A COMPARISON BETWEEN GROUP AND INDIVIDUAL PROBLEM SOLVING BY R&D ENGINEERS

by

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Chairman, Departmental Committee on Graduate Students

ABSTRACT OF THE THESIS

Title of the thesis: A Comparison Between Group and Individual Problem Solving by R&D Engineers

Name of the author: Arthur Gerstenfeld

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The National Aeronautics and Space Administration often awards parallel contracts for research and development. These contracts afford the researcher an opportunity to study various aspects of the R&D process in different laboratories at the same time, while each laboratory is working on the identical problem.

Interviews with project personnel, interviews with government personnel, questionnaires and tape recorded project meetings were all utilized in the gathering of data.

This study explores the relationship between group and individual problem solving and its effect on success. The success ratings are based on evaluations of the government technical monitors who have cognizance over the particular project. The information channels that generate ideas are considered and compared between the higher and lower rated laboratories. Conditions of prior experience are analyzed and a laboratory that had broad general experience is compared with a laboratory that had prior specific pinpointed experience.

The four hypotheses examined in the study are: 1) Group problem solving will be more effective (in terms of evaluated solution quality) than problem solving by individuals. 2) The R&D laboratory which utilizes more internal sources of information will perform more successfully than the laboratory that relies heavily on outside sources of information. 3) Prior experience with a technique which is not appropriate for the present problem usually results in an unsuccessful solution (negative biasing set). 4) An R&D laboratory considers constraints simultaneously and there is not a substitution effect of one constraint for another.

The conclusions arrived at in the study are: 1) Group problem solving worked better in one laboratory than in another, and it is not possible to say that group problem solving will be more effective than problem solving by individuals. 2) Group problem solving resulted in higher evaluated solution quality when the group spent less conference time in giving opinions and more time in asking for opinions and showing a moderate degree of disagreement. 3) The results indicate that in those cases where high group participation was utilized in problem solving, there was a greater degree of considerations of cost and schedule constraints. This confirms D. C. Barnlund's (1959) conclusion that group members saw different issues and a larger number of issues than a single person working alone. 4) The internal sources of information, such as technical staff, company research, personal experience and experimentation, are the major idea generators for the more successful laboratory. It is concluded, especially in light of the previous research, that internal sources of information have a high effectiveness while external sources of information have a low effectiveness. 5) It is concluded that when prior experience is specific and pinpointed, the present solution may merely repeat the prior solution, or alter the prior solution. When the prior experience is broad, the atmosphere is clear for consideration of many alternatives, then narrowed down to a final solution.

A revised method of considering previous experience is discussed and recommendations made. The positive values of group interaction and the ability to consider more issues is discussed and recommendations presented. The successful use of internal sources of information leads one to encourage the use of this channel of communication and to de-emphasize dependence upon outside sources of information.

Thesis Advisor: Thomas J. Allen, Jr.
Title: Assistant Professor of Industrial Management

May 10, 1966

Professor William C. Greene
Secretary of the Faculty
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

Dear Professor Greene:

In accordance with the requirements for graduation, I herewith submit a thesis entitled, "A Comparison Between Group and Individual Problem Solving by R&D Engineers."

In the course of preparing this thesis, I have become deeply indebted to Professor Thomas J. Allen for his stimulating suggestions, patience and counsel; to Professor Donald Marquis for his advice in guiding the research effort; and to my wife, Peggy, for all of her encouragement.

In addition, without the cooperation and support of the Marshall Space Flight Center, National Aeronautics and Space Administration, the personnel of that Center, and all the cooperating firms and their employees, this study would not have been possible.

Sincerely yours,

Arthur Gerstenfeld

AG:mb

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER I

INTRODUCTION

Research and development is a problem solving process that has become significant as both industry and government are more and more committed to large expenditures of personnel and funds. The annual expenditure of $20 billion for research and development involves economic growth and military security as well as company profits.

Many different types of managerial techniques may be utilized with varying degrees of success. This research is concerned with the effect of three factors and their interaction on the R&D problem solving process. Under consideration are the use of groups or individuals in problem solving, information sources which are used for generation of ideas, and the effects of past performance on present behavior.

Group vs. Individual Problem Solving

A great deal of effort has been expended in the social psychology of group processes for decision making. In the studies reviewed by Collins and Guetzkow (1964) they state that, in general, products produced by groups are superior to the products produced by individuals. However, the superiority of the group is very often not as great as might be expected.

The studies of Lorge, Fox, Davitz, and Brenner (1958) emphasize that it is not possible to state simply that group productivity is or is not superior to the productivity of individuals working in isolation.

They go on to state that, for purposes of both theory and application, it is necessary to consider the conditions under which groups are superior.

In one of the most comprehensive reviews of research with group problem solving contrasted to individual problem solving, Lorge et al. analyzed in detail the studies done in the years 1920-1957. They concluded, after analyzing 74 different studies, that past research has suffered from a lack of reality. "The problems, in general, have been puzzles, riddles, or information-test questions." They state that the results from such tasks were not sufficiently conclusive to allow an unambiguous generalization about the superiority of groups over individuals with more realistic problems.

The participants in 72 conferences in business and government studied by the University of Michigan (Marquis, Guetzkow and Heyns, 1951) rated their satisfaction with several aspects of the conferences. The results indicated that the larger the percentage of agenda completed in a meeting, the more the participants are satisfied with it. Satisfaction is also higher in meetings where the agenda topics are completed with dispatch. The longer it takes to reach a decision on the substantive topic, the lower the satisfaction. Meetings in which the observers rated the problem solving as orderly, efficient, and rapidly paced also showed higher member satisfaction. Shorter meetings leave the participant more satisfied than long ones. Unfortunately, no direct measure of problem difficulty or evaluation was obtained in the field study of 72 conferences.

By the utilization of parallel programs, for the first time we are able to study the effects of group and individual problem solving with realistic problems. Utilizing the Interaction Process Analysis (Bales, 1950) permits one to compare the social behavior of one laboratory with that of another laboratory. Since evaluation is also available, it is possible to consider the profiles in relationship to high or low success. In the past, the profiles provided a frame of reference, but without evaluation, it was only possible to conclude that one group was similar or not similar to another group. This research relates the interaction analysis with high or low success in group problem solving.

Sources of Information

A study by Shilling and Bernard (1964) related communication practices to productivity and efficiency in 64 selected biological laboratories. They find that the use of paid consultants outside of the laboratory shows a consistent inverse relation with eight measures of productivity and efficiency.

Twenty-two proposal competitions for government R&D contracts were researched by Allen (1964). The examination involved 156 proposal teams to determine the relative use of three sources of technical information. The extent to which each proposal team relied upon literature search, the use of staff specialists within the laboratory and the use of outside sources of information was related to the technical quality of its proposal. It was again found that technical quality is inversely related to the extent to which the proposal team relies upon individuals outside of the laboratory as sources of information. A study by Allen, Andrien and Gerstenfeld (1966) on information sources for generation of ideas showed that higher rated teams are relatively stable in all phases of information gathering while lower rated teams initially spend far more time gathering information than they do in the later stages and fluctuate more throughout the project.

Prior Experience Creating a Biasing Set

Allen and Marquis (1964) studied the effect of prior experience on success by comparing the behavior of eight laboratories in two R&D proposal competitions. The findings showed that if the prior experience is limited to a technique which is appropriate to the present problem, successful solution is almost certain. Prior experience with a technique which is not appropriate usually results in an unsuccessful solution. In the latter case, if more than one alternative approach is considered, the probability of achieving a successful solution is increased from 0 to 0.5.

The hypotheses to be considered are as follows:

1) Group problem solving will be more effective (in terms of evaluated solution quality) than is problem solving by individuals.

2) The R&D laboratory which utilizes more internal sources of information will perform more successfully than the laboratory which relies heavily on outside sources of information.

3) Prior experience with a technique which is not appropriate for

the present problem usually results in an unsuccessful solution (negative biasing set).

4) An R&D laboratory considers constraints simultaneously and there is not a substitution effect of one constraint for another.

CHAPTER II

RESEARCH METHODS

Definition of Problem Tasks

The contracts selected for study were awarded from a major government laboratory. Two laboratories were presented with identical work statements. The parallel project research provides an opportunity to partial out the substance of the project and permits study of several variables and their effect upon technical merit.

The project work statement reads as follows: Investigate and perform a preliminary design study of a family of instruments for observing specific properties of lunar surface and subsurface materials. This investigation will provide nonfunctional mock-ups of the scientific instruments to be used for future design integration testing.

After discussions with the laboratory representatives and the government technical evaluators, this complex design was subdivided into six major problems and then many, more detailed subproblems. The major problems are as follows:

1) Measurement of radioactivity (alpha, beta and gamma-ray intensities),

2) Measurement of thermal properties on the lunar surface and subsurface (infrared radiation, thermal conductivity and diffusivity, temperature),

3) Measurement of acoustic properties on the lunar surface and

subsurface (subsurface velocity and wave transmission characteristics),

4) Measurement of electrical properties on the lunar surface and subsurface (impedance, permeability, relative permittivity and resistance),

5) Measurement of lunar physical characteristics, mainly density, at the moon surface, at ten-foot and at 100-foot depths,

6) Measurement of scanning spectrometers on lunar surface.

Data Collection

Data collected are of five types including interviews, tape recorded project meetings, and questionnaires.

1. Interviews. At the beginning of the project, the project managers as well as the assigned engineering personnel in each laboratory were interviewed and told about the research to be performed. Findings of previous studies were cited, and for the laboratories' participation, they were to receive a report upon conclusion of the study. Interviews were also conducted with the government project manager as well as with the cognizant technical officers at the sponsoring agency's headquarters in Washington. Evaluation questionnaires were sent in advance of the interviews listing each detailed subproblem so that adequate preparation for the meetings could be performed.

2. Information Source Questionnaire. This questionnaire was completed on a weekly basis by the engineer in charge of each subproblem. He circled the number that corresponded to the number of men assigned full time and part time during the week's activity. For

part-time assignments, he was asked to indicate the percentage of time used on the particular project.

The respondent circled those sources affecting the problem in any way that week. He was asked to indicate which source(s) had a serious impact upon his visualization of the problem or any of its potential solutions at any time during the preceding week.

3. Participation Questionnaire. Each laboratory further subdivided the six major problem areas into twenty-two nearly identical subproblems. The assigned engineer, confirmed by the project manager at each laboratory, indicated by circling the appropriate number, the percentage that the group or individual contributed to formulating the decision. The scale runs from 100% individual to 100% group. Laboratory A had 9 detailed problems with the majority of the contribution a result of group effort and 13 with the majority of solutions a result of individual activity. On the other hand, Laboratory B utilized group problem solving more often and had 14 problems where they indicated that the solution was the result of group effort, and 8 where the solution was largely the result of individual effort. The 14 subproblems that Laboratory B selected for group problem solving were identical to the 9 selected by Laboratory A. The laboratories differed in that Laboratory B elected to solve an additional 5 problems by group method and Laboratory A elected to utilize individual problem solving for these five.

The second portion of this questionnaire concerns itself with constraints. The project manager was asked to indicate the importance of cost considerations in reaching this decision. He was also asked to indicate the importance of schedule considerations in reaching this decision. The answers varied on a five-point scale from very low importance to very high importance.

4. Tape Recorded Problem Solving Meetings (Coding). At the initial interview with each laboratory, a request was made to tape record project meetings as a further data-gathering technique for this research. After serious consideration by both laboratories, they agreed to record project meetings and forward the tapes to the researcher. One recorder was left at each plant and as tapes were received by the researcher, the laboratories were sent new tapes for future meetings.

Consideration was given to the use of Mishler's (1966) interaction coding. Items such as laughter, interruptions, simultaneous speech and pauses would be included. On further investigation, it was felt more appropriate to utilize the Bales interaction coding.

The tapes were then coded, using Bales (1950) "interaction process analysis." This consists of a standard set of categories for classifying interaction. The categories are meant to constitute a mutually exclusive, logically exhaustive system. Table I. shows the 12 categories in the system.

All coding was performed directly from the tapes. The twelve Bales categories were arranged on coding sheets and the frequency of each occurrence was noted. The coding was carried out by the researcher with initial trial runs to obtain familiarization. A meeting

TABLE I

OBSERVATION CATEGORIES IN THE BALES CATEGORY SYSTEM
(Adapted from Bales, 1950)

A. EMOTIONALLY POSITIVE RESPONSES

1. Shows solidarity, raises others' status, gives help, reward
2. Shows tension release, jokes, laughs, shows satisfaction
3. Agrees, shows passive acceptance, understands, concurs, complies

B. PROBLEM-SOLVING RESPONSES: ANSWERS

4. Gives suggestion, direction, implying autonomy for other
5. Gives opinion, evaluation, analysis, expresses feeling, wish
6. Gives orientation, information, repeats, clarifies, confirms

C. PROBLEM-SOLVING RESPONSES: QUESTIONS

7. Asks for orientation, information, repetition, confirmation
8. Asks for opinion, evaluation, analysis, expression of feeling
9. Asks for suggestion, direction, possible ways of action

D. EMOTIONALLY NEGATIVE RESPONSES

10. Disagrees, shows passive rejection, formality, withholds help[1]
11. Shows tension, asks for help, withdraws out of field
12. Shows antagonism, deflates others' status, defends or asserts self

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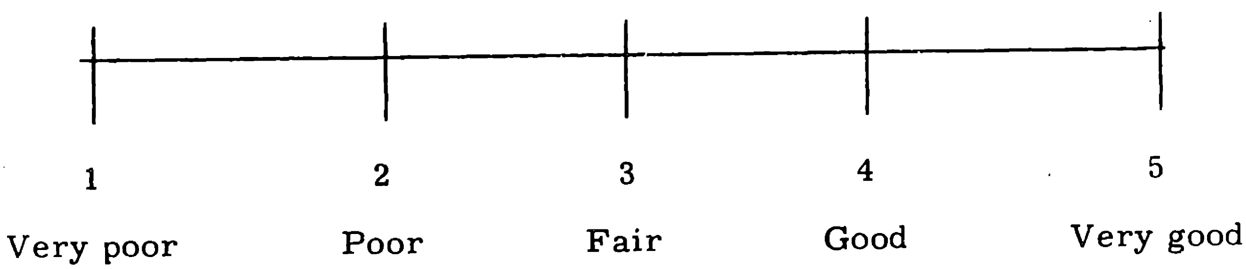
[1]Due to the nature of the problems, Category 10 is expanded to include technical as well as interpersonal disagreement.

was then established between the personnel at the Bales' Laboratory of Social Relations, Harvard University and the researcher so that coding could be performed in their presence. The method was confirmed and intercoder reliability obtained.

The balance of intercoder reliability was performed here at the Sloan School by randomly assigning 25% of the tapes to a second coder. A tape consisted of an average of 66 acts and the level of reliability was set at 85% for act-by-act comparisons.

The interaction profile, which consists of a frequency count of the number of scores entered in each category, was then constructed. For comparisons across studies, rates are computed as percentages in each category of the total number of scores for all categories.

5. Government Evaluation Form. The government technical monitor was interviewed and asked to rate the performance of both Laboratories A and B on each of the detailed subproblems. He was given a list of these problems with a blank space next to each one. The information was sent in advance of the interview to permit time to consider the scores and confer with other members of the evaluation team. Each problem was then rated in accordance with the following scale:



Data Analysis

The detailed subproblems (α to π) were compared for Laboratory A and Laboratory B, to consider whether or not there was a significant difference in the government evaluator's ratings between Laboratory A and Laboratory B.

A two-way analysis of variance was employed to determine the following:

1) Whether there is a significant difference between the evaluation scores received in the category of group or individual, irrespective of laboratory.

2) Whether there is a significant difference between the two laboratories' performance ratings.

3) Whether there is a significant interaction that indicates that one laboratory performs better with group problem solving and the other with individual problem solving.

The next step was to try to account for the differences based on the data received. Both Laboratory A and Laboratory B are not significantly different in size and management structure. The number of engineers assigned and educational backgrounds of project personnel are similar. The important variables that differ and are under study include the following:

1) The amount of group problem solving and individual problem solving as it differs between Laboratory A and Laboratory B,

2) The sources of information that are utilized by Laboratory A and the sources that Laboratory B utilizes,

3) The previous experience as it may affect a positive or negative bias.

CHAPTER III

EFFECTIVENESS OF GROUP PROBLEM SOLVING

We must recognize that the task or problem on which the group is working influences the extent to which a group is – or is not – superior to its individual members working in isolation.

Definition and Relevant Literature

For purposes of definition, one may consider a "group" as a co-operative association of individuals whose members have come together in physical proximity, have organized for common goals, and have accepted commitment for the group's purposes. There is little reason to assume that a group of individuals would do a better job than would a single individual of plotting the geographical locations of branch units with pins on a map. All 25 members of a group might see that a pin representing a branch should be placed in Cleveland; but since there is only one pin and one map, the 25 individual efforts can appear but once in the group product. Since the task is simple and routine, 25 members would redundantly replicate each others' efforts with little gained by the multiple checks.

The above example is admittedly an extreme case as cited by Collins and Guetzkow (1964). Barnlund (1959) has demonstrated that, in certain instances, the group can surpass its most capable member. He concluded in his "Recognition of Valid Conclusions" tests that the interacting groups performed significantly better than their superior members had performed on the previous form of the test. Barnlund demonstrated that groups can achieve efficiency beyond the ability of their most capable member on a complex task.

Husband (1940) attempted the study of a group in contrast with an individual as measured by required manhours to arrive at a solution and the quality of the product. He used three tasks: deciphering a code, solving a jigsaw puzzle, and solving arithmetic problems. The N was 40 working alone and 80 in pairs. Pairs were superior on the first two tasks (deciphering a code, solving a jigsaw puzzle), but on the third (arithmetic problems) there was no significant difference. His pairs did better on problems requiring some originality or insight than on the more routine arithmetic problems.

As a result of several studies, D. C. Barnlund (1959) concludes: "Groups had greater critical resources than did individuals working alone. In spite of the uniform level of ability, group members saw different issues and a larger number of issues than a single person working alone."

Variance Between Laboratories and Between Group and Individual

In studying the relationship between group and individual performance, the first approach will be to consider the relation between Laboratory A and Laboratory B, group and individual, and the government technical monitor's success ratings. The government technical monitor rated the performance of the subproblem solutions proposed by Laboratory A and by Laboratory B. The ratings were performed after each laboratory submitted a report of its findings and also made an oral presentation. The N.A.S.A. personnel were given an opportunity to question and probe each laboratory's recommended solutions. The results in Table II show that, on the average, Laboratory B was rated higher than Laboratory A. Each number represents the rating on a particular subproblem with a range from 5 (highest) to 1 (lowest).

The results in Table III show that there is not a significant difference between columns. It is therefore not possible to confirm the first hypothesis which stated that those subproblems which utilized group problem solving would be judged more successful than those that resulted from individual effort.

The difference between rows, however, is significant ($p < .01$), indicating that, on the average, Laboratory B was rated higher than Laboratory A. This is no surprise since it is expected that one laboratory will be rated higher than the other. The large degree of the difference is of interest and encourages one to look further, attempting to examine the factors that led to the disparity of the scores.

Of most interest is the statistical interaction term between the laboratories and the method of problem solving.[1] By closer examination of Table II, one can observe that Laboratory A did better with group problem solving ($\bar{x} = 3.67$) than with individual problem solving ($\bar{x} = 2.62$). Laboratory B, on the other hand, did more poorly on those

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[1]Statistical interaction refers to the effect due to the combinations of two nominal-scale variables when additivity does not hold.

TABLE II

TWO-WAY ANALYSIS OF VARIANCE BETWEEN LABORATORIES AND GROUP OR INDIVIDUAL PROBLEM SOLVING

	Group	Individual	
Laboratory A	3, 4, 3, 3, 3, 4, 4, 4, 5 $\Sigma x = 33$ N = 9 $\bar{x} = 3.67$	2, 3, 3, 1, 1, 2, 1 2, 3, 5, 5, 4, 2 $\Sigma x = 34$ N = 13 $\bar{x} = 2.615$	$\Sigma \bar{x} = 6.28$ $\bar{x} = 3.14$ N = 22
Laboratory B	5, 4, 4, 3, 2, 5, 3 5, 5, 4, 3, 3, 4, 4 $\Sigma x = 54$ N = 14 $\bar{x} = 3.86$	5, 5, 5, 3, 5, 5, 5, 5 $\Sigma x = 38$ N = 8 $\bar{x} = 4.75$	$\Sigma \bar{x} = 8.61$ N = 22 $\bar{x} = 4.31$
	$\bar{x} = 7.53$	$\bar{x} = 7.36$	

TABLE III

BETWEEN LABORATORIES, BETWEEN METHOD, AND INTERACTION SIGNIFICANCE

	Sums of Squares	Degrees Freedom	Est. of Variance	F	Significance
Total	6.368	43			
Between subclass	2.303	3			
Between columns	.006	1	.006	.051	.8218
Between rows	1.352	1	1.352	11.061	.0019
Interaction	.945	1	.945	9.268	.0041
Error (within subclass)	4.065	40	.102		
Error (total)	5.010	41	.122		

problems which utilized group activity ($\bar{x} = 3.86$) and better on individual effort ($\bar{x} = 4.75$). This interaction term is significant at $p < .01$.

There is apparently something about the interaction of Laboratory A that enables them to improve results when group effort is applied.[2] This does not apply to Laboratory B. This leads one to consider the types of interaction which may be studied by the taped problem solving meetings.

Group Interaction Profile

The Bales category system provides a number of scores that describe quantitatively the functioning and structure of groups. The distribution of the total number of acts among the twelve categories can be computed for a group and plotted in the form of a group profile which shows the relative frequencies of the twelve types of interaction. Table IV presents Laboratory A and Laboratory B summary profiles, and Figure 1 graphically displays the distribution.

Since two small independent samples of equal size are being compared, the Kolmogorov-Smirnov two-sample test may be applied to the data. (See Table V.) The test utilizes a cumulative frequency distribution for each sample of observations, using the same intervals for both distributions. The test focuses on the largest of the differences

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[2]Group Interaction refers to the behavior and influence that individuals in the group have upon each other.

TABLE IV

GROUP INTERACTION PROFILE

	Interaction-Process Analysis Category	Laboratory B	Laboratory A
1	Shows solidarity	.6	0
2	Shows tension release	4.0	3.7
3	Shows agreement	17.0	17.6
4	Gives suggestion	4.0	3.0
5	Gives opinion	48.5	35.0
6	Gives information	8.5	12.0
7	Asks for information	8.0	4.3
8	Asks for opinion	7.4	15.0
9	Asks for suggestion	1.0	.7
10	Shows disagreement	1.0	8.7
11	Shows tension	0	0
12	Shows antagonism	0	0

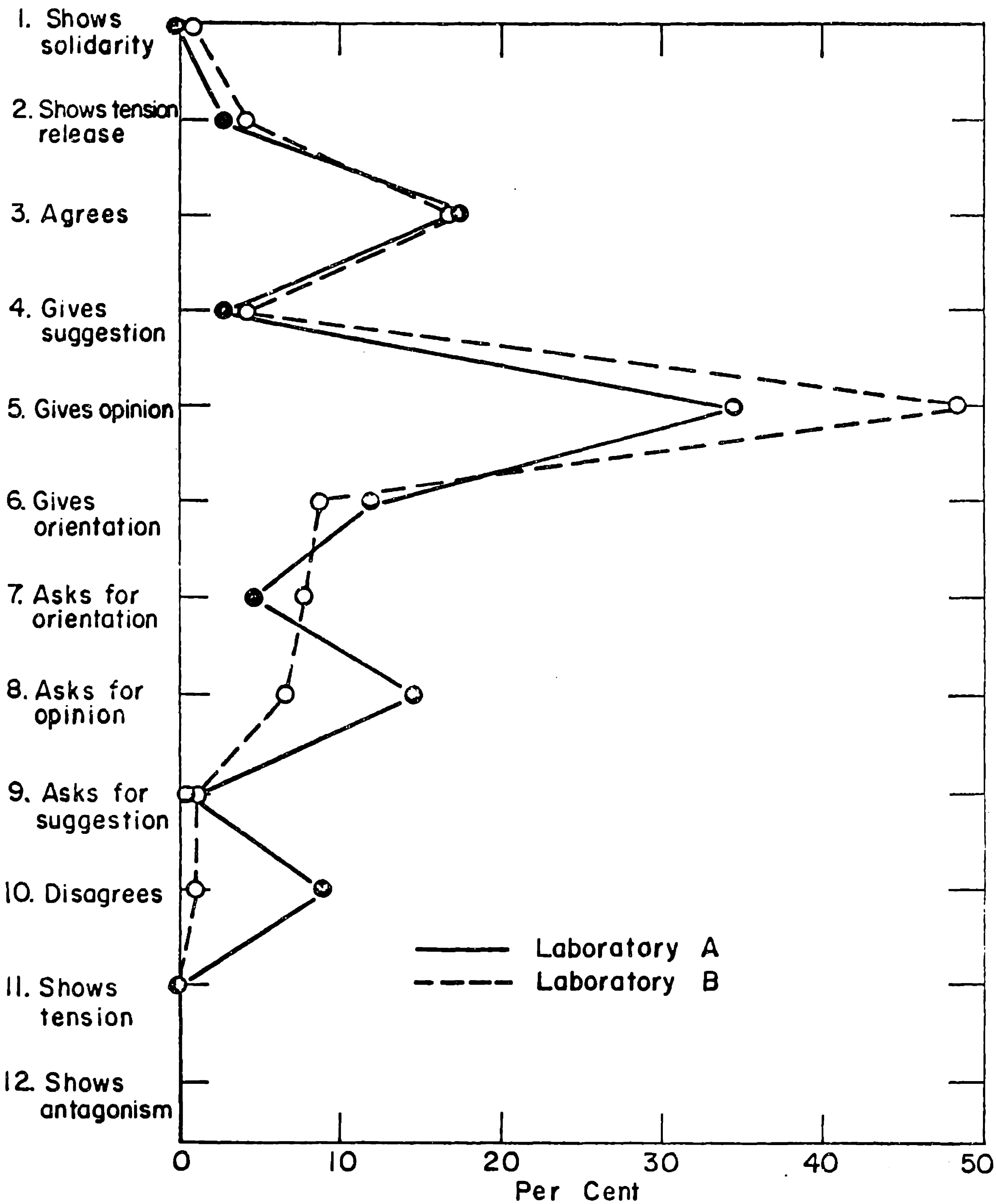

FIG. I THE DISTRIBUTION OF THE TOTAL NUMBER OF ACTS AMONG THE 12 CATEGORIES IN THE BALES CATEGORY SYSTEM

TABLE V

KOLMOGOROV-SMIRNOV TWO-SAMPLE TEST BETWEEN LABORATORIES

	1	2	3	4	5	6	7	8	9	10	11	12
Laboratory B	.6	4.6	21.6	25.6	74.1	82.6	90.6	98.0	99.0	100	100	100
Laboratory A	0	3.7	21.3	24.3	59.3	71.3	75.6	90.6	91.3	100	100	100
Difference	.6	.9	.3	1.3	14.8	11.3	15.0	7.4	7.7	0	0	0

$N = 12$
$K_D = 15.0$
$p < .01$

between the per cent of acts in a category to the total, between Laboratory B and Laboratory A.

We may conclude that there is a significant difference in the interaction profiles between Laboratory A and Laboratory B.

The laboratory that performed better on group problem solving gave 13.5% fewer opinions and asked for 7.6% more opinions. (More of the conference time was spent in individuals asking others for opinions than in the giving of opinions.)

The laboratory that was better able to use group problem solving gave 4.5% more information and asked for 3.7% less information.

The laboratory that performed better on group problem solving had 7.7% more disagreement than its parallel competitor.

These results have two implications:

1) The parallel projects provide a feasible vehicle for comparing group interaction profiles with performance.

2) Should the results be supported by additional studies, we should then try to structure our groups with more emphasis on asking opinion, less emphasis on giving opinion, more emphasis on giving information and more emphasis on some disagreement.

Group Effect on Constraint Considerations

Since all engineering projects are bounded by constraints, it would be of value to consider the interaction and tradeoffs among constraints. The effect of group or individual problem solving is studied in relation to its effect upon constraints.

Three common constraints in every engineering project are technical, cost, and schedule. The most easily measurable of these are the cost and schedule; hence, this initial analysis limits itself to these two dimensions.

The engineering teams from Laboratory A and Laboratory B were asked on the participation form to indicate the importance that schedule considerations had in formulating the final decision for each subproblem. This same question was asked regarding cost considerations. The responses varied from very low importance, to low importance, to moderate importance. The long-range R&D studies emphasize the technical considerations to such a high degree that schedule and cost considerations had no subproblems that the laboratories rated at more than moderate importance. This confirmed the findings of Marquis and Straight (1965) stating that technical performance is by far the most important consideration, being ranked first by 63% of the company respondents and 97% of government respondents. Meeting delivery schedules is a poor second with achievement of target costs third in importance.

Table VI relates the type of group participation to the laboratory's concern for cost considerations. It indicates that in those cases where high group participation is utilized in problem solving, the split is almost even between high cost considerations and low consideration for costs. In those cases of low group participation and highly individual problem solving, little consideration is given to cost constraints. This might suggest the hypothesis that groups are capable of considering cost constraints as well as the technical problem solving. However, individual problem solving so absorbs the participant with the technical aspects that he has little concern for cost considerations.

A similar relationship exists when considering schedule constraints. (See Table VII.) Those subproblems with high group participation

TABLE VI

RELATION OF HIGH OR LOW GROUP PARTICIPATION TO COST CONSIDERATIONS

	High Cost Considerations	Low Cost Considerations	
High Group Participation	7	6	13
Low Group Participation	1	9	10
	8	15	23

Using Fisher Exact — p = .037

TABLE VII

RELATION OF HIGH OR LOW GROUP PARTICIPATION TO SCHEDULE CONSIDERATIONS

	High Schedule Considerations	Low Schedule Considerations	
High Group Participation	11	6	17
Low Group Participation	1	6	7
	12	12	24

Using Fisher Exact — p = .01

exhibited high concern for schedule considerations. Those subproblems with low group participation showed significantly less consideration for schedule. Perhaps, by the same reasoning, the individual problem solving so absorbs the participant with the technical aspects that he has little concern for schedule considerations. We may be witnessing a confirmation of Barnlund's conclusions that group members saw different and a larger number of issues than a single person working alone.

By using the reasoning of Barnlund, one may consider that the larger number of issues included schedule and cost considerations in addition to technical problem solving.

The question next considered is the following: As a laboratory starts concerning itself about one constraint, does it sacrifice its concern about another constraint? Specifically, if a laboratory puts emphasis on cost considerations, does it sacrifice schedules in order to do so?

The statement often voiced by industry representatives to the government might read as follows:

"If you want my laboratory to control costs, then you'll have to delay delivery." The emphasis may, of course, be reversed where the laboratory claims that the tight delivery leaves the laboratory with no ability to control costs. This thesis proposes those statements invalid and presents initial data to substantiate the argument. These results are based on the answers to the questions on the participation forms indicating the importance of schedule and cost considerations for each subproblem. Table VIII lists the results of the two questions for both

TABLE VIII. COST AND SCHEDULE CONSTRAINTS

The questions asked of Laboratory A and Laboratory B by subproblem are as follows:

1) Indicate approximately, the importance of cost considerations in reaching this decision:

1	2	3	4	5
Very low importance	Low	Moderate	High	Very high importance

2) Indicate approximately, the importance of schedule considerations in reaching this decision:

1	2	3	4	5
Very low importance	Low	Moderate	High	Very high importance

	Laboratory A*		Laboratory B**	
Subproblem	Cost	Schedule	Cost	Schedule
α	2	3	3	3
β	1	1	2	2
ν	1	1	1	2
δ	1	1	1	2
ϵ	2	3	1	2
ζ	1	2	1	2
η	1	2	1	1
θ	1	3	2	3
ι	2	3	1	1
κ	1	2	1	1
λ	1	2	1	2
μ	2	3	1	1
υ	1	2	3	3
ε	1	1	3	3
o	1	2	1	2
π	1	2	1	1

*Based on the Pearson's Product Moment Test $r = .74$. (More than 50% of one variable is explained by the other variable.) Based on an F test, $p < .05$.

**Based on the Pearson's Product Moment Test $r = .78$. (More than 50% of one variable is explained by the other variable.) Based on an F test, $p < .05$.

Laboratory A and Laboratory B with the number one indicating very low importance, two indicating low importance, and three indicating moderate importance.

The correlations from Table VIII indicate strongly and significantly that as consideration for costs is increased, then so is the degree of concern for schedules.

Hypothesis four on page five is confirmed. The R&D laboratory considers constraints simultaneously and there is not a substitution effect of one constraint for another.

The scattergram shown in Figure 2 illustrates the relationship between the degree of concern for schedule and cost considerations. The relationship held up with a surprising degree of similarity between both Laboratory A and Laboratory B.

Discussion

It was expected that there would be a significant difference between laboratories in the performance rating. This was confirmed. It was originally hypothesized that group problem solving will be more effective (in terms of evaluated solution quality) than is problem solving by individuals. This was not the case, so that we cannot state that group problem solving is better than individual problem solving.

The data indicated that group problem solving was more effective in one laboratory than in the other. This led to the investigation of the group process. The approach was to utilize the tape-recorded problem solving meetings. The Bales coding indicated that the laboratory that

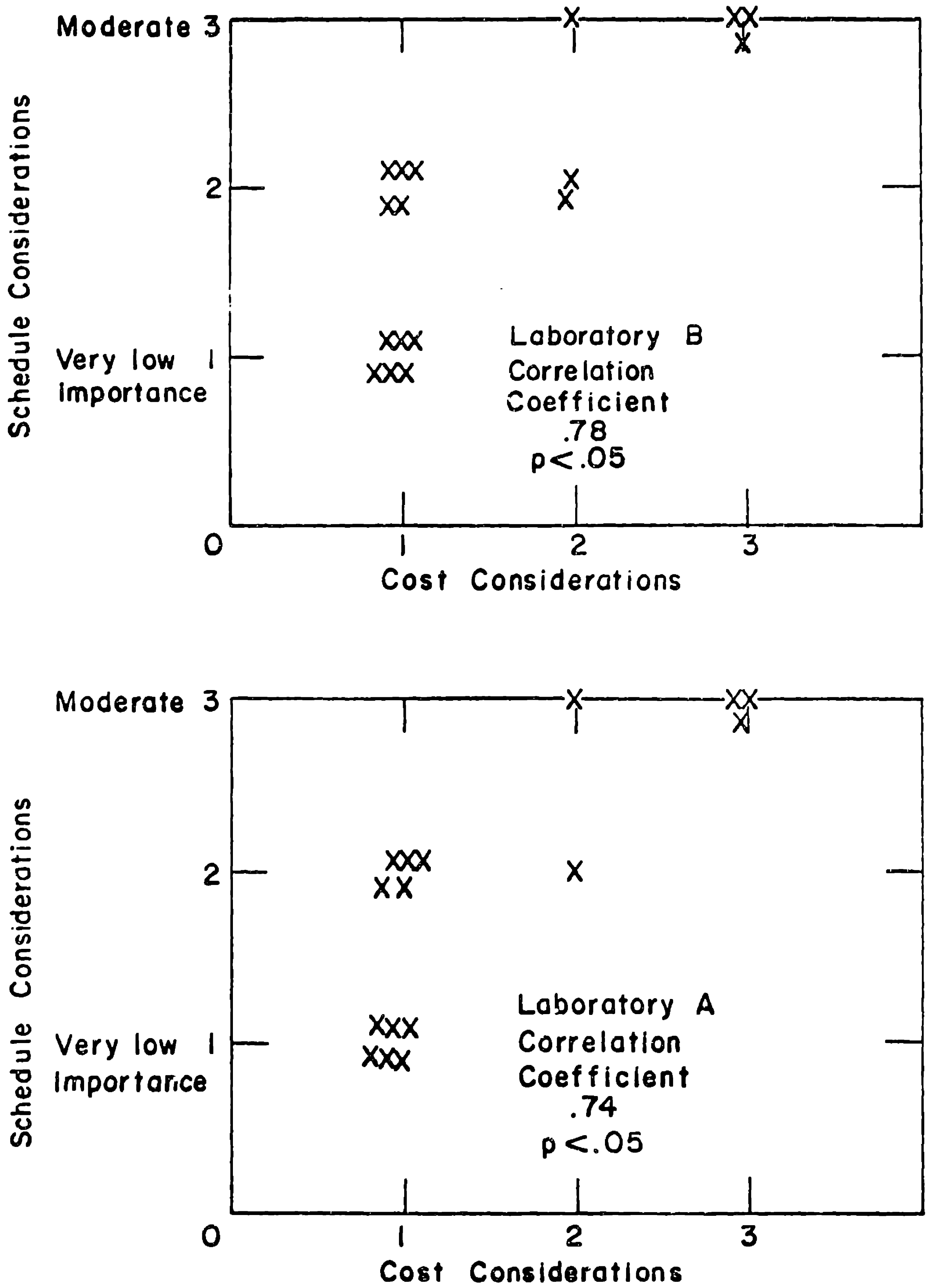

FIG. 2 CONSTRAINTS: SCHEDULE CONSIDERATIONS VS. COST CONSIDERATIONS

was more effective in group problem solving spent more conference time in asking for opinions and in disagreement. It is reasonable to expect that a more effective group problem solving meeting will have more disagreement that will further stimulate the ideas and challenge the approaches. When a conference is dominated by the giving of opinion, with little interchange and little disagreement, then it may be expected to be less effective.

Differences in opinions and ideas among group members need not lead to dissatisfaction and unpleasant experiences but rather can lead to invention and creative problem solving (Maier, 1958). When opposing viewpoints are brought together in a free exchange, the resulting conflict may be resolved by the creation of a new solution which either reorganizes or incorporates the different viewpoints. Recent studies have provided support for these propositions by showing that differences among group members promote effective problem solving (e.g., Ghiselli and Lodahl, 1958; Hoffman, 1959).

One might therefore go several steps beyond and say that if group maintenance becomes the key motivation, then the group will be less effective. If the confidence of the group is sufficient, then disagreement can be tolerated and should be even encouraged. In such a situation, it would be helpful to consider that disagreement can be categorized into interpersonal and technical. It would be the aim of the members to actively participate in technical disagreement with the minimum of interpersonal disagreement.

Studies by Torrance (1955), Riecken (1958) and Maier and Solem

(1952) show how formal status, "talkativeness," and majority opinion, respectively, may contribute to incorrect solutions and prevent the acceptance of correct answers. Riecken's (1958) study of "talkativeness" parallels Torrance's findings in showing that the most talkative group member, regardless of the adequacy of his information, exerts considerable influence over his group's decision. Riecken compared the effect of giving a hint concerning the "elegant" (creative) solution to the most talkative versus the least talkative members of groups. The hint was much more often accepted from the most talkative member.

If the conference becomes dominated by the giving of opinion, with only small amounts of asking for opinions, then the time would probably be more usefully spent by preparing a report and circulating it for distribution. The group problem solving must be truly a group effort in order to warrant the time expended by all of the individuals present. It is not unusual to have what may be considered a group effort but which, in essence, is individual problem solving.

The Bales coding is a method for the observation of social behavior that has been used by a number of different investigators. The population of profiles obtained by investigators who have used the method in a standard way for a given sort of group, task, or unusual condition provides a frame of reference within which any one profile gains added meaning. One may understand more about the particular situation from which his profile was obtained by discovering what other kinds of situations have given similar or different profiles. Bales and Hare (1965) presented twenty-one reference populations of interaction profiles.

The described procedure limited all conclusions to the fact that one group was like or unlike another group. In the research performed by this study of Laboratory A and Laboratory B, one is able to relate the profile with high or low success.

The results indicate that problems solved by use of high group participation are capable of considering a larger number of issues. One might use this evidence to aid in the decision as to whether it is appropriate to assign a group or an individual to a particular problem or task. If the problem consists of only technical aspects and is limited to a single discipline, it would be advisable to have this as largely individual problem solving. If, on the other hand, the problem covers a wide range of issues, the individual problem solver will not perform as well as a good interacting group. The group will be capable of considering more issues and ramifications than individuals will.

Task forces are often assigned by government agencies and industry on problems with a large range of issues. Task forces can be a waste of manpower if the issues are limited in number and interaction is not a necessary ingredient for the problem solving.

Conclusions

One can state that group problem solving is superior to individual problem solving, but only under certain conditions. The conditions require a spirit of inquiry among the group and a moderate amount of disagreement. One can state that the group is superior at considering a larger range of issues, based on the research presented here showing the strong relationship between group problem solving and considerations for cost and schedule constraints in addition to the technical problem solving.

CHAPTER IV

EFFECTS OF INTERNAL AND EXTERNAL SOURCES OF INFORMATION

Definition and Relevant Research

Research and development is a problem solving process depending on information inputs from the environment as well as on the stored knowledge and the ability of the personnel involved. Improvement in the flow of scientific information is an important goal of R&D management, but it is dependent upon a better understanding of the process itself.

In research performed on fourteen projects (five parallel sets of R&D projects plus four single projects), it was learned that 15.43% of engineering time was spent in information gathering. The subsets are as follows:

Literature search	6.70%
Consultation with external information sources	4.22%
Consultation with technical staff	4.51%
All information gathering	15.43%

(Allen, Andrien and Gerstenfeld, 1966)

For the purposes of this research, the categories of literature, vendor, customer, and other external sources are all considered outside sources of information. The categories of technical staff, company research, personal experience and experiment are considered inside sources of information.

Each laboratory was asked the question, "If information which had a serious impact upon your visualization of the problem or any of its potential solutions was received at any time during the past week, please circle the source(s) of that information."

Shilling and Bernard (1964) found that the use of outside consultants by industrial bio-scientists was negatively related to eight "measures of laboratory productivity and efficiency." Seven sets of parallel R&D projects involving fifteen laboratories were examined by Allen (1965). The research concluded that better performing groups are found to rely more than poorer performers upon information sources within the laboratory, for generation of ideas.

Laboratory Performance and Information Channels

Table IX shows the frequency of the use of inside sources and outside sources by both the higher and lower performing teams. There is a significant difference between the sources of information utilized by the higher rated team and by the lower rated team. The second hypothesis is confirmed, which states that the R&D laboratory which utilizes more internal sources of information will perform more successfully than the laboratory which relies heavily on outside sources of information.

Discussion

Previous research has been supported, emphasizing the positive effects of utilization of internal sources of information and the negative

TABLE IX

RELATION OF LABORATORY PERFORMANCE TO SOURCES OF INFORMATION

Evaluation of Laboratory Performance	Sources of Information: Inside	Sources of Information: Outside	
High	28	0	28
Low	20	22	42
	48	22	70

$\chi^2 = 19$ $p < .01$

effects resulting from external sources. One may consider several aspects of this phenomenon: namely, why the situation exists and then what may be done about it.

When considering the "why" aspects, this researcher takes into account not only this study but many years of previous experience, as well. The internal sources are on hand and should be readily available. The problem or the information seeking requires rapid attention, and the delays caused by external sources can seriously impair solution quality. The analogy that comes to mind is the advantage of computer time sharing with immediate response and batch processing with built-in lag time.

The internal sources speak a language or code that greatly enhances communication during the problem solving. The outside sources must often spend much time and effort in getting acquainted with the problem and existing conditions. In addition, the outside sources will usually compare the situation to a prior solution and this is often not appropriate.

The internal information channel has the advantage of reduced interpersonal conflicts, since a previous working arrangement has been established. The personalities of the individuals are known to each other and coping mechanisms have been built up. The external information channel is often not used properly, brought on board too late, and not aware of the entire picture.

In most technical problem solving, there is seldom a single bit of input that leads to the solution. The more common situation is continual input, tests, changes, and revised input. This arrangement is appropriate for internal channels but most difficult to achieve for external sources.

One must not overlook the value of informal information sources as idea generators. The discussions over coffee, during lunch or in the halls are often key factors in the formulation of problem solutions. This channel can be used by internal people but is not a practical source of information for outside channels.

Conclusion

In light of the previous research results plus the finding presented above, one concludes that internal sources of information are more successful than external channels. Laboratories should be encouraged to utilize internal sources and reward systems should be designed with this aim in mind. The utilization of outside sources is no substitute for internal capability. Recognizing the value for internal communication, formal as well as informal exchange of ideas must increase. Perhaps more informal dinners, lunches or weekly in-lab meetings would foster a greater exchange of ideas. The external channel plays a role, but in recognizing its limitations, one may use the source with high discretion.

CHAPTER V

PRIOR EXPERIENCE AS IT AFFECTS POSITIVE AND NEGATIVE BIAS

Definition and Relevant Research

The effects of prior experience on research performance has great impact on the alternatives considered. Maier (1933) increased the proportion of successful problem solutions by lecturing subjects to seek for various problem difficulties and to "keep your mind open for new meaning and . . . for new combinations."

Allen and Marquis (1964) have shown the effects which prior experience can exert on research performance. In that study, two contracts were selected for the research from the files of a major government procurement center. The over-all task was then broken into several subproblems. The research showed that where there was prior experience with the successful technique only, results were four successful solutions and one unsuccessful solution. In those cases where there was prior experience with the unsuccessful technique only, there were two successful solutions and six unsuccessful solutions.

The study concluded that while prior experience only with a technique which is appropriate for the present problem can, of course, result in a successful solution, prior experience with a technique which is not appropriate for the present problem can result in an unsuccessful solution.

Luchins' series of "Einstellung" experiments (1942) using water bottle problems are pertinent. He showed that past experience with a particular method for solving problems caused subjects to use that method in solving problems which could have been solved using a simpler method, and reduced their ability to solve similar problems for which the method was inappropriate. The past experience seemingly blinded subjects to the existence of an alternative method.

This research suggests, perhaps, a subtle shift in the consideration of prior experiences. I propose to illustrate not only appropriate or inappropriate prior experience. It is this researcher's contention that prior pinpointed, specific experience can be dysfunctional. Prior broad general experience can be functional. This not only becomes clear when viewing the results of this study but is borne up by additional data in "A Model for the Description and Evaluation of Technical Problem Solving" (Frischmuth, 1966).

General vs. Specific Experience

The effects of prior experience are so closely related to success that it is interesting in this study to consider the prior experience and its effects on biases for Laboratory A and Laboratory B. Laboratory A had extensive experience in the design of a similar problem for use on an earlier program (Pinpoint). Laboratory A's staff had worked on the previous program and this was largely instrumental in their receiving a contract for the problem studied here.

Laboratory B had no such specific experience but had extensive knowledge based on commercial applications (Broad). They have several research laboratories and are generally considered leaders in their field. They had no specific experience with a package of this sort but qualified for the contract on the basis of their thorough understanding of the technology.

An example of Laboratory A's prior experience leading to a negative biasing set is found in the Interim Report – Phase 1. In this experiment, artificial seismic waves, created by explosives, are reflected and refracted and translated into electrical signals. These signals are then analyzed to determine the nature of subsurface material from acoustic velocity information.

On the earth's surface, acoustical velocity information is obtained in the following manner: A hole is drilled approximately 100 feet deep and a charge is placed at the bottom. The hole is then filled with water to prevent the energy from being dissipated in the air. The charge is then detonated and a receiver on the surface enables one to calculate the acoustic velocity through the material between the charge and the receiver.

In the lunar environment, it would not be possible to fill the hole with water because of availability, pressure and temperature constraints. A surface receiver would merely measure the acoustic velocity through the air from the charge placed at the bottom of the hole. This procedure would not result in any information about the nature of the subsurface material.

Both laboratories recognized this fact. Laboratory A suggested a device of the type developed by them for an earlier program. The government technical monitors were asked to evaluate the subproblem solution. The Laboratory A solution was evaluated poorly since the government technical monitors believed that a "mere scaling up in size" of the former approach would not satisfactorily meet the requirements of the present program.

It was the contention of the government technical monitors that new and original ideas and designs should be the results of these studies. When the design represented merely modifications to an existing design, this was not considered favorably. In this case, a negative bias developed through prior experience resulted in a poor performance rating. This could have been overcome by the consider- ation of more alternative approaches to the problem.

Laboratory B, who had prior experience of a general nature, stated that the absence of borehole fluid in the lunar environment would make the sonic measurements very difficult. They went on to analyze several approaches and finally concluded that the technology required to design a suitable instrument for measuring sonic velocity does not exist at the present time.

The government technical evaluators considered this as a more realistic assessment of the problem and now may consider several courses of action. They are considering eliminating this measurement in the expectations of gathering comparable data on the returned core sample. Or they may issue a separate study contract for the feasibility of performing downhole lunar sonic measurements.

For Laboratory B, the company engineers did not associate the problem with one they had solved before. Laboratory A's analysis merely repeated the former approach to the problem.

This research indicates the negative value of specific pinpointed experience and the positive value of broad general prior experience. To further illustrate the influence of prior experience, Table X shows the reference bases used by both the lower rated and higher rated laboratories from quotations in the Phase I Interim Reports.

Discussion

When the prior experience is pinpointed and specific, the temptation of the problem solving group is to perform in one of two ways. They may merely repeat the prior solution, or they may alter the prior solution; but the starting point is from the previous solution and not from the necessary broad base. When the prior experience is broad, then the atmosphere is clear for consideration of many alternatives, then narrowed down to a final solution.

These results have many implications for both R&D management and for the government evaluation team. If R&D management were to recognize a prior pinpointed previous experience leading to negative bias set, they could encounter this in one of two ways or perhaps a comination of each. One possibility for overcoming set would be the consideration of a greater number of alternative approaches before proceeding to the final solution. A second possibility would be the rotation of project personnel with the previous individuals made available as internal sources of information to the newly assigned group. This may have the dual advantage of a fresh approach as well as facilitating

TABLE X

PRIOR EXPERIENCE AS IT AFFECTS PRESENT PROBLEM SOLVING

Lower Rated Laboratory	Higher Rated Laboratory
1) "A conventional-type bowspring was used on the project ω probe, but it was to be used in a shallow hole. The proposed probe is to be used in 10- and 100-foot holes."	1) "In conventional well logging, the measurement of total natural radiation is often performed simultaneously with another type of measurement, electrical, sonic, or neutron."
2) . . . We recommend "thermal diffusivity technique proposed and developed for project ω."	2) "For lunar application, a device similar to the conventional tools will be desirable."
3) "Active seismic measurement similar to project ω experiment."	

intra-laboratory communication.

From the standpoint of the government evaluation procedures, this research would seem to indicate that the present weightings be changed as follows: The item classified as "experience" is too broad and often what may appear favorable on the surface actually are situations that create negative bias.

Perhaps the classification "experience" should be subdivided into the subsets of pinpointed, specific experience, and broad general experience. The results of this research, as well as the other results cited previously, would encourage one to emphasize the weightings of broad general experience and de-emphasize the cases of prior pinpointed, specific experiences. Certainly, in the latter case, one must be very wary and proceed with caution and safeguards to prevent a mere redesign of a previous study.

There are very few completely original ideas so that problem solving usually consists of recalling a previous situation, relating the new situation to the old, and modifying the original solution. With that in mind, the role of prior experience is seen to exert a significant influence.

There are many pitfalls that arise because of this phenomenon. The previous experience may have led to a successful solution, but it may not be appropriate to relate it to the new situation. A second pitfall which was witnessed in this research is that the prior experience is so imbedded in the thinking that alternate approaches are not even considered.

Conclusion

The effect of prior experience on success in R&D problem solving was studied. The prior experience in the area concerned does not, by itself, result in a higher or lower probability of obtaining a correct solution. As witnessed in this research, extensive previous experience with a similar problem may inhibit the consideration of appropriate alternatives for successful solution of the present problem.

CHAPTER VI

RELATION BETWEEN GROUP, INFORMATION CHANNEL AND PRIOR EXPERIENCE

Conclusions

This study has investigated two laboratories' approaches to the same R&D problem. As a result of a N.A.S.A. parallel contract, each laboratory started at the same time, stopped at the same time and had identical work statements.

Four relationships are investigated:

1) The relationship between group problem solving and performance,

2) The relationship between internal and external sources of information and performance,

3) The effects of positive and negative biasing sets,

4) The interaction between time and cost constraints and their relationship with group and individual problem solving.

One of the laboratories performed better with individual problem solving than with group effort. The second laboratory performed better on those subproblems in which they utilized group effort and poorer when applying individual effort. It is not possible to therefore state whether group or individual effort results in better performance.

These results then led to a consideration of the interpersonal interactions of each laboratory. It was observed that there was a statistically significant difference in the interaction profile of the two laboratories. The laboratory that was evaluated higher in group problem solving spent less of the conference time in giving opinions and more time in asking for opinions and showing a moderate amount of disagreement.

Observers of group interaction are impressed with the great differences among groups and among the individuals in each group. One group may be successful while another is not. This research demonstrated a methodology for comparing group and individual problem solving and for comparing groups with each other and with evaluation.

High group participation subproblems are shown to have significantly higher concern for cost and schedule constraints. This relationship suggests that the individual problem solver has all he can do to cope with the technical aspects and that group interaction aids in widening the scope of considerations.

The constraints of cost and schedule are shown to be strongly positively correlated. One constraint does not have to substitute for another but in general, the constraints may be considered simultaneously. Two schools of thought may be considered at this point. The first states that time is cost and that therefore as delivery considerations increase in priority, so do cost considerations. The alternative view states that increased emphasis on schedule can only be accomplished with decreased emphasis on cost. The background for this line of reasoning is the necessity for additional capital equipment, close control, premium wage payments and others. This study seems to substantiate the first viewpoint that managers and government can emphasize schedule considerations without having to have a deterioration in cost considerations.

Positive and negative biasing sets were witnessed and each team was observed to rely heavily on previously experienced methods of approach to the problem. This phenomenon has many implications for both the government evaluation teams as well as for R&D management. When a laboratory has previous experience very close to the new project, it may be expected that the new solutions will closely resemble the old. However, when a laboratory has broad general knowledge in a field, it may be expected that there will be more originality resulting from the new study.

This could have significant impact on one of the principal factors in proposal evaluation. Perhaps the element of experience should be weighted to emphasize broad general familiarity rather than very similar previous project performance. It may be expected that a higher degree of originality will emerge from an in-depth competence rather than from specific pinpointed previous experience. R&D management may overcome this past experience bias set by consideration of more alternatives or by rotating design personnel and perhaps using the previously assigned people in a consulting capacity. This would have the added advantage of increasing the number of internal sources of information which were found to be closely correlated with success.

Recommendations

The decision to utilize a group effort or an individual effort is often one that is made lightly and with few considerations in mind. From the standpoint of maximum utilization of R&D personnel and from the standpoint of probability of success, this decision must be allotted significant consideration.

The use of group problem solving is recommended on those subproblems that require a large range of considerations. However, the group must truly interact by exhibiting "asking" as well as "giving" and display a moderate amount of disagreement.

If the two criteria can be met, then group problem solving is recommended. In those cases where a large range of issues is not involved and interpersonal interaction is not necessary, it is recommended that the problem solving be performed individually. There is a tremendous waste of manpower in utilizing group activity when it is not needed and the contribution of many of the participants is negligible.

In a study by Hoffman and Maier (1961), the over-all findings supported those of an earlier one. On the various problems, the solutions by heterogeneous groups either were scored as significantly superior in quality to those of the homogeneous groups, or did not differ in quality. Never were the homogeneous groups better than the heterogeneous groups. It is therefore recommended that when the criteria mentioned above are met and the decision is to utilize group problem solving, then the members will be most effective if the group is heterogeneous.

Steps should be taken to increase the use of internal information channels. Informal communication between peers often forms a valuable source for the generation of ideas. Departmental and interdepartmental seminars would prove a valuable source for the exchange of ideas. An atmosphere must be created that would encourage the exchange.

A weekly notice in the form of a small bulletin should inform staff members what others are working on and what their most serious problems are. It is all too often that a problem solution is "in-house" but not in the possession of the individual assigned to it.

An incentive or reward system should be established that would encourage the use of internal information sources. Rewards might be based on over-all laboratory performance which would encourage interchange. In addition, rewards might be given in the form of recognition at the seminars.

It is recommended that in those situations where original ideas and designs are required, emphasis be placed on prior experience of a general nature and not previously specific experience. Since problem solving is at best a recall of a previous experience with modifications for the new situation, it may be expected that the new design will resemble the original. Following Wertheimer (1945) and Maier (1933), creative problem solving is the process of forming a solution pattern which is a combination of previously dissociated experiences. It is recommended that the government rating system on bid proposals be revised to divide the category called "experience" into subsets called broad, general experience and specific experience with heavy weighting on the former.

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APPENDICES

APPENDIX A

INFORMATION SOURCE QUESTIONNAIRE

Subproblem: ______________________________

a. No. of men assigned full time: 1 2 3 4 5 6 7 8 9 10

11 12 13 14 15 16 17 18 19 20

b. No. of men assigned part time: 1 2 3 4 5 6 7 8 9 10

c. In the case of part time indicate average % of time used on this project: 10 20 30 40 50 60 70 80 90

d. If information which had a serious impact upon your visualization of the problem or any of its potential solutions was received at any time during the past week, please circle the source(s) of that information on the line below. Sources are defined on the reverse side.

Information Source: L V C ES TS CR PE E

Comments (if any): ______________________________

____

____

e. Please estimate the percentage technical completion of the portion of the project with which you are concerned ____%. (This need not be a monotonically increasing function of time. Since it is a subjective estimate and since R&D is characterized by the continual discovery of new problem areas, this estimate may decrease as well as increase from week to week.)

APPENDIX B

PARTICIPATION QUESTIONNAIRE

Subproblem: ____

Please answer the following by circling the appropriate number:

1. Indicate the percentage that the group or individual contributed to formulating the decision:

100%	90	80	70	60	50 - 50	60	70	80	90	100%

← Group → | ← Individual →

2. Indicate approximately, the importance of cost considerations in reaching this decision:

1	2	3	4	5
Very low importance	Low	Moderate	High	Very high importance

3. Indicate approximately, the importance of schedule considerations in reaching this decision:

1	2	3	4	5
Very low importance	Low	Moderate	High	Very high importance

APPENDIX C

GOVERNMENT EVALUATION FORM

Please answer the following by listing the appropriate number as indicated on the following scale:

1	2	3	4	5
Very poor	Poor	Fair	Good	Very good

1) Selection of subsurface measurements ___________

2) Selection of nuclear measurements ___________

3) Selection of electrical measurements ___________

4) Selection of thermal measurements ___________

5) Selection of mechanical measurements ___________

6) Selection of optical measurements ___________

7) Selection of sonic measurements ___________

8) Obtaining the necessary interface and drill data in order to design optimum experiments ___________

9) Calculating the effect of limited spectral response on the temperature measurement error ___________

10) Calculating the effect of spectral emissivity on the temperature measurement error ___________

11) Verifying the feasibility of measuring borehole temperature to the greatest accuracy required for determining borehole temperature gradient ___________