995). Lovett and Anderson (1996) investigated an analog of the water jug problems, and convincingly demonstrated that the repeated activation of the same procedure in prior learning history, and the activation of the same procedure within the local problem-solving context, resulted in additive set effects. It is less clear whether the repeated activation of the same knowledge elements in declarative memory contributes to set effects in problem solving. Until now, such effects have not been empirically demonstrated.

Insight

Most current theories of insight problem solving rest on the assumption that some problems cause impasses because they deceive the problem solver into constructing an incomplete or overly constrained problem representation that does not include the solution (Kaplan & Simon, 1990; Knoblich, Ohlsson, Haider, & Rhenius, 1999; MacGregor, Ormerod, & Chronicle, 2001; Ohlsson, 1992). Impasses are encountered after an initial phase in which the procedures activated by the initial representation have been applied to the problem without success (Knoblich, Ohlsson, & Raney, 2001; Ohlsson, 1992). During impasses no further ideas about how to proceed come to mind. Feeling-of-knowing judgments show that problem solvers do not feel that they are approaching the solution until the moment immediately before it is attained (Metcalfe & Wiebe, 1987).

If the impasse persists, the problem solver will eventually have to give up and declare failure. To resolve the impasse, the problem solver must revise his or her biased initial representation of the problem. The new representation might change the problem space by activating previously dormant knowledge (procedures, rules, etc.) thus allowing the problem solver to continue. In past work we have proposed two principles for when impasses are encountered and how they are resolved (Knoblich et al., 1999; 2001; Ohlsson, 1992).

The first principle is the retrieval and relaxation of constraints on the goal representation. Faced with an unfamiliar problem, the problem solver will recall prior knowledge of similar problems encountered in the past, including constraints on the goal representation. These constraints may not be adaptive vis-à-vis the unfamiliar problem. If not, the space of options will not contain any solution to the current problem. Impasses caused by an overly constrained solution space can be broken, by relaxing the inappropriate constraints. The second principle is chunk retrieval and chunk decomposition. Familiarity with a class of objects leads to the creation of patterns that capture recurring constellations of features, a process generally referred to as chunking (cf. Chase & Ericsson, 1973). When faced with an unfamiliar task, the problem solver will automatically recognize instances of familiar chunks in the environment. If the available chunk repertoire does not parse the problem situation in a way that allows finding the solution, an impasse results. Such impasses can be broken, by decomposing the inappropriate chunks into their component features.

Does Insight Create Set?

The present experiment addressed the question of whether the repeated solution of problems that require the problem solver to change the goal representation by relaxing inappropriate constraints, can affect the solution of problems that can be solved with moves activated by the initial problem representation. We hypothesized that there might be a set effect for new moves that results from a prioritization of new procedures that were discovered after having changed the problem representation. We assessed this effect by comparing problem solvers who repeatedly solved problems that needed constraints in the goal representation to be relaxed with a control group in which unrelated problems were solved (anagrams).

We used the task domain of matchstick arithmetic for our study (Knoblich et al., 1999; 2001; Knoblich & Wartenberg, 1998). Each matchstick arithmetic problem consists of an incorrect arithmetic expression written with Roman numerals and with the operators "+" and "-" and the "=" sign; in the following, we shall let the term "operator" include the equal sign. Numerals and operators are constructed out of matchsticks. The task is to move exactly one stick so as to change a false expression into a true one, consisting only of Roman numerals and the arithmetic operators.

Our earlier studies indicate that matchstick arithmetic problems activate prior knowledge of standard arithmetic. Specifically, arithmetic operators are represented as constants and values are represented as variable, in the initial goal representation. Thus, the only moves that will be initially considered are those that transform the values. We refer to problems that can be solved by such moves as Type A problems (see first row of Table 2 for an example). Other problems can only be solved, when arithmetic operators are transformed, as for instance problems of Type C and D (see Table 1). In order to solve these types of problems one needs to relax the constraint on the goal representation that arithmetic operators are invariant. Our hypothesis that new moves discovered after changing the goal representation will create set effects for familiar moves, translates into the prediction that repeatedly solving Type C or D problems will make it generally harder to solve Type A problems.

To test the more specific hypothesis that this type of set effect stems from the repeated activation of the same move, we looked at two different set-groups (see Table 1). In the same-move group, the problem solvers repeatedly solved problems that required them to move a stick between the equal-operator and the minus-operator (Type C), that is, to carry out exactly the same move, before solving the Type A problem that could be solved with a familiar move. In the same-goal group, the problem solvers repeatedly solved problems that required them to manipulate the arithmetic operators in three different ways (Type C, D, and T, see right column in Table 1). If set effects are due to the repeated activation of the same move they should be stronger in the same-move group.

In addition, we assessed how the different set manipulations affected the solution of Type B problems in which a stick needs to be moved between a value and an arithmetic operator (see Table 2, second row). If set effects generalize to all moves that manipulate values, the solution of Type B problems should become more difficult than in the control group. If manipulating operators changes the goal representation in a way that activates a variety of new moves that involve a manipulation of arithmetic operators, the solution of Type B problems should become easier. Such positive transfer effects might be stronger in the same-goal group, because manipulating operators in different ways may change the goal representation in a more persistent manner.

Futhermore, we investigated whether creating an "operator set" also influences the solution of problems that require changing the problem representation in a different way, namely the decomposition of chunks that are tightly bound, as in problems of Type X (see Table 2, third row). In this problem one only needs to manipulate values. They are very difficult, nevertheless, because the chunks involved are especially hard to decompose. If the hypothesized operator set specifically affects finding other unfamiliar moves, the set effects should be especially strong for problems of Type X.

Finally, we also analyzed whether the solution of each target problem made it harder to solve the set problem that followed immediately afterwards. If the solution of a target problem drives down the activation of a specific procedure that has been repeatedly activated such effects should be more pronounced in the same-move group.

Method

Participants

The 108 paid participants (38 male), were recruited by advertising at the University of Munich campus and in local newspapers and received 7 . They ranged in age from 17 to 58 years. We selected only participants, who reported to be familiar with Roman numerals. Participants were randomly assigned to the same-move, the same-goal, or the control group.

Material

The material consisted of matchstick arithmetic problems, all of which could be solved by moving a single matchstick in order to transform a false arithmetic expression into a correct one. Participants in all groups solved three target problems (one of type A, B, and X, respectively; the two sets of target problems used in the experiment are displayed in Table 2).

Participants in both experimental conditions additionally worked on 21 set problems (a block of set problems preceded each target problem). Table 1 displays a list of set problems a participant in each experimental group might have worked on before solving a target problem.

Table 1: Example for five consecutive set problems (SP) in each experimental group.

	Experimental group	
	Same-move	Same-goal
SP1	Type C: IV = II – II Solution: IV – II = II	Type C: VIII = VI - II Solution: VIII - VI = II
SP2	Type C: IX = VII – II Solution: IX – VII = II	Type D: III = III + III Solution: III = III = III
SP3	Type C: VIII = VI – II Solution: VIII – VI = II	Type T: III = II = V Solution: III + II = V
SP4	Type C: X = VIII – II Solution: X – VIII = II	Type C: VII = V – II Solution: VII – V = II
SP5	Type C: XII = VI – VI Solution: XII – VI = VI	Type D: VI = VI + VI Solution: VI = VI = VI
…		

In the same-move group, the participants solved set problems that could only be solved by moving a stick between the equal and the minus sign (Type C problems, see first column of Table 1). The same-goal group worked on set problems that could be solved by one of three different transformations of operators (Type C, D, and T problems, see second column of Table 1). In Type T problems one needs to transform a tautology into a regular arithmetic expression, e.g. by turning the "="into a "+". A randomization procedure ensured that each of the three different moves occurred roughly equally often in each block of set problems. The control group solved anagrams instead of the set problems, for an amount of time that had been determined as the range of solution times for solving a block of set problems in a pilot study (six to ten minutes).

Table 2: The two sets of target problems used in the experiment.

	Target set 1	Target set 2
Type A Solution	IX = X – III IX = XI – II	VI = VIII – IV IV = VIII – IV
Type B Solution	XI = VIII – IV XI = VII + IV	VII = III – III VI = III + III
Type X Solution	XI = X – IV VI = X – IV	IX = X – VI IV = X – VI

Procedure

Upon entering the lab, all participants received an instruction about how to solve matchstick arithmetic problems. The instruction stressed (1) that all problems could be solved by moving one stick, (2) that sticks could not be removed, and (3) that the only valid symbols were Roman numerals and the arithmetic operators "+", "-", and "=". Participants in the control group were also instructed about solving anagram problems and they were told that, while they solved anagrams, a matchstick arithmetic problem would appear once in a while.

During the experiment participants were seated in front of a computer screen. The display consisted of two main areas. The upper area presented the problem, the lower area was used to type in solutions to the problem. In the beginning of each trial a problem appeared. As soon as participants thought they had found a solution, they entered it, using six keys on the keyboards labeled "I", "V", "X", "+", "-", and "=". They received feedback about whether the solution was correct. In the latter case, they continued to search for a solution until they reached the upper time limit. This limit was three minutes for set problems and six minutes for target problems. If a set problem was not solved within the time limit the solution was given. The same display was used to display anagrams in the control group. Participants in this group used the common keyboard mapping for typing in the solution to the anagrams.

A block of set problems preceded each target problem. The number of set problems in each block varied between five and eight, in order to avoid anticipations of the serial position at which a target problem might appear. The last target problem was followed by a further set problem. The order of target problems was randomized. The set problems were randomly drawn from a large sample of problems of type C, D, and T.

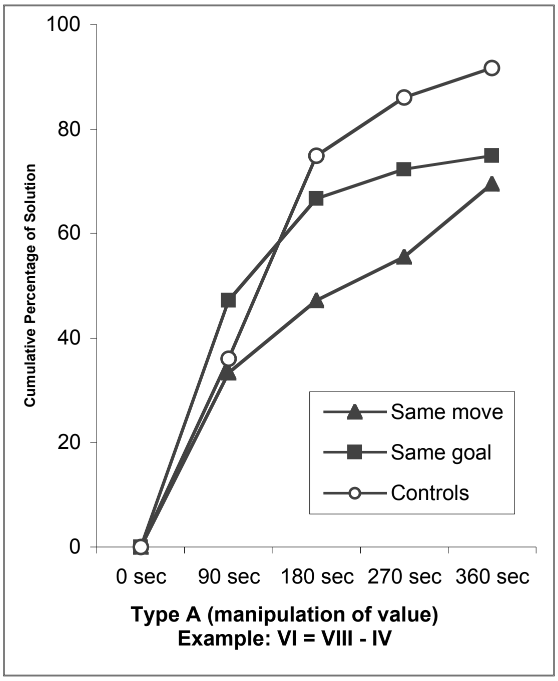
Results

We analyzed two dependent variables. The first was the frequency of solutions for each target problem in 90 s intervals. The second was the solution time for set problems.

Solution frequency for target problems

We conducted pair-wise χ^2-tests to compare the frequency of solution across five different 90s intervals. Participants in the control group were better able to manipulate values in target problems of Type A than both experimental groups (see Figure 1). Accordingly, there were highly significant differences between the control group, and the same-move group, χ^2 (4, 36) = 31.95; $p < .001$, and the control group and the same-goal group χ^2 (4, 36) = 18.23; $p < .01$. Thus, solving operator problems generally created a set for solving value problems. A further χ^2-test confirmed that there also was a highly significant difference between the two experimental groups χ^2 (4, 36) = 18.99; $p < .001$. The set-effect for the solution of Type A problems was stronger in the same-move group.

Figure 1: Cumulative frequency of solutions for target problems of Type A across 90 s intervals, for different experimental groups.



The pattern for target problems of Type B was very different (see Figure 2). Here, the same-goal group performed much better than the same-move group and the control group. Solving different types of operator problems actually ameliorated performance on Type B problems. Accordingly, there was no significant effect between the same-move group and the controls, but a highly significant difference between the same-goal group and the control group χ^2 (4, 36) = 30.83; $p < .001$. Additionally there was a highly significant difference between the same-goal group and the same-move group, χ^2 (4, 36) = 34.13; $p < .001$. This result indicates that solving set problems by manipulating arithmetic operators in different ways led to a positive transfer effect for target problems of Type B in the same-goal group.

Figure 2: Cumulative frequency of solutions for target problems of Type B across 90 s intervals, for different experimental groups.

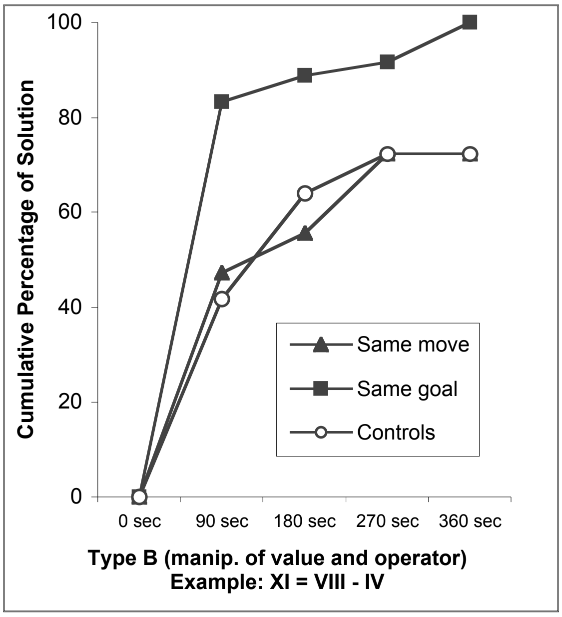
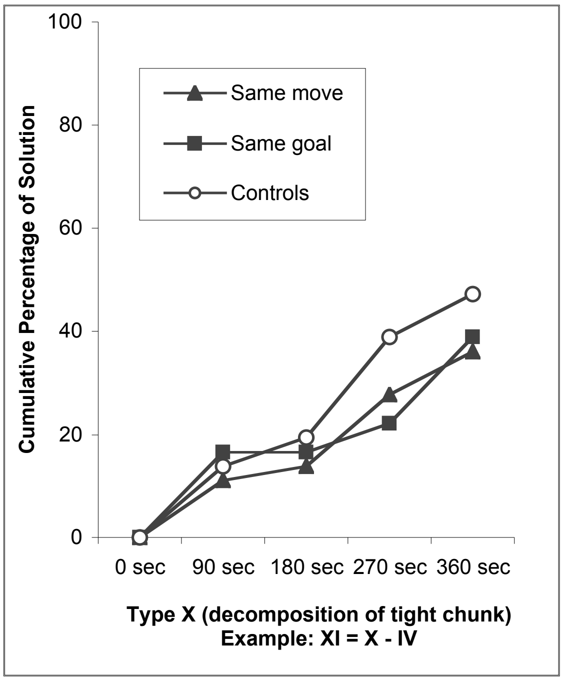


Figure 3: Cumulative frequency of solutions for target problems of Type X across 90 s intervals, for different experimental groups.

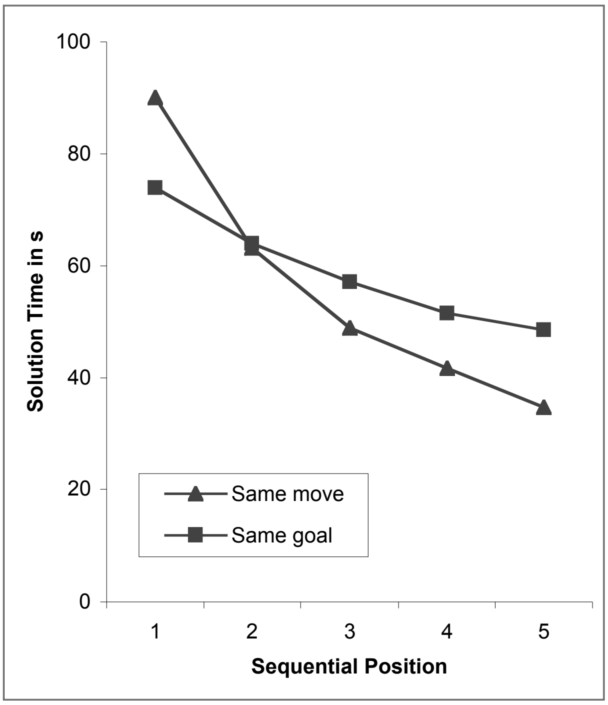


Participants in the control group solved more problems that required the decomposition of a tight chunk (Type X), especially in later intervals (see Figure 3). However, a χ^2-test revealed no significant difference between the same-move group and the controls ($p > .10$). The difference between the same-goal group and the controls just fell short of reaching significance, $\chi^2(4, 36) = 9.24$; $p = .055$. The lack of a significant effect is probably due to a floor effect (the low solution rates make it harder to detect significant effects). There was also no significant difference between the experimental groups ($p > .10$) for Type X problems.

Solution time for set problems

In the next step, we analyzed whether participants in the two experimental groups became faster for consecutive problems within each block of set problems. This analysis provides a check for the set manipulation. Only the first five trials were included in the analysis. Solution times for problems that were not solved (11.6%) within the time limit were replaced with the maximal solution time of 180 s.

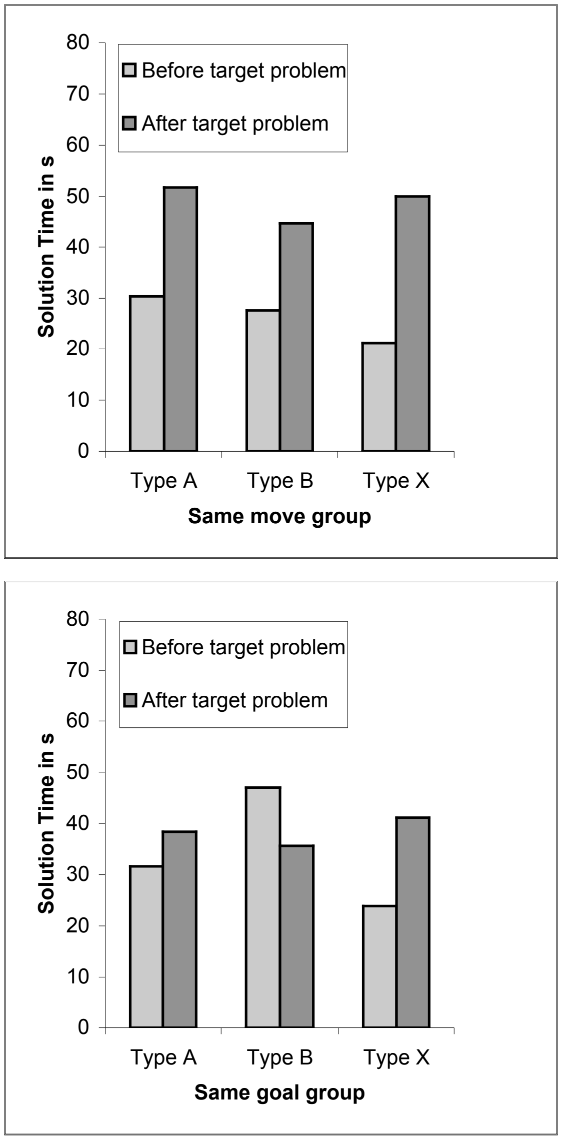
Figure 4: Solution time (in s) for set problems across consecutive trials of a set block, for the two experimental groups.



The solution time generally decreased across consecutive set problems (see Figure 4). The decrease was more pronounced in the same-move group than in the same-goal group. A mixed ANOVA with the between factor Group (same move and same goal) and the within factor Position (1, 2, 3, 4, and 5) revealed no significant main effect for Group $F(1, 70) = .34$; $p > .10$, but a significant main effect for Position $F(4, 280) = 28.64$; $p < .001$, and a significant interaction between the two factors $F(4, 280) = 3.90$; $p < .01$.

In the next step, we analyzed the solution times for set problems that immediately preceded and followed a target problem. This analysis allows us to assess to which extent the solution of a target problem slowed down the solution of the next set problem.

Figure 5: Cumulative frequency of solutions for target problems of Type X across 90 s intervals for the same-move group (top) and the same-goal group (bottom).



The upper panel in Figure 5 demonstrates that in the same-move group solving a target problem generally slowed down the solution of the following set problem. The lower panel in Figure 5 illustrates that the pattern was different in the same-goal group. Although the pattern for Type X looks similar to the one for the same-move group, there was no substantial slow-down after solving target problems of Type A and B. Only the result for Type X is similar to same-move group.

We conducted two 2 x 3 ANOVAs with the within factors Problem type (A, B, and X) and the factor Target set (before and after target), one for each experimental group. There was a significant main effect for Target set in the same-move group, $F(1, 35) = 19.1$; $p < .001$. All other main effects and interactions were not significant. Thus, only in the same-move group, the solution of a target problem significantly slowed down the solution of the following set problem.

Discussion

The results of the present experiment provide clear evidence that the repeated solution of problems that require the problem solver to change the goal representation by relaxing inappropriate constraints, can affect the solution of problems that can be solved with moves activated by the initial problem representation. The result that such effects were stronger, when the same new move was carried out over and over again, suggest that these set effects are due to the repeated activation of a solution procedure that became available after a change in the problem representation, and not to the change in the problem representation per se. In this case the set effects should have been equally strong in the same-goal group. A further important result was that only the same-goal group showed positive transfer effects for the Type B problem that required manipulating a value and an arithmetic operator, at the same time. This result suggests that a persistent change in the goal representation that activates a variety of new moves might only take place if different procedures activated by this representation lead to success. The pattern for Type X problem was somewhat ambiguous, but it provide a first hint that set effects might also make it harder to discover new solutions to problems.

The results of the present experiment alone do not allow us to conclude that the set effects are specific to moves that follow a change in the representation of a problem. After all, the same effects could be present after repeatedly carrying out familiar moves. The result that the solution of the first set problem solved after a target problem was somewhat slowed down seems to support this assumption. However, this effect was quite small (about 20s solution time) and only present in the same-move group. In addition, we have also conducted another experiment that we cannot report here because of space constraints (Oellinger & Knoblich, in prep.). In this experiment, we tried to create an additional set for unfamiliar problems by having problem solvers repeatedly solve familiar problems before they attempted to solve unfamiliar target problems that required a change in the problem representation. There was no indication for additional set effects in this experiment.

Together, the results of these experiments suggest that moves that are discovered after a change in the problem representation create specific set effects for familiar moves. Our preferred explanation for this result is that these moves are prioritized relative to familiar moves in order to increase their availability in the solution of subsequent problems. Such a prioritizing might also explain the strong within-domain transfer that we have observed in earlier studies.

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