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Positive and Negative Biasing Sets: The Effects
of Prior Experience on Research Performance

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ABSTRACT

The effect of prior experience on success in solving discrete problems was studied by comparing the behavior of 8 laboratories in 2 R & D proposal competitions. The findings show that prior experience does not, by itself, influence the likelihood of achieving a correct solution. If the prior experience is limited to a technique which is appropriate to the present problem, successful solution is almost certain. But 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.

If research is thought of as a form of problem-solving behavior by groups, we would expect to find evidence in the real-life research situation of some of the principles which have been established by the experimental study of thinking in the psychological laboratory.

The present investigation makes use of the proposal competition for government contracts as a natural situation in which some theoretical principles of problem solving can be examined.

In contracting for research and development, the government usually solicits proposals from several contractors having previous experience in the appropriate field of endeavor. The agency responsible for the R & D project draws up a work statement describing the mission the system is to perform and setting forth certain criteria to which the design must adhere. This work statement is incorporated into a formal Request For Proposal which is sent to the competing firms. Each company presented with a work statement is confronted with a series of problems. In designing the system as a whole, it must find solutions to the design of the system's component parts, each of which may be considered a separate problem.

THE EFFECT OF SET ON PROBLEM SOLVING

It is known that the likelihood of finding a solution to a problem may be raised or lowered because the problem solver is set to respond in certain predetermined ways. Prior experience with tools or approaches used in solving similar problems in a certain way may result in a "set" which biases the problem solver and can divert him from consideration of alternative solutions. The phenomenon of set is based on the transfer from one problem to another and may be manifest in either positive or negative effects

on the solution of the later problem. Positive and negative biasing sets are thus defined as sets developed by experience with earlier problems which transfer to a new problem and either aid or inhibit the solution of that problem. Prior experience with a given solution process or tool will, in most cases, help the subject immediately to see its applicability to the situation at hand and thus provide a successful solution. In other cases, transfer from previous experience may create a set that results in familiar but inappropriate solutions and blocks discovery of a different and superior solution.

The existence of sets with positive transfer effects has been demonstrated by Saugstad (1955) and Staats (1957). Saugstad presented various objects necessary to solve a problem and had subjects list all possible functions for each object; 13 out of 57 subjects included the functions necessary to solving the problem. All of these 13 subjects later solved the problem whereas only 58% of the remainder were successful. In a similar experiment Staats found low but significant correlations between time required to solve a problem and the frequency and latency of correct functional responses in a post-solution listing of possible uses of a key implement in the solution.

Negative biasing sets resulting from prior successful use of a particular solution process have been demonstrated by Luchins (1942). He administered a short series of problems of this type: "If you had three empty jars that hold 21, 127, and 3 quarts, respectively, tell how you might measure accurately 100 quarts of water." These problems established the solution procedure of filling the largest jar and emptying from it with the aid of both the other jars until the required amount was left in

the largest jar. Following five problems solved in this manner, two problems were given of the type: "If you had three jars that hold 23, 49, and 3 quarts, respectively, tell how to get 20 quarts." Subjects without the experience of the five prior problems proceeded by a simple subtraction of two jars. But more than 80 per cent of the experienced subjects "solved" the new problems by the familiar procedure involving three jars.

Similarly, Duncker (1945) has shown that use of a tool in what is considered to be its normal function will inhibit a solution process requiring the tool to be employed in an unusual function. What Duncker has called "functional fixedness" may be regarded as a complex set with negative transfer effects. Birch and Rabinowitz (1951) and Adamson (1952) have conducted experiments confirming Duncker's results.

That a negative biasing set might exist in the type of problem solving performed by engineers is exemplified by an incident encountered during employment of the first author as an engineer by a large defense contractor manufacturing a ballistic missile system. In addition to its normal mission as an offensive weapon, various portions of the system (booster rockets, launch system, etc.) were adaptable to other uses--for instance, the orbiting of a satellite. It was the possibility of one of these unorthodox applications that led a government-sponsored nonprofit corporation to approach the company with a request for certain information pertaining to missile performance. When the proposed mission was explained to company representatives, they quickly concurred in their understanding of the requirements and agreed to perform an analytic investigation to determine just what the capabilities of their missile would be for the given mission.

When the results of this investigation were later delivered, the

engineers of the nonprofit corporation were astounded, for the capabilities fell far short of what they had predicted. Several phone calls were made and an agreement was reached to double check the results. The reworked analysis and a study of an improved version of the missile still fell far short of what had been originally expected. This activity consumed several weeks of work by engineers on both sides and a considerable volume of correspondence.

Finally a second meeting was called to resolve the apparent contradiction. It turned out that the missile manufacturer had, one year earlier, performed a study concerned with a very similar mission and had submitted an unsolicited proposal to the government based upon the study. Although the new mission proposed by the nonprofit corporation was similar in most respects to the earlier one, the approach differed in several critical areas. When confronted with the new problem, the company engineers immediately associated it with the problem they had solved one year before and failed to take proper account of the critical differences in approach. The analysis they performed merely repeated the former approach to the problem. Once this discrepancy was brought to the attention of both parties and a clear understanding of the new mission was obtained, the analysis was repeated with results very closely in agreement with the performance predicted by the nonprofit corporation. In this case, a negative biasing set, developed through prior experience, caused an initial failure and a delay of several weeks in the design and implementation of an important weapon system with the waste of several thousand dollars of engineering effort.

RESEARCH METHODS

Two contracts were selected for study from the files of the Air Force Electronic Systems Division. The Air Force Cambridge Research Laboratory was the agency responsible for technical evaluation of the proposals for these contracts. The contract files contain a copy of the work statement for each task, copies of all proposals submitted and a report on the technical evaluation performed by scientists in the Cambridge Research Laboratory. The latter document indicates, with substantiating reasons, which proposals were acceptable and which were not, and sometimes lists the proposals in the order of their technical merit.

Work statements and proposals were studied carefully to obtain a general understanding of the Laboratory's desires and of the problems presented in the Request for Proposal. The overall task was then divided into several sub-problems. The breakdown was checked with the scientists responsible for the project in the Laboratory in order to guard against possible misinterpretation of the work statement or misunderstanding of the technical ramifications of the task. Since the task of preparing a proposal comprises a series of smaller problems to be solved, the breakdown allows the analysis of the solution processes on each of these smaller problems.

The technical evaluators for the two proposal competitions were asked to categorize solutions to the sub-problems as either successful or unsuccessful. They were also questioned to determine whether any firms had presented solutions which might be considered outstanding. These interviews provided a better rating of the relative technical merit of

proposals than could be obtained solely from the technical evaluation report.

From each of the firms that had submitted proposals for the two contracts, information was obtained on the amount and kind of relevant prior experience. Interviews were conducted with the individuals responsible for proposal preparation in eight laboratories, five for Problem A and three for Problem C.

Description of the Problems

The two problems, with their respective sub-problems, can be described as follows:

Problem A: To design a portable meteorological set to measure wind velocity, air temperature, relative humidity, and atmospheric pressure. It was to be capable of withstanding a parachute drop from an airplane, or a ten-foot free fall. The set was to be operated by one man and was to be powered by self-contained batteries.

Sub-problems: The four sub-problems were the design of the four meteorological measuring devices (wind speed, air temperature, relative humidity, and atmospheric pressure) capable of operating under the rugged conditions specified.

Problem C: To design a rocket payload and ground-based support equipment to be used in measuring absorption of radio signals as they pass through the "D" layer of the ionosphere. The radio signals were to be at frequencies of 1 megacycle per second and below. The payload was to include radio receivers tuned to the frequency or frequencies of interest; telemetry equipment which would measure signal strength received and transmit this and other necessary information to a ground station; and the

required antennas.

Sub-problems: Based upon the technical evaluation, Problem C was divided into two sub-problems. The first of these involved the selection of a ground transmitter to operate as a signal source and the design of a system configuration for accomplishing the experiment. The second sub-problem was the design of a tracking system to measure missile position relative to the ground transmitter.

The data are from five laboratories that worked on the four sub-problems of Problem A, and from three laboratories that worked on the two sub-problems of Problem C, making a total of 26 possible solutions.

RESULTS: THE EFFECTS OF PRIOR EXPERIENCE

Prior Experience in General

For each sub-problem the person in charge of preparation of the proposal was asked: "Did anyone on the proposal team have prior experience with the design of...the type of sub-system or equipment required by the sub-problem?" On Problem C, all of the laboratories interviewed had prior experience on all sub-problems. For this reason, the effect of prior experience, per se, could not be determined. On Problem A, of six instances in which a laboratory did not have prior experience on a particular sub-problem, three solutions were judged successful by the technical evaluators, and three were unsuccessful. Of the fourteen instances in which a laboratory had prior experience, seven were successful and seven unsuccessful. It is clear that successful solution of the sub-problems does not depend upon prior experience as such.

Positive and Negative Biasing Sets

Prior experience may lead to successful solutions or to unsuccessful ones. One clear case of negative biasing set will be described as an example. In this instance, the engineer said that he was performing research on the use of thermistor beads for certain applications at the time he received the Request for Proposal for Problem A. He went on to say that his research on thermistor applications immediately brought to mind their possible use in two of the sub-problems (A-1 and A-2). He then designed solutions to these sub-problems using thermistor beads. The technical evaluators, however, believed thermistors to be too brittle for the application and judged both solutions to be unsuccessful.

In another case the transfer was clearly positive. The members of the proposal team had just completed an \$8,000 company-funded research program involving the use of a variable capacitance device as a pressure transducer for jet aircraft engines. This device employs the sides of an aneroid vacuum box as plates of a capacitor. As the distance between the sides changes with external pressure, the capacitance varies as a function of this distance. When the capacitor is incorporated into an electrical circuit whose output is a function of the capacitance, it provides an electrical signal which is a function of atmospheric pressure. When the Request for Proposal was received, the group immediately saw the applicability of this new device and designed a solution to sub-problem A-4. The technical evaluators judged this to be a successful solution.

These two examples demonstrate the existence of negative and positive biasing set in problem solving. In both cases, the researchers had been using a device in a slightly different application and when confronted with a new problem immediately applied this device to a new application.

In one case the transfer led to unsuccessful consequences while in the other it led to success.

Prior Experience with Successful Technique. The 26 sub-problem solutions have been classified according to the nature of the prior experience of the laboratory in the relevant area. Rows 1 and 2 of Table I show that of 11 laboratories which had prior experience with the successful technique, 7 submitted successful solutions. Even more striking is the fact that of those laboratories which had experience only

TABLE I
RELATION OF PRIOR EXPERIENCE TO SUCCESS
IN SOLUTION OF SUB-PROBLEMS

Number of instances of:	Successful solutions	Unsuccessful solutions
Prior experience with successful technique only	4	1
Prior experience with both successful and unsuccessful technique	3	3
Prior experience with unsuccessful technique only	2	6
No prior relevant experience	3	4

with the successful technique, four out of five submitted successful solutions. These results take on even greater significance when it is recalled that prior experience, in general, bore no relation to success.

Prior Experience with Unsuccessful Technique. Table I also indicates support for the hypothesis of negative biasing set. The data show that experience with a particular technique, when transferred to a new problem, may hinder rather than aid success. Comparison of rows 1

and 3 makes the consequences of negative biasing set perfectly clear.

Prior Knowledge of Successful and Unsuccessful Techniques. Prior knowledge of the successful or unsuccessful technique, as distinguished from actual experience, is also related to success in problem solving

TABLE II
RELATION OF PRIOR KNOWLEDGE TO SUCCESS
IN SOLUTION OF SUB-PROBLEMS

Number of instances of:	Successful solutions	Unsuccessful solutions
Prior knowledge of successful technique only	2	1
Prior knowledge of both successful and unsuccessful technique	10	9
Prior knowledge of unsuccessful technique only	0	4
No prior relevant knowledge	0	0

(Table II). When both techniques are known, neither appears to predominate. However when only one technique is known there is a tendency to exclude the other approach. Prior knowledge seems to have much the same effect as prior experience.

Overcoming Set. In three cases the proposal team, having had experience with either the successful or unsuccessful technique, nevertheless proposed techniques with which they had had no experience. In two cases, the solution was judged successful; in the third, the group rejected their successful prior experience to adopt a new and unsuccessful solution.

Overcoming Negative Biasing Set in Relation to Number of Alternative Approaches Considered. The biasing effect of prior experience is known to be a function of the number of alternatives considered in the problem solving process (Luchins, 1942, Maier, 1961). The mean number of alternative approaches considered in the six instances of negative biasing set was 1.33. The mean number of alternatives considered for the remaining twenty instances was 2.13. Figure 1 demonstrates that set may be overcome

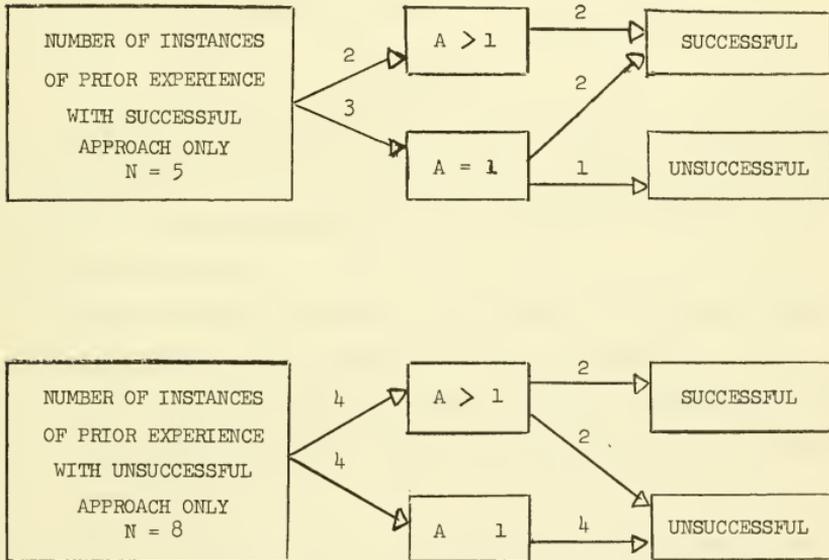


Figure 1. Relation of the number of alternative approaches considered (A) and the nature of prior experience to success in solving sub-problems in two proposal competitions.

by the consideration of more alternative approaches to a problem. Of the eight instances in which the laboratory had prior experience with a technique which would be unsuccessful if applied to the present problem, four considered no alternative approaches and all four submitted solutions which were evaluated as unsuccessful. In four other instances the laboratory considered two, three, or more alternative approaches, and half of them achieved a successful solution. The additional effort required to search for and compare several alternative approaches is justified by the decreased susceptibility to negative biasing set.

CONCLUSIONS

The effect of prior experience on success in solving discrete sub-problems involved in preparing a proposal was studied by comparing the behavior of eight laboratories in two R & D proposal competitions. The principal findings are:

1. Prior experience in the area concerned does not, by itself, result in a higher or lower probability of correct solution.
2. Prior experience only with a technique which is appropriate for the present problem usually results in a successful solution (positive biasing set).
3. Prior experience only with a technique which is not appropriate for the present problem usually results in an unsuccessful solution (negative biasing set). However, if such laboratories consider more than one alternative approach, the probability of success is increased from zero to one half.

4. Prior knowledge, as distinguished from prior experience, shows much the same set of relations with solution success.

These results, obtained on only a small sample of problems and of laboratories, are presented not to settle any questions, but to open up a new field of inquiry by demonstrating the feasibility and fruitfulness of a new method for the study of the research process.

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