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The Influence of Open Goals on the Acquisition of Problem Relevant Information

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Abstract

There have been a number of recent findings that indicate that unsolved problems, or open goals more generally, influence cognition even when the current task has no relation to the one where the goal was originally set. It was hypothesized that open goals would influence what information entered the problem-solving process. Three studies were conducted to establish the effect of open goals on the acquisition of problem relevant information. It was found that problem relevant information, or hints, presented implicitly in a second task in between attempts at solving problems aided problem solving. This effect can not be attributed to strategic behavior after participants caught on to the manipulation as most participants were not aware of the relationship. The implications of this research are discussed including potential contributions to our understanding of insight, incubation, transfer, and creativity.

The Influence of Open Goals on the Acquisition of Problem Relevant Information

Many aspects of human problem solving are now well understood, and much of this understanding is based on how people work within a certain problem space in order to solve a problem (Newell & Simon, 1972). In extending the theory of problem solving to more complex and ill-structured problems, Simon (1973) noted that in solving such problems there must be a noticing and evoking mechanism that brought relevant information into the immediate problem-solving process at the right time. This mechanism must be able to notice relevant information from the environment or evoke it from memory. Such a mechanism may also play a role in solving insight problems requiring a representation change as people seem to be guided in their search for a new representation by noticing certain invariants in their repeated failures to solve a problem (Kaplan & Simon, 1990). These examples highlight the role of noticing relevant information during problem solving, and they indicate the importance of understanding under the conditions under which information is likely to be noticed and incorporated into problem solving. There are a number of variables that may influence which information gets noticed. The research presented here examines the role that open goals play in acquiring relevant information.

The definition of an open goal used in this paper is that an open goal is a goal which has been set but one for which the associated task has not been completed. Zeigarnik (1927/1938) originally demonstrated that interrupted tasks were recalled more readily than completed ones. A number of researchers attempted to replicate this finding with a variety of tasks, but the results of these replications were mixed (see van Bergen, 1968 for a review), More recently, studies have shown that unsolved problems were recalled better than solved problems, and the relative number of unsolved and solved problems played a role in determining whether there is a recall advantage for unsolved problems (Patalano & Seifert, 1994; Seifert, Meyer, Davidson, Patalano,

& Yaniv, 1995; Seifert & Patalano, 1991). There have also been a number of studies which demonstrate that unsolved problems or open goals in general are maintained in an accessible state and may exert some influence on other tasks (Marsh, Hicks, & Bink, 1998; Patalano & Seifert, 1994; Rothermund, 2003; Seifert & Patalano, 1991; Shah & Kruglanski, 2002). In the work presented here open goals are synonymous with unsolved problems. However, the more general construct of open goals, instead of unsolved problems, is used in this paper because some of the results just mentioned are from domains outside of problem solving. Identifying open goals as a general construct helps to emphasize the possibility that a common mechanism that is operating in all of these domains.

Such a mechanism has obvious benefits in areas like prospective memory where it has been proposed that yet to be completed intentions are maintained at a heightened level of activation as items related to these intentions are recognized faster than unrelated items (Goschke & Kuhl, 1993; Marsh et al., 1998). In addition, it has been shown that memories for unfulfilled intentions are more likely to be retrieved at appropriate times when the intention is encoded along with a general class of enabling objects in mind (Patalano & Seifert, 1997). Research on memory recall shows that items in memory for which there has been a failure to recall the item are more likely to be recalled successfully after a subsequent presentation of the item in a second task than are items which are presented without a previous recall failure (Seifert et al., 1995; Yaniv & Meyer, 1987; Yaniv, Meyer, & Davidson, 1995). These results led to the proposal of a memory sensitization hypothesis where retrieval cues for which a retrieval failure has occurred are marked in memory some way that makes it more likely that further exposures to the target of the marked cue will lead to assimilation of the target so that future attempts at recall will be more likely to succeed.

Open goals are not always beneficial as they have also been shown to interfere with performance on other tasks. Shah and Kruglanski (2002) found that anagram solving performance was affected by a subliminal prime related to an alternative task goal. Rothermund (2003) found that distractor items from unsolved problems interfered with task switching while distractor items from solved problems facilitated the switch. These findings illustrate the generality of the influence of open goals as effects have been found across a number of different types of tasks including processes of memory, attention, and problem solving.

The emphasis of the studies presented in this paper is on understanding the role that open goals play in problem solving. The main hypothesis under investigation is that open goals influence the acquisition of problem relevant information by increasing the likelihood that such information is acquired and used in solving the problem. The alternative is that problem relevant information is just as likely to be acquired when it is presented immediately before work on the problem has begun as when it is presented after some initial work on the problem. The results of this investigation have implications for our understanding of how people solve problems including phenomena such as insight, incubation, transfer, representation change, and creativity.

Insight

The problem-solving research that has examined how information relevant to unsolved problems is acquired has focused on the role such a mechanism may have in overcoming impasses in insight problem solving (Christensen & Schunn, 2005; Dodds, Smith, & Ward, 2002). Some of the earliest work on insight problems is consistent with an influence of open goals as Maier (1931) found that participants exposed to an implicit hint during work on an insight problem solved the problem more often than participants who did not receive the hint. Furthermore, the majority of participants who solved the problem after receiving this hint did not report any awareness of having received the hint. Making use of this implicit hint is exactly what one would expect if having the open problem-solving goal made participants more likely to incorporate information from the environment into their problem solving. There have also been more recent studies which have shown that unreportable processing of solution-related information contributes to the experience of insight (Bowden, 1997; Bowden & Jung-Beeman, 2003a).

Langley and Jones (1988) describe one idea for how exposure to new information can lead to the solution of unsolved problems through insight. Their account is based on spreading activation, and relies on the assumption that a problem may be connected to many other items in memory (i.e., high fan) while other items related to the problem may be connected to fewer items (i.e., low fan) so that exposure to the right item will lead to reactivation of the problem. While their account is partially based on factors known to influence memory retrieval and accounts for why the useful information was not retrieved on the initial attempt at the problem, they do not provide any empirical support for their hypothesis.

Seifert et al. (1995) present an opportunistic assimilation hypothesis for how acquiring new information can promote insight after an impasse. Their proposal was that when impasses are encountered a set of failure indices are set up in memory which link to the problem. Encounters with information in the environment may lead to retrieval of these indices when the information is related to the problem. This new information may lead to an insight that helps to overcome the impasse. They presented two sets of results that indirectly support their hypothesis. One was their replication of the Zeigarnik effect which they used to argue that reaching an impasse was key to increased accessibility of unsolved problems relative to solved problems (Patalano & Seifert, 1994; Seifert & Patalano, 1991). They also presented evidence showing that a failure to recall an item from memory in some cases increases the likelihood that chance encounters with the stimuli in another task will lead to improved recall in future retrieval attempts (Yaniv & Meyer, 1987; Yaniv et al., 1995).

One problem with the opportunistic assimilation hypothesis is that there is no direct evidence that the proposed effect actually occurs in problem solving. In addition, no details are offered on what failure indices are and how they would be accessed at the right moment when someone is engaged in an unrelated task. It may be that these indices and associated problem information are maintained at a heightened level of activation or accessibility, but their studies do not provide evidence of long-term heightened activation given that topic familiarity is an alternative explanation of their priming results (Connor, Balota, & Neely, 1992).

The evidence presented for opportunistic assimilation is suggestive, but it is far from clear that this kind of effect would occur in a problem solving task. Memory retrieval is a key component in many forms of problem solving, and so the results supporting the opportunistic assimilation hypothesis suggest that this kind of effect may be found in a problem solving task. However, there are many other processes involved in problem solving including those of representation and search, and representation change is often a key component in insight problem solving (Knoblich, Ohlsson, Haider, & Rhenius, 1999; Ohlsson, 1992).

A recent study by Christensen and Schunn (2005) did find that participants trying to solve insight problems benefited from exposure to analogically similar insight problems and solutions that were presented during breaks in problem solving. However, their participants indicated awareness of the relationship so some of their results could have been due to strategic search for related problems after they caught on to the relationship. In addition, they only presented hints to the solution of the problem after the problem had been worked on, so it is impossible to rule out that the hints would have helped even if presented before problem solving began.

These findings in the insight literature provide some support for the idea that open goals may direct the acquisition of problem relevant information. However, they also highlight the need for a set of carefully controlled studies that examine whether these effects occur in a problem solving task. The goal of the studies presented here is to investigate whether open goals influence the acquisition of relevant information from other tasks.

Incubation

Incubation is another related area where open goals are likely to have an effect. Generally, incubation is defined as some break from the problem that aids problem solving. Past attempts to find incubation effects have resulted in both success and failure (e.g., Dominowski & Jenrick, 1972; Dreistadt, 1969; Fulgosi & Guilford, 1968; Olton & Johnson, 1976). One review of incubation effects called into question the existence of incubation (Olton, 1979). More recently, reviews of the incubation literature have concluded that incubation is a real phenomena (Dodds, Ward, & Smith, in press; Kaplan, 1989). There have been a number of theories of incubation including those that involve unconscious work (e.g., Campbell, 1960; Simonton, 1999), forgetting (e.g., Simon, 1966; Smith, 1995; Smith & Blankenship, 1991), priming (e.g., Langley & Jones, 1988; Seifert et al., 1995), and combinations of forgetting and priming (Kaplan, 1989).

Presenting answers to problems in another task that occurred during a break in problem solving was found to produce a marginally significant incubation effect (M. T. Mednick, Mednick, & Mednick, 1964). Using the same problems and a similar method, Dodds, Smith, and Ward (2002) failed to find a significant incubation effect unless the participants were instructed to look for hints during the second task. The lack of a significant difference when participants were not given instructions indicates that there might be limitations on how problem relevant information can be acquired. One possible reason for the lack of an effect could be due to the fact that the task in which hints were presented by Dodds et al. involved mainly orthographic processing and not semantic processing. It has been shown that semantic priming effects are enhanced when tasks involve a greater amount of semantic processing (Becker, Moscovitch, Behrmann, & Joordens, 1997).

There have also been attempts to study incubation and insight using less direct measures. Instead of looking at improvement on problems after a break, some researchers have examined measures of accessibility such as lexical decision or word naming times in order to figure out what is going on during incubation and insight. Over short delays, answers to unsolved problems are primed relative to words unrelated to the problems in lexical decision and naming tasks, and the amount of this priming is related to the insight experience that participants report (Beeman & Bowden, 2000; Bowden & Beeman, 1998; Bowden & Jung-Beeman, 2003a; Dorfman, Shames, & Kihlstrom, 1996; Kihlstrom, Shames, & Dorfman, 1996; Shames, 1994). The finding that priming occurs for answers to unsolved problems is interesting since the answer has not been generated in the case of unsolved problems.

These results from the incubation literature indicate that the type of task in which hints occur may have an impact on any effect of open goals, and that hints presented in another task may be responded to faster than neutral words. These possibilities are investigated in the studies reported here.

Problem Solving and Memory Retrieval

In general, there is evidence throughout the literature that open goals influence cognition. The studies presented here were designed to provide further evidence that open goals do influence cognition and specifically to show that they influence the acquisition and use of problem relevant information. All of the studies presented here make use of a design where participants work on a set of problems, followed by a second task where implicit hints are presented for some of the problems that participants left unsolved. After the hints have been presented, participants then get a second opportunity to work on the old (and sometimes new) problems.

The studies reported in this paper use compound remote associates test (RAT) problems to study the influence of open goals due to the fact that they are short insight-like problems where the prior knowledge of a participant is not a concern. Each problem consists of three words, and the task is to find a fourth word that forms a compound word or common phrase with each of the other words (Bowden & Jung-Beeman, 2003b). While these kinds of problems have been used in the past as a test for creative ability (S. A. Mednick, 1962), we use them just as a problem solving task.

RAT problems rely on memory retrieval, and, as noted earlier, memory retrieval plays a role in many aspects of problem solving behavior. These problems are problematic for people because the cues provided are not particularly good retrieval cues. The cues only have a weak association to the target word. There has been some evidence that people can distinguish between an immediate insight-like recognition of these problems and one where there is strategic testing of a candidate solution (Bowden & Jung-Beeman, 2003a). Participants may answer some problems quickly through this kind of automatic recognition and retrieval, but at some point participants switch into a more methodical generate and test procedure.

This generate and test procedure is evident in Figure 1 which shows excerpts from a verbal protocol study in which participants thought aloud while solving RAT problems (Moss, 2006). In these protocols it is clear that the primary method of problem solving is a generate and test procedure. The generate process generates a candidate word based on one or more of the words given in the problem plus any additional information that has been acquired through search. Each word in a RAT problem usually has more than one meaning or associated concept. For example, the word “iron” can be a metal, a small appliance, an action, or even part of the name of a beer as shown in Figure 1. Finding the right associate requires searching for it using the right representation. After trying to generate an answer related to iron as a home appliance, a participant may try to find a new interpretation. An example of a request to the generate process could then be to find an associate of iron as a metal. This process is able to take advantage of some of the results of previous search efforts.

Another example of search and representation from Figure 1 is the statement “lets see what kind of law”. Here the participant is searching for associates using a “type of” query which may lead to results such as “criminal law”. Participants also report using simple strategies such as choosing the least frequent word or the one with the fewest associates. These examples illustrate that while RAT problems are tied to memory retrieval, they also involve aspects of problem solving including strategies, representation change, and search. These characteristics make RAT problems a good place to start when looking for open goal effects that have previously only been found in a memory retrieval task.

While RAT problems rely on memory retrieval, their solution does involve problem solving processes that are not present in other recall tasks such as retrieving a word from its definition Yaniv et al. (1995). Figure 2 shows excerpts from protocols in the same study presented in Figure 1, but in this case participants were verbalizing while trying to retrieve a word from its definition using the same definitions used by Yaniv et al. (1995). The most obvious difference between the RAT and the word retrieval tasks is that participants do not verbalize much, if at all, in the word retrieval task. The two examples presented in Figure 2 show that the only verbalization produced is a repetition of the definition given to the participant. This inability to verbalize is to be expected as participants can only be expected to verbalize information that enters into working memory (Ericsson & Simon, 1993). A word's definition should have strong semantic links to the word itself so only a simple retrieval request is needed to produce the answer, and little to no search information enters working memory. This comparison provides further evidence for the search processes involved in RAT problem solving.

Another difference between RAT problem solving and the word retrieval task used by Yaniv et al. is that participants' ratings of their proximity to a solution on RAT problems using a feeling of warmth scale are not predictive of their future chances at solving the problem or the effect of seeing the answer in another task (Moss, 2006). For word retrieval, Yaniv et al.'s participants' ratings of feeling of knowing did relate to future attempts at recall, the impact of seeing the target word, and the amount of priming seen in a lexical decision task. In fact, an alternative explanation of their priming results is based on the relationship of topic familiarity and feeling of knowing rather than the status of the prior retrieval attempts (Connor et al., 1992).

Finally, Yaniv et al. (1995) present two studies in which they obtained an interaction effect that ruled out the possibility that just seeing the word recently led to improvements in recall. However, it is not clear how much of this effect was due to strategic behavior after participants caught on to the manipulation. In fact, their study which showed the strongest interaction involved presenting a small set of lexical decision trials in which the target word was embedded after each word definition trial. It seems likely that their participants caught on to the manipulation and may have strategically looked for the target word in the lexical decision task immediately following an unsuccessful recall attempt. In fact, participants recognized having seen target words more quickly and accurately than they recognized other words from the lexical decision trials. It is important to assess the degree to which these kinds of results are due to strategic behavior by participants as opposed to more automatic cognitive processes.

While RAT problems do not involve particularly complex problem solving processes, the experiments presented here represent an important extension to prior results. Experiment 1 demonstrates that hints do affect performance on RAT problems. Experiments 2 and 3 show that the effect of the hint is not due to a simple priming explanation where the recency of seeing the hint improves performance on the RAT problems. Experiments 2 and 3 also examine whether the results could be due to participants catching on to the experimental manipulation.

Experiment 1

Failed recall attempts have been shown to bias acquisition of information from another seemingly unrelated task (Yaniv & Meyer, 1987; Yaniv et al., 1995) but the same thing has not been demonstrated for a problem-solving task. RAT problems have been shown to induce priming in answer words regardless of whether they were solved or not, but the task in which priming has been measured always immediately followed each RAT problem (Shames, 1994; Yaniv & Meyer, 1987). This study examines whether a priming effect occurs when the delay is increased to include a number of intervening problems. If a maintained level of activation is associated with the way open goals influence cognition in real-world problems involving long periods of time, then priming should be observed.

Method

Participants. The participants were 39 undergraduate students at Carnegie Mellon University who completed the study as part of a course requirement. All of the participants were native English speakers.

Materials. The remote associates problems used in this study were taken from a recent set of normed RAT items (Bowden & Jung-Beeman, 2003b). The 20 RAT problems we used were chosen from the normed set so that the mean proportion of participants solving them was .51 with a range of .38-.64. For each answer to the RAT problems, three words of the same length and similar frequency were selected from a database of words (Balota et al., 2002) to serve as control words. A set of 20 nonwords of similar length were also obtained from the same database. The set of words and RAT problems were generated so that none of the words were associated with any of the RAT problems, and none of the words in the RAT problems were associated with words in another RAT problem. Word association was determined using a set of word association norms (Nelson, McEvoy, & Schreiber, 1998).

Design. The experiment involved two blocks of RAT problems and an intervening lexical decision task. The first block of RAT problems was followed by a lexical decision task where answers to some of the RAT problems appeared as stimuli. The lexical decision task was followed by another attempt at the same set of RAT problems. The two factors in the study were whether the RAT problems were initially answered correctly or incorrectly and whether or not the answer was presented as an implicit hint during the intervening lexical decision task. While the solution status of the RAT problems was not manipulated, the presence or absence of the answer in the lexical decision task was assigned randomly to half of the problems in the solved and unsolved groups for each participant.

Procedure. All tasks were presented on a computer with a 17-in. monitor using E-Prime software (Schneider, Eschman, & Zuccolotto, 2002). Participants were given instructions on how to complete both tasks, and they were told that the experiment would involve alternating between the two tasks a few times. The RAT problems were called word association problems, and participants were told that they should answer the problems by generating a word that forms a compound word or common phrase with each of the other three words. They were told that they would be given 30 seconds to answer each problem. They were only allowed to enter one attempted answer for the problem. In order to discourage frequent guessing as a way to finish the experiment faster, a score was presented on the screen after each RAT problem in addition to feedback about whether the problem was answered correctly or not. The score was increased by five points for each correct answer, decreased by two points for each incorrect answer, and did not change when no answer was provided. The RAT problems were presented as three words arranged in a vertical column in the center of the screen with an outlined box presented beneath the last word in which the participants typed their answer. After the problem was answered, feedback on the answer (solved/unsolved) as well as the current score was presented for one second followed by the next problem.

Participants were initially given two practice RAT problems. This practice period was followed by the presentation of the first block of 20 RAT problems. After completing the 20 RAT problems, the participants completed a lexical decision task.

Participants were instructed on which key to press for the word and nonword responses and to respond to each string of letters as quickly and as accurately as they could. They were given 20 practice lexical decision trials with feedback before the experiment began so that they learned the correct key mappings. Each trial began with a fixation cross presented in the center of the screen for 1500 ms followed by the stimuli which remained on the screen until the participant responded. A blank screen was presented for 500 ms between trials. A total of 50 trials made up the lexical decision task with 25 word trials and 25 nonword trials. The first 10 trials were considered practice trials and consisted of 5 words and 5 nonwords presented in a random order for each participant. These trials were included to allow the participant to fully switch to the lexical decision task before collecting reaction times for the critical experimental stimuli. The remaining 20 words consisted of 10 control words and 10 hint words that were answers to the previously presented RAT problems. When possible, the hints consisted of 5 answers to RAT problems that the participant got correct and 5 words from problems that the participant got incorrect or failed to answer in time. For each hint, a set of three words of similar frequency and length had been constructed beforehand, and during the study one of these words was randomly chosen to serve as a neutral control for that hint. These 40 non-practice words and nonwords were presented in random order. In cases where a participant did not have at least five incorrect or five correct answers, the number of lexical decision trials was reduced by one control word and one answer word for each number less than five.

After the lexical decision task was completed participants were informed that they would now be presented with the same set of 20 RAT problems again. This was the first time the participants were informed they would see the same problems again. After completing this final set of RAT problems the participants were debriefed.

Results

Data from three participants were excluded from all analyses because they guessed at the answers to the RAT problems in an apparent attempt to finish the study quickly. The criteria for exclusion were answering more than 15 RAT problems in either of the two sets of 20 and getting less than 50% of the answered problems correct.

Improvement on RAT Problems. The improvement from the first attempt at the RAT problems to the second attempt was assessed by examining the proportion of RAT problems that were solved correctly on the second attempt after being left unsolved initially. So for the hint condition, this number would be the number of previously unsolved RAT problems that were solved on the second attempt for which a hint had been presented divided by the number of unsolved RAT problems for which a hint had been presented. The results for the no-hint condition were calculated in the same way. For this analysis, one subject was excluded because there were no unsolved RAT problems for which a hint had not been presented. This occurred because the program that ran the experiment randomly chose 5 unsolved problems to include in the hint condition, and this method assigned none of the unsolved problems to the no-hint condition because this participant solved many more problems than expected on the initial attempt.

Participants on average solved 46% of RAT problems on their first attempt. Problems which had been solved on the first attempt were solved more than 95% of the time regardless of whether a hint was presented. For unsolved problems, participants improved more in the hint condition (M = .23, SE = .03) than in the no-hint condition (M = .14, SE = .03), $F(1, 34) = 5.53$, $p = .03$, $\eta = .14$. This result means that the hint was effectively acquired and used in problem solving at least some of the time. Problems which had been answered correctly the first time were answered correctly the second time 96% of the time.

The success rate for the initial block of RAT problems was also examined in relation to improvement on the second block of RAT problems in order to assess the plausibility of the hypothesis that having fewer open goals would lead to a higher chance of improvement on problems where the answer was presented. There was a significant correlation between the proportion of problems left unsolved on the initial block of RAT problems and the improvement on the unsolved problems for which a hint was presented, $r = -.36$, $p = .03$, but there was no significant correlation between the number left unsolved and improvement for problems in the no-hint condition. This result could indicate that having fewer open goals increases the chances of acquiring relevant information as it may be harder to maintain a large number of open goals.

Lexical Decision. Accuracy on the lexical decision task was 97% or better in all conditions. A detailed examination of the responses in the lexical decision task revealed that five participants had unusually high average response times with more than 20% of their responses to words taking more than one second. These participants may have realized that some of the words were answers to previously seen RAT problems and tried to process the words accordingly. These four participants were not included in the analysis of the lexical decision responses. The exclusion of these participants from the analyses of the RAT problems did not change the results of those analyses. For the remaining participants, response times to word stimuli longer than 1300 ms (0.5% of the data) were excluded from the analysis as such extreme times are indicative of lack of attention for a particular trial.

The mean correct lexical decision response times are presented in Table 1. These times were analyzed in order to determine if there was any evidence that participants were primed to respond to answers to the RAT problems, or hints, relative to the control words. The response times were analyzed using a 2 x 2 repeated measures ANOVA where the factors were whether the RAT problem corresponding to the presented hint was solved or not and whether the word presented was a hint (i.e., an answer to a RAT problem) or was a control word. There were no significant main effects, but there was an interaction, $F(1, 30) = 10.23$, $p = .003$, $\eta = .25$, which was due to the fact that participants responded faster to hints than control words only for unsolved problems, $F(1,30) = 9.46$, $p = .004$, $\eta = .24$. This result indicates that participants were primed to respond to the word that related to an open goal. Interpretation of these results is somewhat limited by the fact that whether a problem was solved or not was not a true independent variable, although whether a hint was presented for each set of solved/unsolved problems was a randomly assigned variable.

Discussion

The results demonstrate that the hints presented in the lexical decision task did improve performance on the RAT problems more than just a second attempt at the same problems. Participants were not explicitly informed of the relationship between the tasks, and so the results seem to contradict the findings of Dodds et al. (2002). However, it could be that the tasks used to present the answers differed in that the lexical decision task may have required some semantic processing which the word finding task used by Dodds et al. did not. This issue is explored in Experiment 2.

The negative correlation between the number of problems left unsolved on the initial attempt and improvement on problems for which hints were presented may be indicative of a limit on the number of open goals that can successfully be maintained. As the number of open goals increases, the ability to recognize relevant information may decrease due to interference or a resource limitation. Another possible interpretation of this correlation is that participants who performed better on the RAT problems were also better at making use of the hints. This issue is further addressed in Experiment 3.

The significant priming effect for hints to the unsolved problems in the lexical decision task is interesting because it not only replicates similar findings from other work on memory retrieval and RAT problem solving but also extends these findings as priming was found over many more intervening problems and over a longer period of time than in prior work. This result means that leaving the RAT problem unsolved somehow primed participants to respond to stimuli related to that problem. Priming was not found for answers to solved problems even though participants had just generated the answer minutes before they were asked to respond to it in the lexical decision task. This result provides some support for the idea that open goals are serving as a source of maintained activation even over a number of intervening problems.

While word length and frequency were controlled for, the lexical decision results could be due to the fact that there were uncontrolled for differences between the answers to RAT problems and the neutral words. Experiment 2 improves upon this methodology by using answers to RAT problems as both hints and neutral words so that the same stimuli appear in both conditions across participants.

Experiment 2

The purpose of this experiment was to compare the effectiveness of presenting a hint the problem had been attempted to the effectiveness of presenting the hint after an open goal had been established. This is an attempt to both replicated the results of Experiment 1 and to determine whether the effect of the hint seen there is due to the presence of open goals or merely to the recency of the exposure to the hint prior to the second attempt at the problems.

In the first study, participants improved more on RAT problems when the answer was presented during a separate lexical decision task even though they were not informed about the relationship between the two tasks. One explanation for this result that has nothing to do with open goals is that the words in the lexical decision task increased the activation of the answers so that participants were able to retrieve the correct answers when shown the RAT problems for a second time. This experiment evaluated the effect of presenting the answer for the problem before seeing the problem so that the effect of increased activation for the answer word can be evaluated without the presence of the associated open goal.

When comparing the effectiveness of the hint in these two conditions, one issue that must be considered is that participants can experience fixation on RAT problems due to interference from the first few words or concepts that are recalled (Smith & Blankenship, 1991). The idea is that it becomes more difficult to think of new associated words due to interference from the words already recalled. Smith and Blankenship (1991) demonstrated that some of this interference can be overcome by taking a break from the problem so that the previously solution attempts decay making it easier to think of new items.

Given that interference plays a role in the difficulty of solving these problems it should be expected that presenting the answer word before there has been any attempt at the problem would have a larger impact on RAT problem solving than in the case where there has already been a failed attempt at problem solving. If it is the case that presenting the word just raises its activation level which increases its probability of recall, then having no prior interference from distractor words would increase the effectiveness of presenting a hint relative to the case where there are other activated words competing for recall.

This study also employs a blocked design as it was thought that having fewer unsolved problems before the hint was presented may increase the effect of the hint.

Method

Participants. The participants were 31 people from the Carnegie Mellon community and the surrounding area who participated in exchange for $6. All of the participants were native English speakers and were between the ages of 18 and 35.

Design. The design was similar to that of Experiment 1 except that a condition was added where a hint was presented before the problem had been attempted. This study employed a blocked design where blocks of 5-8 problems were presented with lexical decision tasks between each block as can be seen in Figure 3. There were four pairs of blocks, which will be referred to as sets, with each set being made up of one block where RAT problems were initially presented and a second block which consisted of a second presentation of the RAT problems from the first block as well as previously unseen problems. In between the two blocks making up a set, a lexical decision task was given where answers to half of the previously unsolved problems and half of the unseen problems were given. The second block of RAT problems in each set was followed by a block of lexical decision trials where all of the stimuli were unrelated to the RAT problems. Participants were informed that they would be switching between the two tasks, and this neutral lexical decision task was included in order to reduce the likelihood that participants would notice the relationship between the two tasks, and therefore begin to strategically look for answers in the lexical decision task.

A total of 30 RAT problems were selected from the norms published by Bowden and Jung-Beeman (2003b) using the same constraints for problem selection used in Experiment 1. For each participant, 20 of these problems were randomly selected to be presented twice, and the remaining 10 were presented as previously unseen problems in the second block of each set. The 20 problems were broken into four blocks of five problems each, and these blocks were the first member of each set. The second block of each set consisted of the five problems that had already been seen and 2-3 problems that were previously unseen, with answers to half of the unsolved and unseen problems being presented during the lexical decision task separating the two RAT blocks of each set. Overall, five of the ten unseen problems had their answers presented before being attempted. For the set of unsolved and unseen problems, each problem was randomly assigned to either the hint or no-hint condition.

Each lexical decision task consisted of an equal number of words and pronounceable nonwords. The neutral lexical decision blocks which did not separate pairs of corresponding RAT blocks each consisted of 10 words and 10 nonwords all of which were unrelated to the RAT problems. The lexical decision blocks which contained hints consisted of 9 neutral words and 9 nonwords plus the answers to unsolved and unseen problems along with an equal number of nonwords.

In constructing each block of lexical decision trials neutral filler words were randomly selected from a pool of 107 words unrelated to the RAT problems and their answers. Nonwords were randomly selected from a pool of 168 nonwords. The order of trials within a block of lexical decision trials was randomized. The timing for the lexical decision stimuli and fixation cross was the same as in Experiment 1. The first six trials of each lexical block consisted of three words and three nonwords which were considered practice trials. None of the hints were presented during these practice trials, and they were not included in any of the analyses.

Procedure. Presentation of the RAT problems was the same as in Experiment 1 except that the scoring system was eliminated. Instead, if a participant entered an incorrect answer, the computer made an error sound and the box was cleared, and the participant then had the remainder of the 30 second time limit for each problem to continue working on the problem. If the problem remained unsolved after 30 seconds or it was solved, the problem was cleared and the feedback consisting of the word “Unsolved” or “Solved” was presented in the center of the screen for two seconds before the next problem was presented. After the completion of the study, participants completed a questionnaire to assess their awareness of the relationship between the RAT and lexical decision tasks.

Results

One participant was excluded from all analyses because 49% of his lexical decision responses to word stimuli were greater than 1300 ms. All other participants had fewer than 20% of their response times above 1300 ms.

Improvement on RAT Problems. The design of the study included an initial presentation of RAT problems that were subsequently presented a second time and the presentation of previously unseen problems mixed in with the second presentation of the RAT problems. It was expected that there would be no difference between the initial presentation of the RAT problems and the unseen RAT problems which did not have hints presented since these are both cases where the problem is seen for the first time without first seeing a hint. These two sets of problems did not differ significantly, $t(29) = 1.39$, $p = .18$, and so the problems from these sets were combined into one set which consisted of all RAT problems where no hint had been presented before the initial presentation of the problem.

Problems which participants had answered correctly the first time were answered correctly on the second attempt 98% of the time. The proportion of problems solved in each of the remaining conditions can be seen in Figure 4. The data were analyzed with a 2 x 2 repeated measures ANOVA with the factors being whether this was the first or second attempt at the problem and whether a hint had been presented. Problems which had been left unsolved were more difficult than previously unseen problems, $F(1,29) = 62.32$, $p < .001$, $\eta = .68$. The hint was effective in increasing the proportion of problems solved, $F(1,29) = 5.91$, $p = .02$, $\eta = .17$. There was no interaction $F(1,29) < 1$.

As can be seen in Figure 4, previously unsolved problems were much more difficult than unseen problems. The results in Figure 4 are evidence for some effect of open goals since problems which had already been attempted were more difficult (i.e., they were the unsolved subset) and should have a higher interference level from other incorrect solution attempts which had already been examined and rejected by the participant. Taking into account the relative difficulty of the unsolved problems, the hint led to the solution of 48% more previously unsolved problems while the hint only led to the solution of 22% more unseen problems.

Lexical Decision. Accuracy on the lexical decision task was 95% or higher in all conditions. In order to determine if there was a priming effect in the lexical decision task, the mean correct response times for the hint words for unsolved problems were compared to the hints for the yet to be seen problems. Response times longer than 1300 ms were eliminated (4% of the data). Participants did not respond significantly faster to the hints for unsolved problems ($M = 637$, $SE = 18.9$) than they did to the hints for unseen problems ($M = 639$, $SE = 18.0$), $F(1, 29) < 1$. In other words, the hints for unsolved problems were not primed relative to neutral words.

Awareness of the Manipulation. Eight of the participants reported noticing the relationship between the RAT problems and the lexical decision task. These participants did show a slightly larger effect of the hint regardless of whether the problem was previously unsolved or unseen. This is what would be expected if they were employing some strategy to recall the words they had seen in the previous lexical decision task. The pattern of results does not change with these participants excluded.

Discussion

This study replicates the results from Experiment 1 and provides additional evidence that a simple activation based account is not likely to account for the effect of the hint when there is an open goal. If the effect of the hint was due solely to increasing the accessibility of the answer, then there should be a larger effect of the hint for unseen problems than for previously unsolved problems because these problems do not have any interference from activated problem relevant words other than the answer word. The lower solution rates of the previously unsolved problems across both the hint and the no-hint condition are indicators that prior attempts at solving the problems have activated related but incorrect words, or distractors, which interfere with retrieving the answer. This type of interference has been shown in exactly this kind of situation by analyzing verbal protocols of participants solving RAT problems (Moss, Kotovsky, & Cagan, 2007).

The fact that a majority of the participants did not report any knowledge of the relationship between the two tasks in the study or any strategy to rehearse or remember the unsolved problems makes it unlikely that the results are due to participants trying to strategically recall words that they had seen. Even when those participants who did indicate awareness were removed, the pattern of results did not change.

It should also be noted that any maintained level of activation did not translate into a significant priming effect in the lexical decision portion of this study, but other studies, including Experiment 1, have shown a priming effect in this kind of situation (Beeman & Bowden, 2000;

Bowden & Beeman, 1998; Bowden & Jung-Beeman, 2003a; Kihlstrom et al., 1996; Shames, 1994). These previous studies have all used shorter delays between the unsolved problem and the lexical decision task, and it may be that the priming effect is smaller or less reliable at greater time intervals.

Overall, the results from Experiments 1 and 2 indicate that information presented in a second task has a reliable impact on unsolved problems. However, it is not clear how this information later becomes incorporated into problem solving as the brief increase in activation associated with seeing the hint does not fully account for the results.

One potential problem with this kind of study is that there is no control over whether a problem is solved or not, and this could lead to the case where the hardest problems are over represented in the unsolved condition relative to the unseen condition. An analysis of problem difficulty revealed that there were five problems which less than a third of participants solved on their first attempt. Excluding these problems leads to the results presented in Figure 5 which also suggests that the hint has a larger effect in the case where there is an open goal. In this Experiment problems were randomly assigned to be unseen problems, but in Experiment 3 an effort was made to equate the problem difficulty of the unseen and unsolved condition by insuring that each problem appeared equally often in the unsolved and unseen conditions across participants.

Experiment 3

This experiment was designed to conclusively answer the question about whether the results in Experiments 1 and 2 were due to an open goal mechanism or alternatively can be explained by a simple recency effect where people are more likely to answer the problem after seeing the answer recently. In order to accomplish this goal, the design of Experiment 2 was modified in a number of ways.

The blocked design of Experiment 2 was not used as this did not increase the effect of the hint and may have caused more participants to notice the relationship between the two tasks. Noticing the relationship between the two tasks could lead to a strategic change in behavior, and so in the current study any participant who noticed was replaced by another participant. Moving from a blocked design to one where all of the problems are presented in one block also increases the amount of time between the hint and the presentation of the associated problem which should decrease the effect of the hint in the unseen condition since the word's temporary increase in activation will have had more time to decay.

A form of yoked control was implemented to eliminate the possibility that one or more particularly difficult problems appeared predominantly in the unsolved condition relative to the unseen condition. Finally, participants were informed that they would have another opportunity to work on problems they did not solve to increase the likelihood that they would have an open goal to solve those problems.

Method

Participants. The participants were 52 undergraduate students at Carnegie Mellon University who completed the study as part of a course requirement.

Design and Procedure. The design was similar to Experiment 2 with a few changes. The RAT problems were not broken up into blocks. Participants worked on the initial set of RAT problems followed by the lexical decision task where the hints were presented. Participants then worked on a second set of RAT problems which consisted only of problems that remained unsolved after the first attempt and problems which had not yet been seen. Participants were explicitly informed that they would have another opportunity to work on RAT problems that they did not solve.

After each set of five participants, the RAT problems that those five participants had not solved were randomly assigned to the next five participants as unseen problems. This assignment was done such that no participant saw the same problem twice and each of the next five participants received the same number of unseen problems in both the hint and no-hint conditions. Problems in the unsolved-no-hint condition were assigned to the unseen-no-hint condition and problems in the unsolved-hint condition were assigned to the unseen-hint condition. This design insured that problems appeared equally often in both the unsolved and unseen cases. Grouping the problems over five participants insured that a participant who answered very many or very few RAT problems initially did not greatly impact the overall number of unseen problems for the next set of participants. If a participant noticed the relationship between the two tasks as determined by a questionnaire at the end of the study, then another participant was run in their place. This policy insured that when participants who noticed the relationship were excluded the equivalence between the unsolved and unseen set of problems was maintained.

There were 48 RAT problems which were selected using the same source and constraints as in Experiment 1. For the first set of 5 participants, 30 RAT problems were presented in the first set, and 18 problems were presented in the unseen set. The numbers for subsequent participants depended on the performance of previous participants, as described above, but did not differ greatly from this original distribution. For the initial set of RAT problems, participants worked on the problem for 20 seconds or until the problem was answered. For the second set of

RAT problems including both unseen and unsolved problems, participants worked on a problem for 30 seconds or until the answer was entered.

The lexical decision task consisted of 20 neutral filler words as well as answers to half of the unsolved and unseen problems. The neutral words were randomly selected from a set of 50 words that were of similar frequency and length as the answers to the RAT problems. Enough nonwords were randomly selected from a pool of 160 nonwords so that there was an equivalent number of words and nonwords. The timing of the trials and the number of practice trials were the same as Experiment 1.

Results

In order to rule out strategic effects, 12 participants who noticed the relationship between the tasks were replaced with another participant as noted in the procedure. In addition, one participant was excluded because he reported that he continued to work on past problems to the extent that he ignored the current problem in some cases.

Improvement on RAT problems. The proportion of problems solved in each condition can be seen in Figure 6. The data were analyzed with a 2 x 2 repeated measures ANOVA with the factors being whether the problem was previously unsolved or unseen and whether a hint had been presented. Problems which had been left unsolved were more difficult than previously unseen problems, $F(1, 38) = 95.95$, $p < .001$, $\eta = .72$. There was no overall effect of the hint, $F(1, 38) = 2.726$, $p = .11$. The hint was more effective in the unsolved condition than in the unseen condition, $F(1, 38) = 4.37$, $p = .04$, $\eta = .10$.

The effect of the hint for unseen and unsolved problems was calculated by subtracting the proportion of problems solved in the no-hint condition from the proportion solved in the hint condition for each participant. There was a significant correlation between the proportion of problems left unsolved on the initial block of RAT problems and the effect of the hint for unsolved problems, $r = -.39$, $p = .01$, but not for the effect of the hint for unseen problems, $r = -.10$, $p = .55$. This result is similar to the correlation in Experiment 1 and could indicate that having fewer open goals increases the chances of acquiring relevant information.

Lexical Decision. Accuracy on the lexical decision task was 95% or higher in all conditions. The mean correct response times for the hint words for unsolved problems were compared to the hints for the yet to be seen problems. Response times longer than 1300 ms were eliminated (1.6% of the data). Participants responded significantly slower to the hints for unsolved problems ($M = 591$, $SE = 17.7$) than they did to the hints for unseen problems ($M = 568$, $SE = 14.8$), $F(1, 38) = 6.2$, $p = .02$, $\eta = .14$.

Awareness of the Manipulation. The RAT problem performance for participants who did notice the relationship was analyzed separately. Unsolved problems were harder than unseen problems, $F(1, 11) = 35.51$, $p < .001$, $\eta = .76$. There was an overall effect of the hint, $F(1, 11) = 8.60$, $p = .01$, $\eta = .44$, but there was no interaction, $F(1, 11) = 1.65$, $p = .23$. This result is consistent with a strategic change in behavior to try to remember and recall lexical decision words when solving RAT problems as the hint was equally effective for both unsolved and unseen problems.

Discussion

The results of this study eliminate the possibility that the effect of the hint for unsolved problems is due to the recency of seeing the answer as the hint was just as recent in both the unsolved and unseen hint conditions. This result supports the interpretation of the results from Experiment 2. Furthermore, the effect of the hint is not attributable to a strategic change in behavior due to participants catching on to the relationship between the two tasks. The lack of an effect of the hint in the case of unseen problems in this study when compared to Experiment 2 is probably due to the increased amount of time between seeing a hint for an unseen problem and seeing the problem since there were not multiple short blocks of RAT problems as in Experiment 2. Therefore the brief increase in activation due to seeing the hint therefore had more time to decay before the problem was seen.

As in Experiment 2, hints for unsolved problems were not primed relative to the neutral hints for unseen problems. This fact also argues against a purely activation based account for the results since any sub-threshold buildup of activation during the initial problem attempt should have shown up as a priming effect.

The correlation between the number of RAT problems solved initially and the effect of the hint for unsolved problems again indicates that there could be a limitation to the number of open goals that can be successfully maintained. The fact that there was no corresponding correlation in the case of unseen problems rules out the possibility that people who are better at RAT problems are more likely to make use of hints in general.

General Discussion

The three studies reported here identify a potentially important mechanism of problem solving by showing that open goals influence the acquisition of problem relevant information. Participants benefited from the presentation of an implicit hint especially after leaving a problem unsolved, and most participants were not even aware that they had seen a hint.

Experiment 3 as well as the subset of results from Experiment 2 presented in Figure 5 support the conclusion that simply seeing the answer recently without an open goal does not affect future problem solving attempts as much as seeing the answer when there is an open goal.

These results effectively rule out simple priming explanations for our results that rely solely on the boost in activation received from processing the word in the lexical decision task.

A more complicated version of the priming explanation which could account for the results of Experiment 3 would be that an initial unsuccessful attempt on a problem activates the solution but not enough for the activation to reach threshold and be recalled. Seeing the hint and working on the problem again would lead to further increases in activation that allow the answer to be retrieved. It is then the initial activation from the first solution attempt which produces the interaction in Figure 6. The problem with this account is that the initial sub-threshold activation of the answer that results from the first problem attempt would lead to a priming effect in the subsequent lexical decision task where answers to unsolved problems would be responded to faster than answers to unseen problems. No consistent priming effect was found in the three studies.

The response time results from the lexical decision task were inconsistent across the three experiments. The results in Experiment 1 show an advantage for answers for unsolved problems relative to neutral words while those in Experiments 2 and 3 do not. Experiments 2 and 3 provide a better control group comparison since the hint words for unsolved problems were compared to hints for yet to be seen problems. In Experiment 1 word length and frequency were matched, but there could have been other differences which led to the observed interaction.

A further inconsistency in the lexical decision results is that there was no difference between the unsolved and unseen hints in Experiment 2, but in Experiment 3 unsolved hints were responded to 23 ms slower than unseen hints. There were a number of design differences between Experiments 2 and 3 including the blocked design of Experiment 2 and the fact that Experiment 3 guaranteed that particular RAT problems (and their answers) appeared approximately equally often in the unsolved and unseen conditions. Of the six experiments that we have run in this paradigm, a statistically significant response time difference between hints for unsolved problems and neutral words was found only in Experiments 1 and 3 presented in this paper, and the effects in Experiments 1 and 3 are in opposite directions (Moss, 2006; Moss et al., 2007). While these lexical decision results are mixed, it does not appear that there is a robust priming effect for answers to unsolved problems.

A correlation between the number of unsolved problems and the effectiveness of the hint was found in both Experiments 1 and 3. This correlation may indicate a limit on the number of open goals that can affect future information acquisition. However, results of a study manipulating the number of open goals from 2-8 open goals found no effect of the number of open goals on the effectiveness of the hint (Moss, 2006). In addition, the results of this study found no relationship between working memory measure and the number of open goals. These results indicate that it is unlikely that open goals are being consciously maintained. It may be that the correlations found in Experiments 1 and 3 indicate that there is a limit to the number of open goals, but that the limit is greater than the limited range that was manipulated in this prior study. This could be the case if the limitation is not resource based but due to interference in long-term memory possibly from overlapping representations of problems.

Mechanisms

Zeigarnik (1927/1938) originally proposed that interrupted tasks were recalled better than completed ones because of some form of tension which is only relieved by completion of the task. This explanation is vague, but it does point to the possibility that there is some aspect of the cognitive system that maintains these incomplete goals. Our results show that seeing the hint before the problem is not as effective as when there is an open goal. A mechanistic explanation of the results presented here has to address how the new stimulus, the hint in our studies, becomes connected to a prior open problem solving goal so that when work on the problem resumes the new information can aid problem solving.

There are at least three parts to such an explanation. The first is how the open goal is accessed at the time when new relevant information is encountered. The second part is how the representation of the new information becomes associated with the problem so that the new information can be used when the problem is resumed. The final part is how the information is accessed when the problem is resumed.

Two previously proposed mechanisms for understanding insight and incubation effects can be applied to the studies presented here, but neither fully accounts for the results presented here. The first is the opportunistic assimilation hypothesis which proposes that failure indices which refer to the unsolved problem are stored in long-term memory when a problem has been left unsolved (Seifert et al., 1995). When new relevant information is encountered then these failure indices are accessed and the new information is incorporated into the problem. However, it is not clear why the new information leads to access of the failure indices unless the new information and the problem share some association which would lead to the access of the original goal. In fact, it has been shown that people are more likely to remember intentions to perform some action when the suspended intention is encoded along with information about the type of object which would enable the ability to perform the intended action (Patalano & Seifert, 1997). In this case it is clear how failure indices which encode properties of the enabling object would be accessed when the object is encountered, however problems often go unsolved not because some enabling object is missing but because the problem solver is not able to find an appropriate solution during the initial search of the problem space. It could also be that the problem solver can not find an appropriate representation for the problem. In these cases, it is less clear how failure indices could be encoded so that the right information could lead to their future retrieval.

Langley and Jones (1988) present a model of insight is similar to opportunistic assimilation in that encountering the right information in the environment leads to the retrieval of the prior unsolved problem as well as the mapping of the new information onto the problem. However, they propose that the reason the appropriate information is not retrieved during the initial problem solving is that the original problem may be connected to many chunks in memory and thus have a high fan which reduces the amount of activation that spreads along each link leading from the problem to information in memory. When new information is encountered it then becomes a source of activation and if it has a lower fan it may lead to the retrieval of the original problem. In this case, the higher fan of the source problem and lower fan of the target information explains why the target information was not retrieved in a previous attempt and why an encounter with the target information in the future may lead to the retrieval of the source problem.

These existing ideas do not adequately explain the results presented in this paper for two reasons. The first reason has to with the hint leading to retrieval of the unsolved problem, and the second has to do with the fact that participants were not allowed to resume problem solving when hints were presented. Opportunistic assimilation does not explain why the hint should have led to the retrieval of the open goal as there is not a strong association between the hint and the problem which would lead to the retrieval of failure indices associated with the unsolved problem. The differential fan effect does explain why the answer would remind a participant of the problem even when the problem does not lead to retrieval of the answer if it can be assumed that the answer has a lower fan than the problem. However, it seems rather tenuous to assume that the answer words to RAT problems have lower fans than the three words which make up the RAT problem. If one assumes that each word in a RAT problem has the same degree of fan on average, then it might be possible to argue that the activation from the RAT problem is being divided up three ways as it travels along association links from each of the problem words which accomplishes the same thing as having a higher fan (i.e., less activation ends up at the answer, just like the source problem having a higher fan than the answer). However, if each word has some association with the answer, then the total activation which reaches the answer would be about the same as if activation was spreading from just one of the RAT problem words.

The second problem is that once new information leads to the retrieval of the open problem goal, participants have to continue responding to the lexical decision task and do not immediately resume work on the RAT problem. This situation is not handled by either of the two accounts discussed above as both assume that further problem solving occurs at the time the new information is encountered. Some process must make it more likely that the new information will be incorporated into problem solving once it is resumed.

As mentioned in the introduction, there have been a number of findings which indicate that goals for unfulfilled intensions are maintained at a level of heightened activation (Goschke & Kuhl, 1993; Marsh et al., 1998; Rothermund, 2003). The general argument is that goals spread activation to related items in memory, and that open goals persist as sources of activation even when people move on to other tasks. This would account for the fact that people are faster to respond to items related to unfulfilled intensions than to neutral items (Goschke & Kuhl, 1993; Marsh et al., 1998). Unfulfilled intentions are one type of open goal, and this maintained level of activation could account for the heightened level of accessibility of open goals in ways that opportunistic assimilation and differential fan could not. It has also been shown that open goals can interfere with performance of other tasks, and this type of interference effect could be due to the access of open goals at inopportune times which introduces processing delays in task switching (Rothermund, 2003), or a decrease in motivation for the current goal (Shah & Kruglanski, 2002). However, participants in our studies did not respond faster to hints related to open goals relative to neutral words in the lexical decision task. One possibility is that the hints were not related strongly enough to the open goals to lead to a reliable priming effect, but that the open goals were still maintained at this heightened level of accessibility so that they could be accessed when the hint was presented.

Theories of incubation have been based on forgetting, priming, or some combination of forgetting and priming (Kaplan, 1989; Langley & Jones, 1988; Seifert et al., 1995; e.g., Simon, 1966; Smith, 1995; Smith & Blankenship, 1991). Forgetting involves a decrease in interference as previous ideas associated with the original problem-solving episode decay over time (Kaplan, 1989; Smith & Blankenship, 1991). Kaplan suggests that encountering problem relevant information in the environment may lead to an interactive incubation effect. However, the only details offered on how such a mechanism would operate are that, “The act of priming corresponds to increasing the activation of a node in LTM, and, more importantly, to strengthening the links to that node. Stronger links increase the probability that the concept will be retrieved in the future.” (Kaplan, 1989, p. 94). This idea would be one possible way in which new information could become associated with an open goal without the requirement that problem solving be resumed immediately.

In order to make Kaplan’s idea more concrete, it will be discussed in terms of the model of declarative memory in the ACT-R architecture (Anderson et al., 2004). In ACT-R, the likelihood of a chunk being retrieved from memory is determined by a base-level component and a context component (Anderson et al., 2004). The frequency and recency with which a chunk is accessed leads to increases in base-level activation. The context component is determined by activation which is spread from the problem goal along links with varying degrees of association. The strength of association between two chunks is assumed to reflect the likelihood that a chunk is useful given the content of the current goal (Anderson & Schooler, 1991).

Within this kind of architecture, a priming effect due to a recent encounter with an item would be accounted for by a temporary increase in a chunk's base activation level. However, this kind of account would not explain the long-term interactive incubation effect across hours and days that Kaplan (1989) observed. It also does not fully explain the improvement in solution rate associated with the condition of where hints had been presented for previously unsolved problems in Experiments 2 and 3. Kaplan's explanation of strengthening links or associations to nodes indiscriminately increases the chunk's associations to everything else. While this would increase the chances that the problem solver would retrieve that chunk in problem solving, it only does so if one assumes that *only* problem relevant information becomes primed. If every piece of information that a person encounters is primed in this manner, then there will be ever increasing strengths of association between many chunks in memory. In order to avoid problems under such a theory one must assume that these associations also decay over time, which would seem to lead to the same problems as a temporary increase in activation.

A theory of long-term priming during incubation needs some way to discriminate relevant information from irrelevant information. A lasting influence of open goals provides the beginnings of a mechanism that would provide such discrimination. Modifying Kaplan's explanation of priming above to say that only the association between the open goal and the relevant primed chunk becomes strengthened is one potential way in which open goals could exert their influence during incubation. This strengthening process insures that newly encountered related information is more likely to be used when problem solving is resumed as more activation will spread over the strengthened associative link. An ACT-R model that can solve RAT problems in our experimental paradigm has been implemented (Moss, 2006), and this association strengthening approach is one which could be implemented in such a model for it to account for the results of Experiment 3.

The strengthening of associations between the hint and an open goal relies on the open goal being accessed at some level when the hint is encountered. The process of recognizing the relevance of an open goal and creating or strengthening an association to new information could cause the problem solver to become aware of the original problem if there are no other competing task demands. This kind of process could therefore also explain why items related to unsolved problems cause a delay when switching to a new task (Rothermund, 2003). This hypothesis does not depend on any nonconscious work going on besides the recognition that new information is related to an open goal and the strengthening of an association between the two.

One idea for an open goal mechanism has been presented, and it could be implemented within an existing modeling architecture. However, the details of how open goals are accessed when relevant information is presented have not been fully explained. Identifying open goals as a general construct that can encompass unsolved problems, future intentions, and other instances of interference allows the results from other areas of cognition to inform the development of this theory. Any candidate theory must be able to show how an open problem-solving goal becomes established in such a way that it exerts an influence on which information is acquired. This includes a way of selecting or biasing related information for further processing, and for incorporating this information into the problem. The eventual theory should be both powerful and parsimonious as it will link problem solving with lower level mechanisms including processes of memory and attention.

Conclusions

The results of the studies presented here show that having an open goal makes one more likely to make use of information encountered between problem-solving attempts even if that information is not consciously noticed. These findings support the idea that there is some mechanism by which open goals influence the acquisition and use of problem relevant information. It is unlikely, although not impossible, that the results can be accounted for by a model based on priming alone.

There are a variety of implications of this work. One is that it should be possible to observe and explain opportunistic behavior in a variety of tasks. As task complexity increases people generally respond by setting up a number of subgoals to deal with parts of the problem. Noticing information relevant to a previous subgoal or subproblem could explain the opportunistic deviations that have been noticed in complex problem solving domains like engineering design (Guindon, 1990; Visser, 1990, 1996).

Some of the insights that people experience during an incubation period might be explained by the same open goal mechanism. These kinds of insights and analogies could be one source of creative and innovative ideas. However, analogies and other forms of transfer usually require mapping processes in addition to the noticing of potentially relevant information. The studies presented here all involve presenting the answer to the problem, and so it will be important for future studies to examine situations in which the relevant information may require mapping or some other additional process in order to be used in problem solving.

The results presented here do not imply that all experiences and activities will be useful for solving open problems. The information must be similar enough to the representation of the problem that has been developed during work on the problem. This means that information encountered in activities similar to the problem will probably be more likely to become incorporated into problem solving. For example, a designer may make more progress in overcoming an impasse by looking at a variety of products or working on other design problems, but the designer is less likely to experience insight or make progress by going dancing.

The open goal mechanism that is being investigated here is general in the sense that it operates across a variety of tasks which are not normally considered problem-solving tasks including prospective memory tasks and attention in dual task situations. The interference of open goals with other tasks is also related to work in the social and clinical psychology literature (Klinger, 1996; Shah & Kruglanski, 2002). The three studies presented in this paper demonstrate that open goals can effect the acquisition of problem relevant information. These results constitute additional evidence that can be used in formulating a general theory of how open goals influence cognition in problem solving and other types of tasks.

Future work should investigate the role that open goals play in more complex problems in an effort to show that the results presented here generalize to real-world problem solving. Many details of how this mechanism operates also need to be examined to further development of the theory. The resulting theory has the potential to contribute to our understanding of problem solving, memory, insight, and creativity.

References

Author Note

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Table 1
Mean Response Times (in Milliseconds) for the Lexical Decision Task

	Unsolved		Solved	
	M	*SE*	*M*	*SE*
Hint	565	13.0	580	13.1
Control	597	14.6	568	14.4

Figure Captions

Figure 1. Example verbal protocols of RAT problem solving.

Figure 2. Example verbal protocols from definition recall task.

Figure 3. Blocked design of Experiment 2.

Figure 4. Proportion of problems improved upon in each condition of Experiment 2. Error bars indicate 1 standard error.

Figure 5. Proportion of problems improved upon in each condition of Experiment 2 excluding the five hardest problems. Error bars indicate 1 standard error.

Figure 6. Proportion of problems improved upon in each condition of Experiment 3. Error bars indicate 1 standard error.

<table>
<tr><th colspan="2">Problem: Law, Business, Wet</th></tr>
<tr><td>Verbal Protocol (First Attempt, 60 s):
Law
Business
Wet
Outlaw
Out no
Um
Lets see what kind of law
Uh
Law
Business
What works both business
Uh
Showbusiness
No
Lets see
Wet
Um</td><td>Verbal Protocol (Second Attempt, 30 s):
Law
Business school
No
Law school
Law
Wet
Law oh law suit!
/
Yeah</td></tr>
<tr><th colspan="2">Problem: Shovel, Iron, Engine</th></tr>
<tr><td>Verbal Protocol (First Attempt, 30 s):
Shovel
Iron
Engine
Engine block
No
Shovel
Snow shovel
Snow
No
Uh
Shovel
Iron
Iron on
Engine
Engine
No
Iron board
Engine
Board engine
Shovel board
No
Um
Iron
Clothes
No
Engine</td><td>Verbal Protocol (Second Attempt, 30 s):
Shovel
Iron
Engine
Shovel
Shovel snow
Iron city
No
Engine block
Engine
Ignition
Engine
Uh
Steam engine
Steam
Steam! /</td></tr>
</table>

Figure 1

Definition: Listlessness; state of apathy or indifference	**Definition:** A person who appeals to people's prejudices, making false claims and promises in order to gain power; false leader of people
Verbal Protocol: listless, state of apathy or indifference I don't care Indifferent, don't care I'm…	**Verbal Protocol:** false claims and promises in order to gain power, false leader of people false leader of people just out to gain power

Figure 2

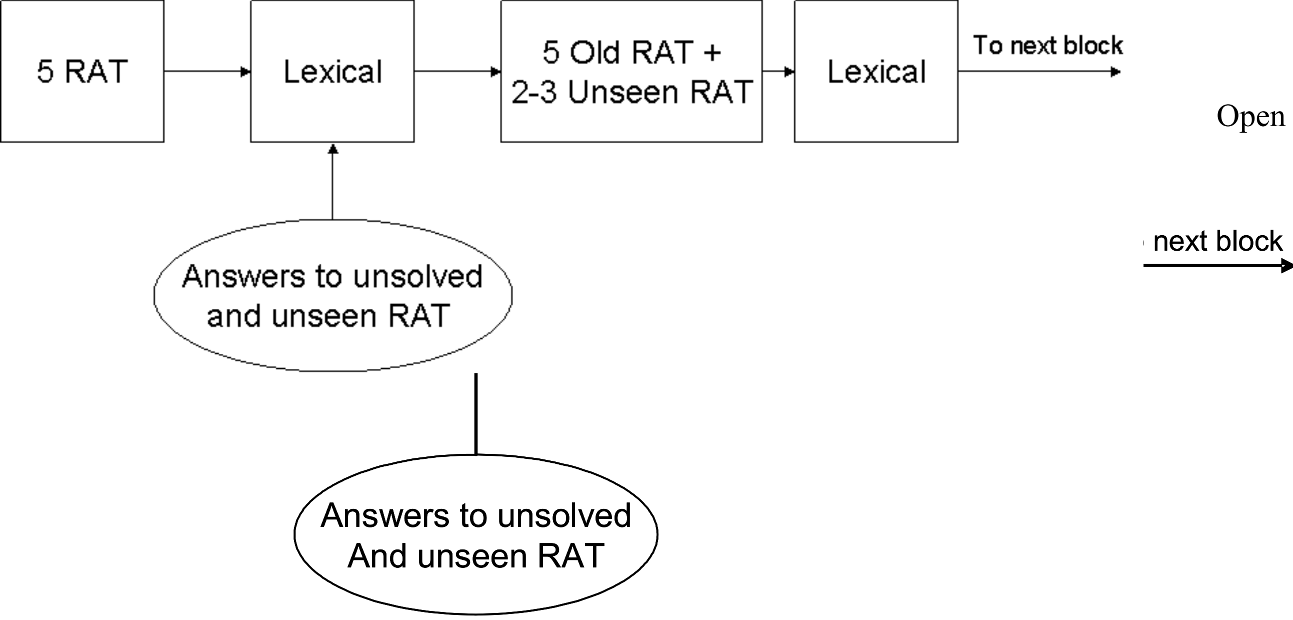
5 RAT
Lexical
5 Old RAT +
2-3 Unseen RAT
Lexical
To next block
Answers to unsolved
and unseen RAT
next block
Answers to unsolved
And unseen RAT

Figure 3

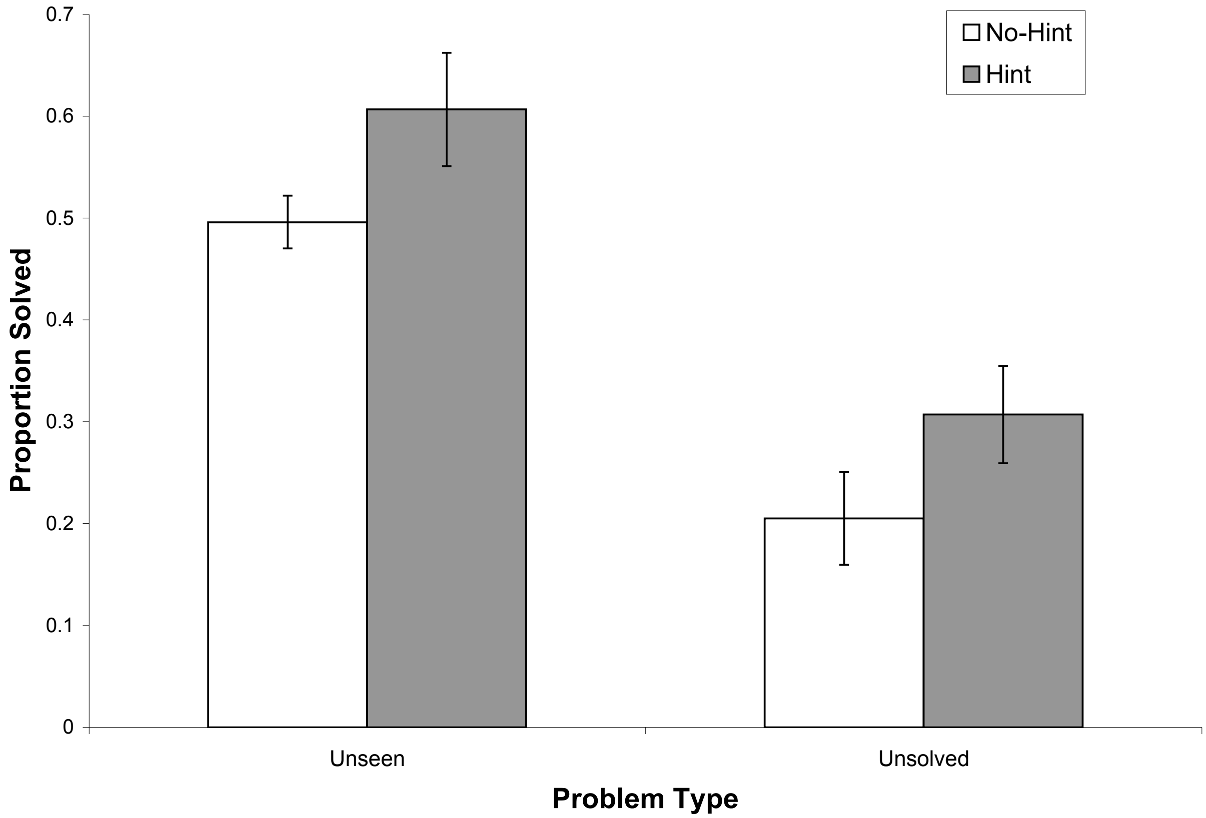
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Proportion Solved
No-Hint
Hint
Unseen
Unsolved
Problem Type

Figure 4

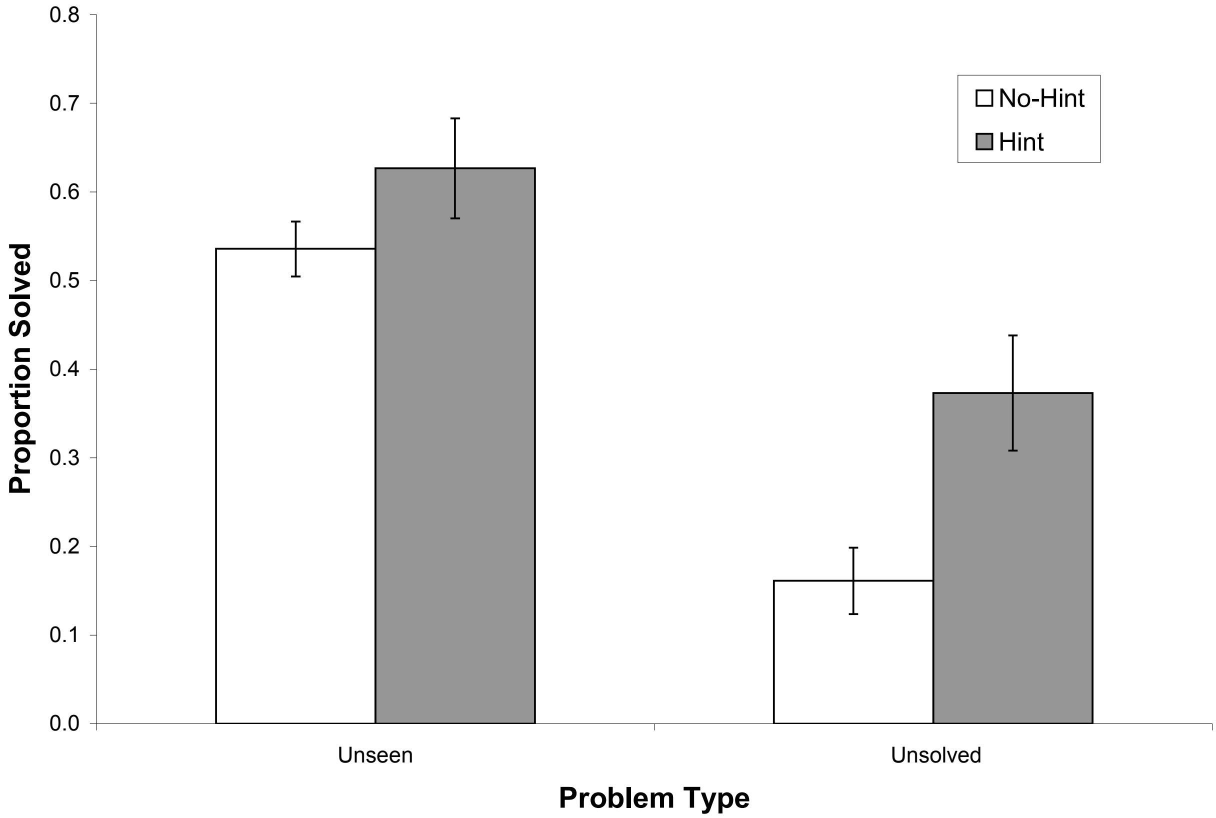
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Proportion Solved
No-Hint
Hint
Unseen
Unsolved
Problem Type

Figure 5

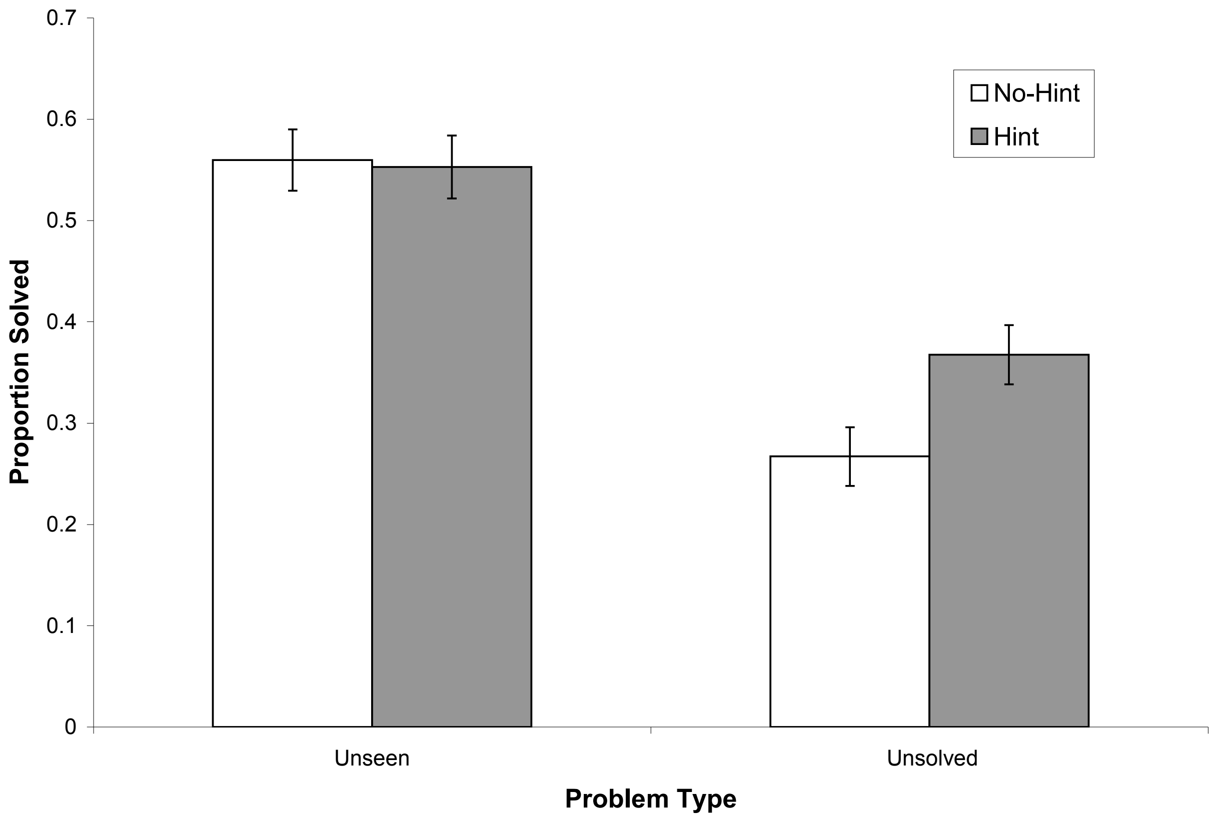
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Proportion Solved
No-Hint
Hint
Unseen
Unsolved
Problem Type

Figure 6