# Convergent or Divergent Problem Space Search: The Effect of Problem Structure on Group Versus Individual Problem Solving

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# CONVERGENT OR DIVERGENT PROBLEM SPACE SEARCH: THE EFFECT OF PROBLEM STRUCTURE ON GROUP VERSUS INDIVIDUAL PROBLEM SOLVING

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## ABSTRACT

Two laboratory experiments investigated whether group interaction hinders searching a problem space. The results from both studies show that individuals engage in a broader search of a problem space when it is either unconstrained or constrained but ill-structured. Conversely, when the problem is well-structured and has a constrained solution state, individuals and groups search that space equally well.

## INTRODUCTION

It is frequently asserted that group problem solving is superior to individual problem solving. There exists a belief in a type of synergistic phenomenon whereby group interactions yield solutions far better than those of individuals. But the research on group versus individual problem solving, although suggestive of such praise, is far from conclusive. For example, several comprehensive reviews discuss the numerous studies both in favor and against group problem solving (Gigone & Hastie, 1997; Hastie, 1986; Hill, 1982; McGrath, 1984). One possible reason for the variability in conclusions regarding the efficacy of groups is the inconsistent use of the proper means with which to determine whether performance gains or losses have occurred. The group will almost always outperform the individual simply because its larger size increases either the amount of "solutions" or the probability that it will have a member in it that can solve the problem. Therefore, the proper test involves forming artificial groups from the pooled responses of noninteracting individuals -- termed the *nominal group analysis* (Ekman, 1955; Lorge & Solomon, 1955; Marquart, 1955). Unless a nominal group analysis is conducted, it is unclear whether there is truly any synergistic effect taking place in the group's interaction or whether it is merely the additive effect of increasing the amount of people working on a problem. Much of the research on group vs. individual problem solving fails to take this into account, with results typically claiming beneficial effects of group problem solving.

From the onset, we readily admit that the utility of groups in differing contexts is most certainly valid when it comes to complex tasks that are clearly divisible (e.g., navigating a ship, Hutchins, 1990), or highly interdependent (e.g., military command and control teams, see Cannon-Bowers & Salas, 1998). Our argument is simply that their usefulness on tasks that can be accomplished by an individual (e.g., creative design) remains unclear. Specifically, empirical studies, using a variety of tasks, continuously demonstrate that the performance of face-to-face groups seldom exceeds the level of their best member (e.g., Gigone & Hastie, 1997). Furthermore, much research reveals that group processes tend to produce inhibitory effects on solution generation such that groups fail to meet even this level of performance, and actually perform worse than would be expected based upon the performance capabilities of their members (e.g., Hastie, 1986; Hill, 1982; Paulus, Dzindolet, Poletes, & Camacho, 1993; Stroebe, Diehl, & Abakoumkin, 1992).

The overarching question is, what are the processes potentially leading to negative effects on group problem solving? We suggest that, first, in order to truly determine the effects of group interaction, the nominal group analysis is required. Only when there is evidence of the real group performing better than the nominal group is it warranted to justify claims of process improvements. Second, we argue that problem space, a concept that has its roots in, and is adapted from, information processing theories of problem solving, may provide a construct with which one can understand the situations potentially associated with poor group problem solving performance. Toward that end, differing characteristics of problem type and the problem solving process are reviewed.

## PROBLEM SOLVING AND PROBLEM SPACE: CONVERGENCE AND DIVERGENCE IN PROBLEM SEARCH

During the past decade cognitive science has substantially influenced social psychology, creating the social cognition movement (e.g., Larson & Christensen, 1993; Levine, Resnick, & Higgins, 1993). Additionally, this influence of cognition has had a substantial impact on the study of groups (Hinsz, Tindale, & Vollrath, 1997). Indeed, groups are sometimes considered to be information processing units in a manner analogous to early views of human cognition (e.g., Newell & Simon, 1972). Here we focus on two related constructs from information processing theory and human problem solving. In particular, by incorporating the concept of searching a problem space (Newell & Simon, 1972), along with the distinction between ill- and well-structured problems (Simon, 1973), we hope to provide additional insight to group problem solving processes.

Within a given problem space, the various elements composing that space can be either well-structured (WSP) or ill-structured (ISP) in that the permitted actions and/or constraints associated with those actions can be either clear or ambiguous (e.g., Reitman, 1965; Simon, 1973; Voss & Post, 1988). A problem structure that elicits agreement as to the definitions of permitted actions (e.g., rules/constraints, problem elements) and the consequences of those actions (e.g., goals) is considered unambiguous or well-defined. But, a problem structure that elicits a highly variable set of potential actions and also disagreement as to the consequences of those actions is considered ambiguous or ill-defined (Campbell, 1988; Reitman, 1965). Given this, the structure of the problem space can vary tremendously with differing tasks. What additionally distinguishes such tasks is the requirement for the divergent production of ideas vs. convergent thinking. ISP's require a divergent process which is "thinking that flows outward from a concept, making contact with other ideas and possibilities that one might not ordinarily consider" (Finke, 1995, p. 255). WSP's require convergent thinking which is characterized as a process that proceeds toward a single answer or thinking that concentrates on a single idea or possibility based upon a set of facts (Finke, 1995).

At issue is the degree to which the structure of the problem space influences group problem solving. We suggest that group interaction may lead to processes that hinder the search for solutions when the problem space is ambiguous or ill-structured. Specifically, problem structure may be an important task component in influencing performance because of a group's inability to engage in a divergent search of that space. Indeed, early research suggested that group interaction leads to fixation on a particular solution path, specifically, a "group tends to 'fall in a rut' and to pursue the same train of thought. The effect of this is to limit the diversity of approaches to a problem, thereby leading to the production of fewer different ideas" (Dunnette, Campbell, & Jaastad, 1963, p. 37). We further suggest that research from cognitive psychology (e.g., verbalization leading to entrenchment, Fiore & Schooler, 1998; Schooler, Ohlsson, & Brooks, 1993), social psychology (e.g., collaboration resulting in disorganized memory retrieval strategies, Basden, Basden, Bryner, & Thomas, 1997) and organizational psychology (e.g., the tendency to routinize behavior, Gersick & Hackman, 1990; Hackman & Morris, 1975), all provide converging evidence that group interaction may inadvertently constrain the idiosyncratic solution search capabilities of its members.

## EXPERIMENT ONE

If the nature of group problem solving failure is due to the structure of the problem space (i.e., ill- or well-structured) this should transfer to more typical tasks designed to measure searching divergent problem spaces (i.e., creative tasks used to measure divergent thinking). Furthermore, if this is due to an inability to engage in divergent problem solving associated with such tasks, then well-structured tasks that require more convergent processes should show no differences in performance between groups and individuals. Thus, the purpose of Experiment One was to directly compare Real and Nominal Groups (RG and NG) on ill- and well-structured problems. We hypothesized that NGs would only out-perform RGs on an ISP but show no differences on a WSP.

### Method

*Participants.* Sixty-eight participants from the University of Pittsburgh were run in the experiment. Thirty-four were run in real groups of three or four, forming ten real groups and thirty-four were run individually, forming ten nominal groups of three or four.

*Materials.* The convergent task was a set of anagrams (see Underwood, Deihim, & Batt, 1994), a form of arrangement problem requiring the selective combining of letter arrangements until the solution is determined (e.g., *RAWET --> WATER*). These problems are considered convergent because they involve honing in on a single solution. The divergent task was the "Uses" test, taken from Wallach and Kogen (1965). In the Uses test, the task is to come up with as many uses for a common object as one can (e.g., *Name all the uses you can think of for a newspaper*). Performance is determined by measuring task fluency (i.e., the ability to generate a large number of ideas).

*Procedure.* Participants were randomly assigned to either the individual or the group condition. In the group condition, three to four participants collectively worked on a problem. In the individual condition, up to eight participants simultaneously worked on the problems but no interaction was permitted. Participants were given 30 seconds for each of 15 items in the anagram test and 3 minutes for the uses test. The order of presentation for problems was counter-balanced across participants.

### Results and Discussion

In order to eliminate redundant items when compiling data for the NGs, a list comprised of each NG's generated items was constructed for the Uses task. Responses were reviewed in order to collapse across similar ideas and this final list was used to score participant responses. Size of the nominal group was matched to the size of the real groups. Because there were groups of different sizes, the data were subjected to a 2-factor ANOVA with Group Type (Nominal vs. Real) and Group Size (Three vs. Four) as between participant factors. Separate ANOVAs were conducted on the divergent and convergent task data. Although there was a main effect of group size on the Uses test, with groups of four generating more items, this did not interact with group type, therefore, we report only the conditions of relevance to our main hypotheses.

Mean output on the divergent task for NGs ($M = 7.2$, $SD = 0.74$) was significantly greater than mean output for the RGs ($M = 3.3$, $SD = 1.2$), $F(1, 16) = 100.1$, ($p < .0001$). There was a numerical difference in performance for the convergent task. RGs solved an average of 91% ($SD = .10$) of the anagrams and the NGs solved an average of 82% ($SD = .13$). This difference was marginally significant, $F(1, 16) = 3.6$, ($p < .08$). We conclude that group interaction hindered a divergent search on the ISP (i.e., the general production of ideas), but it marginally facilitated engagement of a convergent search on the WSP (i.e., finding a single correct solution).

## EXPERIMENT TWO

Given that real groups showed an inability to search an ill-structured problem space, the critical question becomes why did groups fail when divergence was required. The goal of Experiment Two was to investigate two alternative hypotheses that could explain these differences. Performance differences may not be due to the degree of divergence required, rather they could be due to the generative nature of the task (i.e., the requirement to come up with many solutions). As such, this experiment attempts to account for the distinction whereby well-structured and ill-structured tasks are sometimes associated with, respectively, constrained and unconstrained solution states. Specifically, task structure is sometimes confounded with differences in the nature of the solution state. Production tasks (i.e., tasks with unconstrained solution states) are typically considered to be ISPs and divergent, while most problem solving tasks (i.e., tasks with constrained solution states) are considered to be WSPs and convergent.

Given the above distinction, we reasoned that there are two possible interpretations of Experiment One. First, the results could be, as hypothesized, due to the differing requirements for convergence or divergence in searching well- or ill-structured problem spaces. Second, and alternatively, the results could be due to the nature of the solution state for the two tasks. If performance differences between groups and individuals arise in ill-structured tasks, not because of the unconstrained nature of the solution state, but, because of the divergent requirements of the search process, then there should be similar patterns of performance on tasks that have a constrained solution state but which are still relatively ill-structured (e.g., Remote Associates Test). Similarly, if the lack of difference in standard problem solving tasks is due to their convergent processing requirements and not to the constrained nature of the solution state, then groups should be equally able to engage in tasks that have an unconstrained solution state, but which are still well-structured (e.g., Word Production tasks). In sum, this experiment investigates whether the structure of the problem space or the nature of the solution state affects performance differences between groups and individuals.

### Method

*Participants.* Thirty-eight participants from the University of Pittsburgh were run in the experiment. Nineteen were run in real groups of three or four, forming six real groups and nineteen were run individually, forming six nominal groups of three or four.

*Design.* This experiment was a mixed design with group type (nominal versus real) as a between participants variable and problem structure (well-structured versus ill-structured) and solution state (unconstrained versus constrained) as within participants variables.

*Materials.* The two types of well-structured problems were the set of anagrams used in Experiment One (constrained solution state) and word production problems (unconstrained solution state). Word production tasks are a form of arrangement problem requiring the selective combining of letters to find words while following a limited number of rules (e.g., no letter can be repeated within a given word). Specifically, the problem solver generates as many words of a given length as possible from the presented set of letters (e.g., *K E V L S A N W O* → *WOKE, NOSE*). The problem space is considered well-structured in this instance because of the readily apparent relevant variables the problem solver need consider (i.e., the provided letters) and because the required means with which to solve the problem is clear (i.e., simply rearrange letters). The solution state is considered unconstrained because it requires generating as many items as possible.

The two types of ill-structured problems were a set of remote associates problems (RAT) and a brainstorming problem. Mednick's (1962) RAT problems are sets of words that are related in some way by a to-be-determined word (e.g., *strike, same, tennis --> match*). We used Bowers et al.'s (1990) version of the RAT which requires, for each test item, participants to decide between two sets of associates which is correct and provide the answer. The problem requires generating associates in order to find the word that can relate the items in the correct set. Brainstorming involves generating as many possible solutions to a given problem as possible (e.g., *How can you increase international tourism in the U.S.?*). The problem space for these tasks is considered ill-structured because of the requirement to consider, not only the given set of variables (e.g., words in the RAT set or the many differing parts of the brainstorming problem), but, also, which of any other possibilities that could be related, might help. Specifically, in the case of RAT problems, it is unclear which of the many differing kinds of associations are actually valid (e.g., synonyms, different meanings of the words, parts of a phrase), and in the case of the brainstorming problem, which of the many and varied implications associated with the problem need to be considered. Thus, the problem solver is required to engage in a divergent search of the problem space in order to branch outward in their search and make contact with as many related concepts as possible. As shown in Table 1, these tasks require that participants find, either a single correct answer (i.e., constrained solution state in RAT task), or generate as many answers as possible (i.e., unconstrained solution state in brainstorming task).

**Table 1**
**Problem Structure and Solution State for Tasks Used in Experiment Two.**

| | | Problem Structure | |
|---|---|---|---|
| | | Well-structured | Ill-structured |
| Solution State | Constrained | anagrams | remote associates |
| | Unconstrained | word production | brainstorming |

*Procedure.* Participants were randomly assigned to either the individual or the group condition. In the group condition, participants worked collectively. In the individual condition, up to eight participants simultaneously worked on the problems but no interaction was permitted. Participants were given approximately 30 seconds for each of 15 items in the anagram test and 5 minutes for the word production test. Participants were given approximately 20 seconds for each of the Remote Associates Test items and 5 minutes for the brainstorming problem. The order of presentation for problems was counter-balanced across participants.

### Results

Again, in order to eliminate redundant items when compiling NG data, a list comprised of generated items for each NG was constructed separately for the Brainstorming and the Word Production tasks. Responses were reviewed in order to collapse across similar ideas and this final list was used to score participant responses. Separate ANOVAs were conducted on each task. As in Experiment One, size of nominal group was matched to size of the real groups and the same pattern was found as before. We, therefore, report only the analyses of relevance to our main hypotheses.

*Ill-structured tasks.* For the brainstorming task (i.e., ill-structured and unconstrained solution state) mean output for NGs ($M = 26.7$, $SD = 6.2$) was significantly greater than mean output for the RGs ($M = 17.5$, $SD = 6.0$), $F(1, 10) = 6.8$, ($p < .05$). Additionally, for the RAT task (i.e., ill-structured and constrained solution state) mean accuracy for NGs ($M = .53$, $SD = .09$) was significantly greater than mean accuracy for the RGs ($M = .43$, $SD = .05$), $F(1, 10) = 6.5$, ($p < .05$).

*Well-structured tasks.* For the word production task (i.e., well-structured and unconstrained solution state) mean output for NGs ($M = 40.2$, $SD = 8.8$) was significantly greater than mean output for the RGs ($M = 26.8$, $SD = 5.6$), $F(1, 10) = 9.8$, ($p < .05$). Additionally, for the anagram task (i.e., well-structured and constrained solution state) mean accuracy for NGs ($M = .90$, $SD = .05$) was not significantly different from mean accuracy for the RGs ($M = .84$, $SD = .19$), ($F < 1$).

### Discussion

The results from the second experiment provide additional support that the nature of the problem may differentially impact performance differences between real and nominal groups. We find that RGs may perform less well when there is either an ill-structured problem space (as in brainstorming *and* remote associates tests) or when there is a well-structured, but unconstrained solution state (as in word production tasks).

## GENERAL DISCUSSION

In this set of experiments it was shown that problem structure and the nature of the solution state may contribute to performance differences between real and nominal groups. By investigating performance on varying problem solving tasks, we isolated situations where differences do and do not occur. In particular, it was found that the deleterious consequences of group interaction occur to a greater degree when there exists an ill-structured task or an unconstrained solution state. Group interaction, therefore, may produce a general form of search disruption in the problem solving process, thus hindering overall performance (see also Basden et al., 1997; Lamm & Trommsdorf, 1973; Stroebe & Diehl, 1994).

These results support the view that task components influence the degree to which performance differences may occur in interacting groups (e.g., Argote & McGrath, 1993; Hill, 1982; McGrath, 1984; Steiner, 1972). Although a specific mechanism for producing these differences was not definitively isolated, we speculate that the impact of this disruption increases when the problem requires a divergent or generative search. Despite these findings, studies suggest that certain interventions in group problem solving may mitigate the negative consequences of group interaction. For example, the role of a leader or facilitator has sometimes been shown to benefit group problem solving (e.g., Fiedler, Chemers, & Mahar, 1976; Maier, 1967). More recent theorizing suggests that leaders can be effective if they direct interventions that prompt group members to examine their current means of solution generation (Gersick & Hackman, 1990).

Recent empirical research illustrates the important role that facilitators can similarly play in problem solving teams, documenting how they may enable teams to overcome factors which often plague group problem solving (e.g., Oxley, Dzindolet, & Paulus, 1996). Additionally, group interventions developed to assist teams in reengineering and process redesign (e.g., process mapping, see Rummler & Brache, 1995) may be successful because they partition large and complex problem spaces into more manageable units. This, in turn, facilitates searching the problem space and may improve subsequent solution generation (Fiore, Ferketish, Schooler, & McConnell, 1998). Collectively, this body of research suggests that group leaders and/or facilitators may specifically benefit interaction by forcing members of a group to pursue differing areas of a problem space, thus aiding their search.

In sum, we conclude that nominal groups engage in a broader search of a problem space when it is either unconstrained or constrained, but ill-structured. Although only a laboratory study conducted on ad hoc groups, these findings represent plausible conditions to test in applied settings using more complex tasks. In this way, research can determine whether teams *in situ* may similarly suffer from the sometimes negative consequences of group interaction.

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