Negative Effects of Domain Knowledge on Creative Problem Solving

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Abstract

Experts generally solve problems in their fields more effectively than novices because their well-structured, easily-activated knowledge allows for efficient search of a solution space. But what happens when a problem requires a broad search for solution? One concern is that subjects with a large amount of domain knowledge may actually be at a disadvantage because their knowledge may confine them to an area of the search space where the solution does not reside. In other words, domain knowledge may act as a mental set, promoting fixation in creative problem solving attempts. Two experiments using an adapted version of Mednick's (1962) Remote Associates Task demonstrates conditions under which domain knowledge may inhibit creative problem solving.

Introduction

The possession of a large body of domain knowledge is central to expertise. However, the domain knowledge of experts is marked not just by its amount, but also by its structure (Bédard & Chi, 1992, Ericsson & Staszewski, 1989). The organization of domain knowledge in a way that is accessible, proceduralized, integrated and principled, enables experts to excel at memory and problem solving tasks in a number of characteristic ways. An expert can typically recognize, store and retrieve large meaningful chunks of domain-related information. An expert's processing is also commonly more abstract or conceptual than that of a novice. The proceduralization of an expert's knowledge base tends to allow for quick and easy access to memory and possible solution paths. Further, an expert's knowledge usually contributes to better problem representation, as experts are able to engage in more qualitative analysis of a problem, such as by recognizing relevant features, inferring missing information, and imposing constraints in order to narrow the possible search for solution. Over the past twenty years, these distinguishing marks of expertise have been found to be quite robust across a wide variety of domains (See Chi, Glaser & Farr, 1988; Ericsson & Smith, 1991). Yet, expert performance is not uniformly superior, and the above characteristics of expert processing may sometimes lead to inferior performance in particular conditions.

The present study investigated a condition in which people with less domain knowledge may outperform people with a large amount of domain knowledge, namely creative problem solving. Experts have been seen to solve problems in their fields more effectively than novices because a well-structured, easily-activated knowledge base allows for efficient search of a solution space and possibly for automatic access to promising solution paths. But what happens when a problem requires a broad search for a solution outside the usual scope of the domain? One possibility is that subjects with expertise in the domain might actually be at a disadvantage because their knowledge may confine them to an area of the search space where the solution does not reside. In other words, domain knowledge may act as what traditionally has been called a "mental set" in the problem solving literature, constraining search and promoting fixation in the creative problem solving of experts.

In a recent demonstration of induced fixation in problem solving, Smith and Blankenship (1991) significantly decreased performance on Mednick's Remote Associates Task (1962) by priming meanings of words that were irrelevant to solution. One way of viewing these findings is that priming the irrelevant meanings instilled a mental set, which produced an inappropriate initial problem solving attempt as well as fixation on the incorrect solutions, preventing broad search of the solution space. The present study investigates whether domain knowledge may be seen to influence solution attempts in a similar way. Since domain knowledge is easily and possibly automatically activated when experts encounter domain-relevant material, domain knowledge may have a similar influence on solution attempts as the externally-imposed primes in the above studies. In other words, domain knowledge may act as a mental set and promote fixation in problem solving.

Two experiments are reported concerning the possible existence and nature of a mental set due to the possession of a large amount of domain knowledge. The first experiment demonstrated that domain knowledge can indeed act as a mental set with negative consequences on creative problem solving. The second experiment examined the effect of incubation on breaking mental set as a function of whether the set was internally-generated (knowledge-based) versus externally-primed.

Experiment 1

To test the hypothesis that domain knowledge can act as a mental set and promote fixation in creative problem solving, subjects with varying amounts of baseball knowledge performed a Remote Associate Task (adapted from Mednick, 1962). The standard Remote Associates Task (RAT) involves the presentation of three words, such as BLUE, KNIFE, and COTTAGE and prompts the subject to generate a fourth word that forms a familiar phrase with each of three. In this case the fourth word could be *cheese*, forming the phrases *blue cheese*, *cheese knife* and *cottage cheese*.

For this experiment, ten items were created such that the first word could have been part of a baseball-related term. For example, one baseball-related problem consisted of the words PLATE, BROKEN, and REST, with the intended solution of *home*, which would form the phrases *home plate*, *broken home*, and *rest home*. Another ten problems were based on Mednick's original stimuli (1962). As none of the Mednick-based items contained a first word that was related to a baseball term, these trials are termed *neutral*. The BLUE, KNIFE, COTTAGE example that was mentioned above is an example of a neutral trial.

Two versions were created for each baseball-related trial. In one version, such as the PLATE, BROKEN, REST example given above, the answer that was suggested by the baseball-related meaning of the first word formed a phrase with both the second and the third words, and thus was the solution. These versions of the trials are termed *baseball-consistent*. For a second version of each trial, the third word was replaced by a word that would not form a good phrase with the answer suggested by the baseball-related meaning of the first word. For example, the second version of the above problem had the words PLATE, BROKEN, and SHOT. The intended answer was *glass*, forming the phrases *plate glass, broken glass*, and *shot glass*. In these trials, the answer suggested by the baseball-related meaning of the first word formed a phrase with the second word, but not the third. Because the subject did not know that the solution suggested by the baseball term would not work until the third word appeared, these versions of the baseball-related trials were termed *baseball-misleading*.

If expertise does impose a set on problem solving, then subjects with higher amounts of baseball knowledge should be less able to generate correct solutions than subjects with less domain knowledge when answers primed by baseball terms are incorrect (that is, on baseball-misleading trials). It is presumed that there will be no differences in performance on neutral trials.

Method

Participants. Twenty-four University of Pittsburgh undergraduates taking Introductory Psychology participated for course credit.

Materials. Mednick's (1962) Remote Associates task (RAT) was adapted for this experiment as described above.

Procedure. Participants were told that they would perform several problem solving tasks. Before beginning the RAT, subjects were given an example, five practice items, and some acceptable solutions for the practice items. All subjects then performed the adapted RAT. In this version of the task, the three words were presented one at a time, cumulatively. The first word appeared alone in the center of the screen for 5 seconds after which it was joined by the second word which appeared under it. After another 7.5 seconds, the first two words were joined by the third word which appeared under them, and the subject had 30 seconds in which to produce the fourth word. The subject could answer at any time during the 30-second problem-solving period by pressing the space bar, typing in a solution word and pressing the return key. However, if the 30 seconds passed and the subject had not yet responded, then the three words disappeared and the subject was told to enter a solution word and press the return key. The subject had 20 seconds to respond after which the next trial was presented.

Each subject received ten neutral trials and ten baseball-related trials. Five of the baseball-related trials were consistent with the solution suggested by the baseball term, while five were misleading. Presentation order and baseball-trial type were randomized such that each subject received only one version of each item. Responses and response times were recorded via computer. The response time that was analyzed was the duration from the onset of the third word until the subject finished entering a word and pressed the return key, or until the trial ended (including both the 30-second problem-solving and 20-second response periods).

Subjects then completed a mental rotation task, an anagram task, a Gestalt Completion Task and a multiple-choice baseball-term recognition test. All four additional tasks were presented via computer. The final task was a 45-item paper-and-pencil short-answer test of baseball knowledge, the Baseball Knowledge Questionnaire from Spilich, Vesonder, Chiesi and Voss (1979). No feedback was given on any task.

Results

Baseball Knowledge. Performance on the Baseball Knowledge Questionnaire ranged from 2 to 32 correct answers out of a possible 45. Twelve subjects scoring less than 15 were categorized as low-knowledge and twelve subjects scoring 15 or more were categorized as high-knowledge. Even the low-knowledge subjects were familiar with the baseball terms used in this study, as all subjects were able to indicate the correct baseball terms on the baseball-term recognition test.

Correct Solutions. A 2 x 3 (Knowledge Level x Trial Type) ANOVA was computed using proportion of correct solutions as a dependent measure. Table 1 presents the mean proportion of correct solutions for each condition. No significant main effect was found for knowledge level, but there was a significant effect of trial type, $\underline{F}(2,44)=8.56$, $\underline{p}<.001$. Tukey's HSD indicated that there were more correct solutions to neutral trials than to misleading trials, with consistent trials not differing significantly from either of the other two. There was also a significant interaction between knowledge level and trial type, $\underline{F}(1,44)=4.06$, $\underline{p}<.02$.

To see whether this interaction was due to a greater misleading effect among the high-knowledge subjects, a 2 x 2 (Knowledge Level x Trial Type) ANOVA was computed on correct solutions without the baseball-consistent trials. Main effects for trial type, $\underline{F}(1,22)=14.58$, $\underline{p}<.001$, and knowledge level, $\underline{F}(1,22)=4.35$, $\underline{p}<.05$, were significant. Most importantly, as predicted, the interaction was significant, $\underline{F}(1,22)=5.35$, $\underline{p}<.03$, indicating that high knowledge subjects were less likely to correctly solve misleading problems as compared to neutral problems than were low-knowledge subjects.

Incorrect answers on misleading trials were further analyzed on the basis of whether or not they were related to a baseball-related term. Incorrect answers related to baseball were termed "intrusions" High-knowledge subjects made baseball-related intrusions on 31% of misleading trials while low-knowledge subjects only made baseball-related intrusions on 11% of the misleading trials. This difference approached significance, $\underline{t}(22)=1.72$, $\underline{p}<.10$, suggesting that the more-knowledgable subjects tended to be fixated in the solution suggested by their baseball knowledge.

Response Time. A 2 x 3 (Knowledge Level x Trial Type) ANOVA using response time as a dependent measure was computed. As can be seen in Table 1, there was a significant main effect of trial type, $\underline{F}(1,44)=4.68$, $\underline{p}<.01$. Tukey's HSD indicated that misleading trials had significantly longer response

Table 1: Proportion of Correct Solutions and Response Time in Experiment 1

	LK			HK		
	Neut	Cons	Misl	Neut	Cons	Misl
Accuracy	.50	.40	.40	.50	.38	.15
RT(sec)	20.6	20.9	23.0	24.7	26.8	31.4

times than either neutral or consistent trials, which were not significantly different from each other. The main effect for knowledge level was not significant (F=1.45), nor was the interaction between knowledge level and trial type (F=1.00), although response times did tend to be longer for the high-knowledge subjects on the misleading trials. A 2 x 2 (Knowledge Level x Trial Type) ANOVA on response time without the baseball-consistent trials yielded the same pattern of results for both knowledge (F=1.47) and trial type.

Summary

The misleading effect was greater for high-knowledge subjects than for low-knowledge subjects. For misleading items, high-knowledge subjects were much less likely than low-knowledge subjects to arrive at a correct solution. High-knowledge subjects were also more likely to give incorrect baseball-related responses to misleading items. These results suggest that high-knowledge subjects were fixated in their problem solving.

Experiment 2

An important distinction should be made between the mental set and fixation due to domain knowledge observed in the present study, and the kinds of mental sets that have been considered in the literature for the most part that are experimentally produced. Traditional demonstrations of mental set and fixation have used sets that are externally-imposed on the subject through the presentation of an object in a specific context or through practice at a task prior to the experimental task. On the other hand, the proposed set from expertise is internally generated and this may lead to some interesting differences in how sets due to extensive domain knowledge may or may not be overcome.

Most prominently, it would seem that if the sets observed in the high-knowledge individuals are the result of the easy activation of a well-formed knowledge base, then simply an "incubation" period may not do anything to help free a subject from an internally-generated set. However, an incubation period may help break an externally-imposed set as the delay would allow for the dissipation of the inappropriate activation. This would in turn suggest that "distributed" effort toward problem solution (i.e. taking a break during the solution phase) may be the most effective tactic for less-knowledgeable subjects. More-knowledgeable subjects, on the other hand, should not benefit from a "distributed" effort, since their success depends on the dismissing of internally-activated irrelevant stimuli. Even after a delay, high-knowledge subjects should experience the same fixation when their domain knowledge is activated by the content of the reintroduced problem.

A second experiment investigated the extent to which the mental set and fixation that is a function of domain knowledge is different than an externally-imposed set. As noted previously, Smith and Blankenship (1991) have demonstrated that mental sets can be induced by the presentation of irrelevant word associations before or during the RAT. They have further shown that the fixation due to such priming dissipates after an "incubation" period, presumably as the irrelevant activation fades. Internally-generated sets, however, may not be as easy to overcome since the activation of "irrelevant" word meanings comes from the expert's domain knowledge. To test this notion, the first experiment was repeated, but this time fixation was induced. One-half of the high- and low-knowledge subjects were primed for the misleading meanings of terms included in the RAT (i.e., baseball terms for the baseball trials and irrelevant associations for the neutral trials). Further, all subjects performed the RAT twice, half immediately following the first attempt and half with a 10-minute period of "incubation" intervening during which subjects performed demanding tasks. It was predicted that low-knowledge subjects should show an effect due to the fixation manipulation, as well as more of an incubation effect than high-knowledge subjects. High-knowledge subjects should show neither an effect due to the fixation manipulation, nor any improvement due to incubation.

Method

Participants. Forty volunteers from the university community were paid $5 for thier participation.

Procedure. The procedure was the same as in Experiment 1, except that half of the subjects performed a "short-term memory task" prior to the experiment. This was the *fixation-induced* condition. The other half of the subjects began the experiment with the RAT as in Experiment 1. This was the *nonfixation* condition. In addition, all subjects received the RAT twice. Incubation was manipulated by having half of the subjects from each fixation condition perform the second RAT immediately after the first (*no-incubation* condition), while the other half received the second RAT after the Mental Rotation, Anagram, and Gestalt Completion tasks (*incubation* condition). The no-incubation condition performed these tasks after the second RAT. All subjects then completed the baseball-term recognition test and the Baseball Knowledge Questionnaire.

The task that was used to induce fixation was based on a procedure developed by Smith and Schumacher (1992). Subjects were told they were performing a "short-term memory task" Three words were presented on the screen at the same time. Subjects had 5 seconds to find 2 two-word phrases that could be made out of the words. They then had to remember those phrases for 10 seconds, after which they were asked to type in their responses. The words used for this task were two words from each RAT item and either the baseball-related solution (for the baseball trials) or a word that formed phrases with the words but was not the solution (for the neutral trials). Order of items was randomized for each subject. For both administrations of the RAT, all subjects received 10 neutral trials and 10 misleading baseball trials.

Results

Baseball Knowledge. Performance on the Baseball Knowledge Questionnaire ranged from 3 to 33 correct answers with 20 subjects scoring less than 15 categorized as low-knowledge and 20 subjects scoring 15 or more categorized as high-knowledge.

Correct Solutions. A 2 x 2 x 2 (Knowledge Level x Fixation x Trial Type) ANOVA was computed on the number of correct solutions. Table 2 presents the mean proportion correct for each condition. No significant main effects were found for either knowledge level or fixation. There was a significant main effect for trial type, $F(1,36)=42.53$, $p<.0001$, as more correct solutions were offered for neutral trials than for misleading trials. Further, the three-way interaction between fixation condition, knowledge level and trial type was significant, $F(1,36)=4.93$, $p<.03$.

To better understand the significance of the interaction, separate analyses were performed for each fixation condition and knowledge level. As found in Experiment 1, in the nonfixation condition there was a significant knowledge level by trial type interaction, indicating that high-knowledge subjects were less likely to make a correct response on misleading trials as compared to neutral trials than were low-knowledge subjects, $F(1, 16)=6.36$, $p<.02$. The same interaction did not approach significance in the fixation-induced condition, $F<1$.

The fixation manipulation was effective for the low-knowledge subjects, as they made fewer correct responses on misleading versus neutral trials in the fixation condition than in the nonfixation condition, $F(1,8)=4.24$, $p<.05$. The fixation manipulation had no significant effect on the first RAT performance of the high-knowledge subjects, $F=1.42$. Further, the fixation manipulation significantly increased the proportion of intrusions on misleading trials among both the low and high-knowledge subjects, $t(38)=2.57$, $p<.01$. In the non-fixation condition, high-knowledge subjects tended to make more intrusions overall than low-knowledge subjects, but not significantly so, $t(18)=1.21$, $p<.24$. Taken together, these results suggest that the fixation-inducing procedure used in Experiment 2 was successful at inducing a set in the low-knowledge subjects that was similar to that of the high-knowledge subjects.

Response Time. A 2 x 2 x 2 (Knowledge Level x Fixation x Trial Type) ANOVA using response time as a dependent measure was computed. The means for each condition are presented in Table 2. There was no main effect for either knowledge level or fixation. A significant main effect was observed for trial type, $F(1,36)=30.50$, $p<.0001$, with misleading trials taking longer than neutral trials. The three-way interaction between fixation, knowledge level and trial type was approached significance, $F(1,36)=2.72$, $p<.11$. The knowledge-level by trial-type interaction neared significance in the nonfixation condition, $F(1,16)=3.45$, $p<.08$, suggesting that high-knowledge subjects had longer response times on misleading versus neutral trials than low-knowledge subjects.

Table 2: Proportion of Correct Solutions and Response Times in Experiment 2.

	LK		HK	
No Fixation	Neut	Misl	Neut	Misl
Accuracy	.53	.46	.64	.27
RT(sec)	21.7	25.7	17.8	27.8
Intrusions		.14		.20
Fixation				
Accuracy	.58	.32	.58	.36
RT(sec)	19.3	24.8	18.5	23.7
Instrusions		.30		.33

Improvement on Second Remote Associates Task. The measure of improvement from the first RAT to the second was taken from Smith and Blankenship (1991; Improvement = (number newly solved at retest)/(total number of problems - number solved at first test)). A 2 x 2 x 2 x 2 ANOVA (Knowledge Level x Fixation x Incubation x Trial Type) was computed using this measure. There was a significant effect of trial type, $F(1,32)=15.22$, $p<.001$, as more improvement was seen on neutral than misleading items. Further, the two-way interaction between knowledge level and incubation was significant, $F(1,32)=8.59$, $p<.01$. As illustrated in the third and last column of Table 3, incubation (a delay) between the first and second attempts at the RAT was related to greater improvement for the low knowledge subjects, yielding positive incubation effects. For the high-knowledge subjects, however, incubation yielded less improvement than when the second attempt immediately followed the first, resulting in negative incubation effects.

Table 3: Mean Improvement Scores in Experiment 2

	LK		HK	
No Fixation	No I	Incub	No I	Incub
Neutral	.32	.40	.56	.21
Mislead	.07	.21	.12	.11
Fixation				
Neutral	.20	.35	.50	.29
Mislead	.11	.27	.30	.09

Summary

The nonfixation condition replicated the main result of Experiment 1 as high knowledge subjects were significantly less likely than low-knowledge subjects to produce a correct response to misleading trials in the first RAT, demonstrating fixation due to domain knowledge.

Low-knowledge subjects showed an induced-fixation effect due to the fixation manipulation, with a clear decrease in the number of correct solutions when they were primed on irrelevant solutions. High-knowledge subjects, on the other hand, were not negatively affected by the fixation manipulation. This finding supports the idea that the expert's mental set is the result of the automatic activation of their domain knowledge. For the high-knowledge subjects, the priming of the irrelevant solutions was redundant with the activation that was already occurring due to their domain knowledge, thus the priming tasks should have had no additional effect on their problem solving.

In addition to an induced-fixation effect, an incubation effect was observed for the low-knowledge subjects. As predicted, low-knowledge subjects benefitted from a delay between problem solving attempts. Further, not only did the high-knowledge subjects not benefit from a delay, they actually had a *negative incubation effect*, showing significant improvement on the second problem solving attempt when it immediately followed the first. This suggests that the way a mental set can be broken depends on its source. When problem solving impasses are generated by domain knowledge, the present results indicate that a continued or massed effort would be more likely to allow for improvements in performance. On the other hand, impasses generated by particular problem solving attempts or contexts may be more likely to be overcome by incubation.

Discussion

In both experiments, a clear effect of fixation due to domain knowledge was observed in problem solving, suggesting that expertise can indeed instill a mental set and promote fixation. Subjects with the most domain-related knowledge were least able to solve problems correctly when their knowledge suggested an inappropriate solution. The poorer performance of high-knowledge subjects on the misleading problems is consistent with the hypothesis that domain knowledge can act as a mental set. Domain knowledge not only biases a first solution attempt, but also fixates the high-knowledge subject by defining and narrowing the search space, preventing a broad search, and decreasing the chances of finding an appropriate solution. As a result, subjects at lower levels of knowledge (but not no knowledge) were more flexible in their problem solving, making more solution attempts and reaching correct solutions more often than the most-knowledgeable subjects. The specific conditions that this effect was observed under were 1) on a creative problem solving task, where creative is defined as requiring productive (as opposed to reproductive) thinking, and 2) on a task that was of a level of complexity such that novices could engage in problem solving to the same extent as experts.

How is mental set due to knowledge broken?

The source of a mental set seems to play an important role in determining how fixation may be best overcome, and creative thinking may be achieved. Not only was fixation observed in the problem solving of high-knowledge subjects in both experiments, but in Experiment 2 the fixation manipulation was also successful at instilling a set in the low-knowledge subjects through priming irrelevant solutions. Further, for low-knowledge subjects, the sets induced by this fixation manipulation were broken by introducing a delay between solution attempts. For the high-knowledge subjects, however, sets due to the possession of a large amount of domain knowledge were broken when the second problem solving attempt immediately followed the first. In other words, low-knowledge subjects demonstrated more flexible thinking as a result of a distributed effort at problem solving, whereas high-knowledge subjects demonstrated more flexible thinking as the result of a massed effort.

One explanation for these findings is that while breaking the novice set may depend on simply waiting for the activation of recently primed irrelevant associations to fade, breaking the expert set may require more active suppression or inhibition of the irrelevant solution paths that are activated by prior knowledge. Since each time that an expert newly encounters domain-related information irrelevant solutions may be re-activated by domain knowledge via retrieval from long-term memory, the expert would not benefit from a break between repeated solution attempts, or incubation. Instead, during the course of the problem solving, experts need to suppress or inhibit the activation for irrelevant solutions that are generated by their knowledge, which would more likely result from continuous or massed solution attempts. Along these lines Mednick himself (1962) suggested that massed sessions of creative work should be more successful than distributed sessions. Mednick offered that it is only once one gets past "the conventional and stereotyped associations to the elements of a problem" that one can begin to entertain the more remote associations in which are key to creative solutions. Especially for experts whose domain-related associations may be quite robust, it may take time to get beyond initial solution attempts, thereby suggesting that experts' creative problem solving would benefit from a massed effort.

Implications

It is important to note that the present study did not investigate the effects of expertise on domain-related creative problem solving *per se*, rather it provided a demonstration of how the possession of a large amount of domain knowledge may constrain the generation of solutions in the problem solving of experts. While this does not necessarily imply that experts may experience fixation due to their knowledge on creative problems within their domains, there is some evidence to suggest that the mental set due to domain knowledge demonstrated in this study may be generalizable to domain-related problem-solving tasks. For instance, Jansson and Smith (1991) found that advanced design students can be fixated by examples of projects that contain inappropriate features. When asked to design a spill-proof coffee mug without a mouthpiece, designers shown a prototype with a mouthpiece were much more likely to include a mouthpiece in their plans.

In another vein, to the extent that experts may be seen to rely heavily on their prior knowledge and less on the specific information given for problem representation, it is plausible that they may be fixated by that knowledge. And, there are studies in many domains which suggest that in fact experts tend to consider *less* information than novices in their problem solving. For example, experts use less information than novices in auditing (Bédard, 1989), medical internship and residency decisions, and financial analysis (Johnson, 1988). Lesgold (1984) found that expert radiologists spend less time than less-skilled individuals looking at x-rays and fixate at fewer locations. Isenberg (1986) found that experienced business managers solving simulated management problems used less of the information available and often leapt to solutions before the problems were fully presented. Similar results have been found in relation to medical diagnosis (de Graaff, 1989). It is not just the lack of search, but the early commitment to a solution path seen in these last few studies, that suggests that experts in a number of domains may be susceptible to mental set and fixation in their problem solving.

Like other characteristics of expertise, the advantage of extensive knowledge in generating problem representations may benefit problem solving in most domain-related circumstances. Extensive domain knowledge allows experts to infer missing information, make assumptions and post constraints on a problem space, all of which can lead to a narrower and usually more efficient search for solution. But the present study suggests that the influence of domain knowledge on generating problem representations may also have its costs, disadvantaging experts when nontraditional solution paths must be considered.

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