Title
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Authors
Wiley, Jennifer
Jolly, Cara

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When two heads are better than one expert

Jennifer Wiley (jwiley@uic.edu) **Cara Jolly (cjolly1@uic.edu)**
Department of Psychology, 1007 W. Harrison Street (M/C 285)
Chicago, IL 60607 USA

Abstract

In a line of research on expertise and creative problem solving (Wiley, 1998; Wiley, 1999), an instance in which two heads do seem better than one has been found. In a study using a Remote Associates Task, when high knowledge participants were paired with a novice, solution rates actually increased beyond what would be expected from either type of individual working independently. The discovery of a "process gain" condition is quite rare within the social psychology and group problem solving literature. Further, from a cognitive standpoint, it is interesting that experts may sometimes need the assistance of novices in order to be most effective, flexible or innovative in their problem solving.

Introduction

Despite the intuitive appeal of the idea that *two heads are better than one,* few experimental studies have demonstrated an advantage for collaborative problem solving over individual contexts. In fact, individuals in collaborative contexts tend to produce fewer solution attempts, and are judged to generate less creative solutions than individuals acting alone (Mullen, Johnson & Salas, 1991; Taylor, Berry & Block, 1958). The present research investigates conditions under which *process loss* (a term coined by Steiner (1972) to describe the loss in productivity that occurs when individuals must coordinate their efforts in a group) may be avoided or even reversed into *process gain*. When there is a synergetic or value-added effect observed among individuals working as a group versus individuals working alone, this has been termed "process gain".

Why do groups experience *process loss*? Several social factors have been identified as possible reasons. *Process loss* has frequently been attributed to losses in motivation, a lowered sense of responsibility, and less effort by each individual (c.f. Sheppard, 1993). The presence of others introduces an element of evaluation and conflict, not usually present when people act alone. This can have advantages, and theoretically could improve the quality of the group contribution. For example, others may detect errors and provide immediate feedback to any individual in the group. On the other hand, the potential for being evaluated can also have an inhibiting effect, and working with others can cause evaluation apprehension causing poorer performance, and the generation of fewer or less creative ideas. Further, members of interactive groups may experience *process loss* due to coordination problems. Ad Hoc groups need some time together to get past organizational issues.

A final reason why group performance may suffer is due to production blocking or interference from collaboration. That is, when others state their ideas it may cause an interruption in the idea generation process and cause an individual to lose their chain of thought. Working with others adds information, but also adds new channels that need to be attended to. Also, more time may be spent on off-task topics (Dugosh, Paulus, Roland & Yang, 2000). In the end, individuals may be more burdened and enjoy less intact cognitive processing working in groups than when working alone. Studies have directly tested this notion of interrupted cognitive processing among groups, which has been called "production blocking," and support an account of *process loss* as a function of increased disruption in face-to-face collaboration (Diehl & Stroebe, 1987; Stroebe & Diehl, 1994).

Despite the evidence that most group problem solving efforts result in *process loss*, there are theoretical reasons to believe that groups may experience *process gain*. One popular reason why people believe groups should be more effective, flexible and innovative at problem solving is the assumption that each group member brings to the task a slightly different set of task-relevant knowledge. Through discussion, the knowledge of each member can become available for all, giving each member a larger pool of ideas to draw from (Larson, Forster-Fishman, & Keys, 1994; McGrath, 1984). Especially if members possess different background knowledge, group problem solving will give people more opportunity for novel associations. And it has been suggested by a number of researchers that exposure to others' ideas, especially if these represent diverse viewpoints, may increase both the quantity and quality of idea generation in a group context (Jackson, 1996; Paulus, 2000).

There are a few studies in the cognitive science literature that have explored the idea that diversity is the key to the most successful and innovative scientific collaboration. For example, in an investigation of several molecular biology laboratories, Dunbar (1997) has reported that the diversity of a group is very important. When scientists in a laboratory are from diverse backgrounds, they are able to generate many more alternative hypotheses and many different types of analogies in the face of unexpected findings, which in turn can lead to scientific breakthroughs. Although this is an intriguing observation, the idea that diversity in background knowledge contributes to process gain and successful collaborative problem solving has not yet been demonstrated experimentally. The present experiment represents a first step toward an empirical investigation of the role of diversity in background knowledge among group members in effective collaborative creative problem solving.

In previous studies on expertise and creative problem solving, a particular context in which experts are fixated by their knowledge on an incorrect solution has been investigated. Expertise allows people access to a large amount of domain-related information, as well as allowing for fast and easy retrieval of typical solutions in problem solving contexts (Chi, Glaser, & Farr, 1988; Ericsson & Kinstch, 1995). However, when an atypical or creative solution is required, then high-knowledge participants can actually be slower and less likely to reach solution than novices (Wiley, 1998). In following up this original finding, ways to help high-knowledge participants escape their fixation and reach creative solutions have been investigated. Warnings not to use domain knowledge do not help. Giving problem solvers an incubation period or break between problem solving attempts improves problem solving, but only for novices. The only condition that has helped high-knowledge participants to escape their fixation has been when they were given hints about the solution during an incubation period (Wiley, 1999). This suggests that experts may need external cues in order to prime new associations, divert them from considering incorrect solutions, or direct them toward the correct solution. If experts need external cues to help them escape fixation, then they might benefit from collaboration with a less-knowledgeable partner on creative problem solving tasks, making this one case where working together in heterogeneous knowledge groups may be especially productive.

The present experiment tests the hypothesis that collaborative pairs with diverse background knowledge will experience the most process gain in their problem solving. Students solved RAT problems in one of three conditions: either in pairs where both partners had low knowledge; pairs where both partners had high knowledge; or mixed knowledge pairs. Of interest in this study is whether the mixed pairing allows high knowledge participants to escape fixation, and whether any pairs are able to solve more problems together than both members might solve alone (based on solution rates from prior studies).

Method

Participants

Undergraduates were recruited on the campus of Washington State University, Vancouver campus to participate in a problem solving study, and were paid for their participation. Forty-two participants are included in the full design.

Materials

Participants were given a Remote Associates Task (RAT) based on Mednick (1962). In the RAT, solvers need to find a fourth word that forms a good phrase with each of three other words. For example, given the problem KNIFE, BLUE and COTTAGE, the solution is CHEESE. This task is considered a creative problem solving task because it requires the solver to consider a number of meanings for each word, getting past typical uses of words and searching for rare associates that might fit with all three words. The selection and recombination of remote ideas is thought to be an important process underlying creativity and innovation (Mednick, 1962; Simonton, 2001). In this study, the problem sets developed for Wiley was used (1998). Ten of the RAT problems were neutral, based on original Mednick items like the one above. An additional 10 problems were baseball-misleading, such that the first two words primed a baseball-related solution, while the third word could not be paired with that solution. An example baseball-misleading problem is PLATE, BROKEN and SHOT. In response to this problem, participants with high baseball knowledge frequently generate the solution HOME, and take longer to reach a correct solution, or fail to reach a correct solution more often than novices (Wiley, 1998).

Design

The between-groups manipulation has 3 conditions, students either solve in low/low, high/high, or mixed knowledge pairs. All solvers receive 10 neutral and 10 baseball-misleading RAT problems. This yields a mixed 3x 2 (pair knowledge condition by problem type) design. Seven pairs were run in each pair knowledge condition.

Procedure

Following informed consent, pairs were given a word scramble as a warm-up task. Pairs were told that the purpose of the experiment was to see if “two heads are better than one” and they were encouraged to say all guesses out loud as soon as they thought of them so that they could be the most help to their partner. As a first task, the pair was given the word WASHINGTON and asked to find as many words as they could that could be formed out of its letters. Following the scramble task, students were presented with the RAT problems via computer. Solvers were told to type in a solution as soon as they knew it. The program recorded the typed response as well as the solution time. If no solution was entered within 2 minutes, solvers were prompted to type in a solution. After 30 seconds without entering a solution, or as soon as a solution was entered, the next problem was presented.

Following the completion of the RAT, the two participants were seated at separate desks and asked to complete a 45-item baseball knowledge questionnare (created by Spilich, Vesonder, Chiesi, & Voss, 1979). Criteria from previous studies (Wiley, 1998) were adopted, such that scores below

15 were considered low knowledge and above 15 were considered high knowledge. Baseball knowledge could not be assessed until the end of the experiment in case completing the questionnaire beforehand might bias performance on the RAT problems. Because the condition of each pair was not known until after the pair was run, an additional 3 pairs needed to be run to obtain 7 pairs in all conditions. Only the first 7 pairs run in each condition are included in the design.

The whole procedure was generally completed in under an hour. All sessions were video and audio recorded so that the content and number of guesses generated could be later coded.

Results

Performance on Word Scramble Task

The scramble task was included as a warm-up task, since it has been shown that the best collaborative performance requires some familiarity between group members. Although a warm-up task is not a substitute for long-standing group membership, it nevertheless allows the pair to get used to talking out loud and working together. Further, the data from this task can be used to provide a baseline comparison of the fluency and creativity of groups across conditions. The average number of words generated by all pairs was 33.38 (SD 6.1), and there were no differences across groups ($F<1$).

Performance on Remote Associates Task

The critical analysis for this experiment is whether the combination of knowledge levels in each pair affected performance on the RAT.

Pairs in all three conditions did equally well on the neutral problems, each pair getting almost all of them right ($M=9.47$), as can be seen in Figure 1. On the baseball problems, both the high knowledge pairs and the low knowledge pairs solved about 6 baseball-misleading problems correctly. Mixed knowledge pairs, on the other hand, correctly solved 8 baseball-misleading problems on average. The performance of the mixed knowledge pairs was significantly better than the performance of the low/low knowledge pairs, $t(12)=2.12$, $p<.05$. The difference between the performance of the mixed and high knowledge pairs did not reach significance, $t(12)=1.73$, $p=.10$.

Solution rates from previous studies (Wiley, 1998) would predict that each novice should get an average of 4 baseball-misleading problems correct, while high-knowledge participants should get only around 2 misleading problems correct. With these expectations in mind, we can see that when two novices worked together, they correctly solved around 6 problems on average, which is slightly less than one might expect based on average solution rates for novices in previous studies. However, both the high knowledge pair and the mixed knowledge pair correctly solved roughly 2 problems more than we would expect from average individual high and low knowledge performances. Comparisons of observed versus expected outcomes indicated that the mixed knowledge pairs performed significantly better than would be expected based on individual averages ($t(6)=4.01$, $p<.05$). The high knowledge pairs also tended to do better than would be expected, but this did not reach significance ($t(6)=1.9$, $p<.10$). The low knowledge pairs did significantly worse than would be expected based on past performance of low knowledge participants ($t(6)=2.42$, $p<.05$).

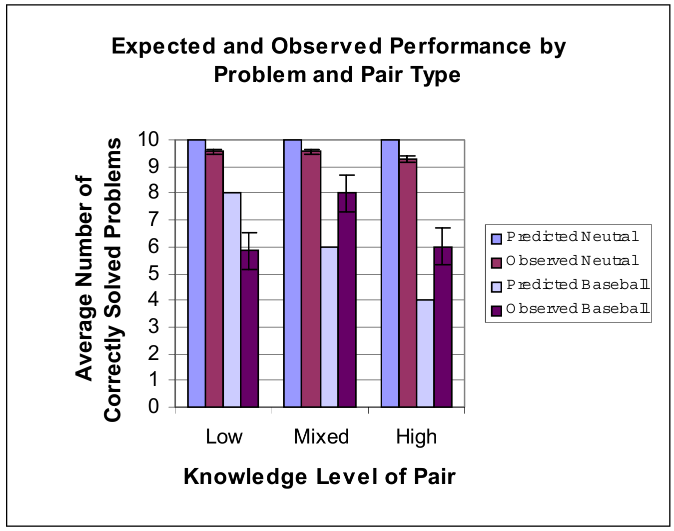

Figure 1: Expected and Observed Performance by Problem and Pair Type

The results suggest the mixed knowledge pairs in this study experienced *process gain*. On a creative problem solving task where experts are fixated by their knowledge, solving problems with a less knowledgeable partner increased solution rates. Collaboration even seemed to help when both partners were high-knowledge.

Preliminary Protocol Analysis

To follow up these results, the protocols of each collaborative session were transcribed and coded in terms of how many guesses each partner made, who contributed the correct answers on the baseball items, and if there were any apparent patterns in the discourse that could offer some suggestion of how the mixed pairs achieved their superior performance. The first, most obvious issue, was whether in the mixed pairs the novice did all the work. For each pair, the number of guesses and number of correct answers guessed by each partner was tabulated. For the mixed groups, the low knowledge partner made an average of 4.1 guesses on each baseball-misleading problem, while the high knowledge partner offered an average of 3.4 guesses. There was no significant difference in the number of guesses on baseball-misleading problems offered by high and low knowledge partners (t<1). Similarly, when correct solutions to baseball-misleading problems were examined, again on average both low and high knowledge partners contributed roughly half of the correct solutions (t<1).

These results suggest that there was something about collaboration that was allowing the high-knowledge subjects to circumvent fixation due to domain knowledge. The most striking pattern that emerged in first pass of coding these protocols, was that the groups with high-knowledge members were much more likely to actually explicitly state the baseball-related solutions in the process of problem solving. As shown in Figure 2, the mixed and high knowledge pairs were much more likely than the low knowledge pairs to mention a baseball-related solution in their guesses, $F(2,18)=5.65$, $MSE=2.07$, $p<.01$. Follow-up tests using Fisher's Least-Significant-Difference Test indicated that both Mixed and High knowledge pairs mentioned more baseball terms than did low knowledge pairs.

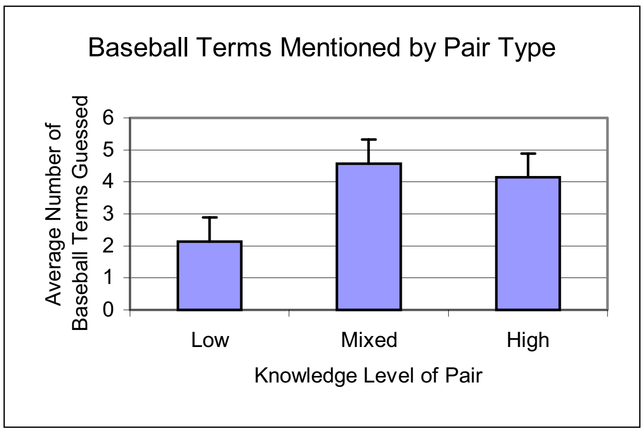

Figure 2: Baseball Terms Mentioned by Pair Type

Thus, one possibility is that by saying the incorrect solutions out loud, or hearing them, high knowledge participants were able to recognize their impasse. This may allow them to move beyond the solution that was fixating them. And, in general, this suggests that when problem solvers reach impasse due to prior knowledge, that collaborative contexts may allow problem solvers to better consider alternative solutions after the wrong solution is stated. The next step is to examine exactly what occurs in the discourse on the successful attempts, such as when the pair finds the solution GLASS to the misleading example problem of PLATE, BROKEN and SHOT, and especially what occurs after an incorrect solution like HOME has been offered.

Conclusions, Implications, and Significance

The results of the present study suggest that, on a creative problem solving task where high-knowledge participants are typically fixated by their knowledge, solving problems with a less knowledgeable partner increased solution rates over what would be expected if each partner worked alone. There also seemed to be some advantage for high-knowledge partners working with another high-knowledge partner. This suggests that collaboration may be one context in which experts may be released from the fixating effects of their prior knowledge.

While this is an intriguing finding, there are a number of specific details of the experimental context that this result was found in that could be contributing to the observed *process gain*. In particular, this study was run at a small liberal arts campus, where familiarity between the student pairs, as well as familiarity between the students and the experimenters may have fostered a highly cooperative atmosphere, allowing for the successful collaboration observed here. However, it is important to note that the students in the mixed pairs were NOT any more familiar or less familiar with each other than were students in the other two groups. Thus, there is still most likely an effect of collaboration at work here. It is an important direction for future research to see if collaboration also helps high knowledge participants in pairs who do not know each other beforehand. Further, it is hoped that more detailed analysis of the protocols might shed greater light on whether there is anything else in the interaction that is allowing the high-knowledge participants to do so well.

The critical contribution of this line of research is that it is the first experimental demonstration of the advantage of collaborative contexts for high-knowledge problem solvers. Admittedly this is a contrived task, and there may not be much demand for "baseball expertise" in daily life nor in any meaningful problem solving or decision making contexts. However, the present demonstration can be seen as having important implications for models of scientific discovery, as the range of solutions that are considered in any scientific investigation may be limited by the expertise of individual investigators. The present results are consistent with recent conceptualizations of scientific reasoning and discovery being most effective when it is a distributed social and cognitive process (Dunbar, 1999; Thagard, 1997). If problem solvers can be fixated by their domain knowledge, then collaboration and distributed efforts of diverse groups with common goals may be critical for the formation of new models in science, the ability to produce new hypotheses in the face of unexpected data, and the discovery of new principles.

Our society places a great value on group problem solving and decision-making contexts. Juries, medical teams, scientific research laboratories, thinktanks are all formed because of the underlying assumption that the group context will lead to more effective, flexible and innovative problem solving and decision making than would be attained in individualized efforts. Unfortunately, time and again researchers have observed the opposite. Groups are less productive, less creative, often biased in their judgments and sometimes unduly influenced by one member. A variety of social factors seem to be responsible for this *process loss*. This ubiquitous finding of *process loss* is what makes the present finding, in which diversity in background knowledge led to *process gain*, of such interest from both a social and a cognitive perspective.

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