Spatial Reasoning as Related to Solving "Story Type" Problems

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SPATIAL REASONING AS RELATED TO

SOLVING "STORY TYPE" PROBLEMS

by

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James Richard Holder

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Solving "Story Type" Problems

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In this study it was hypothesized that the ability to mentally solve "story type" problems, those presented in the form of sentences, is significantly related to one's spatial reasoning ability and that a weakness in this ability, when tested by the "story type" problems, could be compensated for by training in and utilization of overt "paper and pencil" manipulations.

To test the hypothesis, three measures were used. These were the DAT Verbal Reasoning test--used to control the factor of verbal reasoning, the DAT Space Relations test--used to measure spatial reasoning ability, and two forms of a test composed of "story type" problems--used to measure problem-solving ability.

A large group of college students (146) were first tested on the DAT tests and then 18 pairs were selected which were matched as nearly as possible on verbal reasoning abilities while keeping their spatial reasoning abilities as diverse as possible. The 18 pairs were then tested and retested on the problem-solving tests with half of the pairs receiving problem-solving instructions prior to the retest.

Statistical analysis of the results confirmed the hypothesis in that it revealed a substantial positive correlation between spatial reasoning ability and the ability to solve "story type" problems. Also, an analysis of the results showed, to a significant degree, that a weakness in spatial reasoning ability, when used to solve the type of problems considered, can be compensated for by using "paper and pencil" manipulations involving graphic procedures.

(51 pages)

INTRODUCTION

Man, in his everyday life, is continually faced with problems, the solutions of which are necessary for his continued adjustment. Many times these problems are presented in written form, on the order of "story" problems, because man often uses this symbolic form of expression.

Due to the necessity to deal with these written problems, the factors contributing to their successful solution are being continually sought. Also of interest is the development of methods which aid in the solving process.

Many of these problems require man to deal with them by covertly (mentally) manipulating the involved ideas and objects. The ability to use this method of solution, however, seems much more pronounced in some individuals than in others.

The purposes of this study are: (1) to determine the relationship between the ability to solve problems of this type and the ability to mentally manipulate objects and (2) to determine whether a weakness in this mental manipulation ability, when used to solve the story problems which we hypothesize require it, can be compensated for by overt "paper and pencil" manipulations.

REVIEW OF LITERATURE

The field of psychological research dealing with problem solving has been characterized by a state of confusion. This includes research studying the solution of "story-type" problems, problems presented in the form of sentences, and the relation of specific mental abilities to the solution of these problems.

The main reason for the confusion seems to be a combination of the complexity of the subject matter and a lack of integration within the field itself. A lack of theoretical framework associated with experimentation seems to be a contributing factor. Also, a seemingly endless number of experimental problems, lacking known factorial content and reliability, calling for solution, adds to the confusion.

In studies investigating the relationship between the solution of problems and mental abilities, there have been diverse findings, as one might expect.

Billings (1934), for example, in a very thorough study of individual differences in problem-solving abilities using written problems of different types, found what appears to be a general factor of problem solving. He gave one-hour tests in eight academic areas as diverse as geography, arithmetic, and mechanics to 146 college students who were instructed in the materials prior to testing. This was done so that acquired knowledge in the areas would not be a relevant factor in the problem solutions. The average intercorrelation of the results of the tests was 0.67. This was much higher than correlations between the problem-solving tests and knowledge of the material of the problems in the same area and strongly points towards a general ability to solve problems, at least of the types used in the tests. Also substantiating this conclusion was the average correlation of 0.54 obtained between the eight tests and a general intelligence test.

A general factor of reasoning ability was presented by Holzinger and Swinford (1939). Using a factor analysis (bifactor method) of the tests of problem-solving, reasoning, and deduction, many of which were "story-type" problems, they failed to locate a group factor of reasoning. Instead, the tests all had high loadings on a general factor. This factor, the investigators concluded, was composed mainly of reasoning ability.

Guetzkow (1947) administered 22 reasoning tests to 202 subjects and through factor analysis identified at least one general reasoning factor. The tests were made up of such things as spatial reasoning, mathematical reasoning, and reading comprehension. All tasks were factorially complex with accompanying undefined nonerror variance. The general reasoning factor and usual verbal factor were both general but independent.

In investigating a general reasoning factor, Guilford, Kettner, and Christensen (1956), using factor analytic techniques, concluded that general reasoning involves the comprehending or structuring of certain kinds of problems so that solution may take place. They noted that both general reasoning and numerical facility are involved in arithmetic reasoning and that general reasoning "may be a general ability to formulate complex conceptions of many kinds." (pp. 171-172).

Guilford and Christensen, again, in conjunction with Hertzka, as reported by McNemar (1955), investigated the ability to logically reason, defined by them as "the sensitivity to logical relationships in the testing of the correctness of a conclusion." (p. 20) They measured this ability by four tests: two involving syllogistic reasoning, one arithmetic reasoning (but not numerical manipulation), and one problem solving. This last test, though, was highly loaded with general reasoning and eduction of conceptual pattern factors. The results of the tests correlated 0.39 with Verbal Aptitude and 0.58 with Mathematics Aptitude.

In contrast, in relating a general factor to specific factors, Anderson (1967) found, upon reanalysis of Conry's data, that only one factor, general reasoning, was both strongly and continually related to the solution of 17 types of problem-solving measures used by Conry. The data involved was originally obtained from 94 females enrolled in a psychology course. The specific factors and their corresponding variances were: verbal comprehension, 18 per cent; memory span, 16 per cent; spatial scanning, 16 per cent; perceptual speed, 15 per cent; and rote memory, 13 per cent.

But again, returning to more of Guilford and Christensen's work, in association with Merrifield and Frick (1962), evidence is presented that there is no general, single problem-solving ability. The investigators administered a six-hour test battery for analysis purposes to 219 Naval Air Cadets and Aviation Officer Candidates, intercorrelated their scores, and extracted 14 centroid factors. None of these proved to be the general ability under consideration, and the extracted factors were recognized as being more specific and, for the most part, previously identified.

Of particular interest to this review are the major factors that were related to the types of problems calling for mental object and relationship manipulations. Two types of problems, Ship Destination and Logical Reasoning, fall within this category. The Ship Destination problems required that the distance from ship to port, considering the influences of several factors, be found. The Logical Reasoning problems presented a situation in which one must choose a statement logically consistent with given statements—a syllogistic type of problem. The Ship Destination problems correlated 0.45 with General Reasoning, and the Logical Reasoning problems correlated 0.33 with General Reasoning and 0.42 with Eduction of Conceptual Relations (cognition of semantic relations).

In a study of particular interest to this review, Gavurin (1967) investigated the relationship between nonverbal visual manipulation (spatial ability) and the solution of anagram problems requiring implicit letter manipulations. While anagrams cannot be classified as "story-type" problems, the inclusion of this study is important because of the related spatial ability.

Gavurin's study primarily tested the hypothesis that a substantial positive correlation would exist between anagram solving where no overt rearrangement of letters was permitted and performance on a test of spatial ability.

To test this hypothesis, 13 subjects were given ten six-letter, single solution anagrams to solve without manipulations and 14 subjects were given the same ten anagrams to solve using manipulations if desired. Also, all 27 subjects were tested on the Revised Minnesota Paper Form Board Test—a test of spatial abilities. The results of the study revealed: (1) that the two groups of subjects were selected from the same population with respect to spatial aptitude, (2) that a substantial positive relationship (0.54 Pearson Correlation) exists between spatial ability as tested and anagram solving when no manipulation of letters is permitted, and (3) that a low negative relationship (-0.18) exists between spatial abilities and anagram solving when manipulations are permitted. It was concluded that spatial abilities are related to the solution of anagram problems requiring implicit manipulations.

Finally, as somewhat of a clarifying conclusion to the varied results and interpretations thus far presented, French (1965) has emphasized that tests do not measure the same things in every individual. A person's characteristic thought processes, which are exercised in arriving at an answer, change what a test measures, no matter how factorially pure it is. Thus, these characteristic thought processes affect the factor loadings of tests and correlations between tests.

HYPOTHESIS

The ability to mentally solve "story-type" problems, those presented in the form of sentences, having to do with time-distance and object-relationship interactions, is significantly related to one's spatial reasoning ability. This is an ability which, however, can be compensated for by training in and the use of overt "paper and pencil" manipulations.

As corollaries of the basic hypothesis, it is predicted (a) that scores of the instructed group characterized by low spatial reasoning ability will significantly improve, after instructions in the use of specific diagramming techniques, on the second problem-solving test, and (b) that scores of the instructed group characterized by high spatial reasoning ability will not significantly improve, after similar diagramming instructions, on the second problem-solving test.

PROCEDURE

Subjects

The subjects consisted of 36 college students (drawn from a group of 97 students, which was also used for correlational purposes) enrolled in an introductory psychology course at Utah State University. They were, for the most part, freshman students taking the course as non-majors.

Measures Used

The Differential Aptitude Tests (DAT) is a multiple aptitude battery developed by Bennett, Seashore, and Wesman in 1947 and updated in 1963. It is designed for grades 8 through 12 but is suitable for adult populations. It is now available in two equivalent forms, L and M, each consisting of eight tests. In this study, however, only the Verbal Reasoning and Space Relations tests of form L were employed. The Verbal Reasoning test "is a measure of ability to understand concepts framed in words," (Sec. 1, p. 6) and the Space Relations test measures the abilities "to visualize a constructed object" (Sec. 1, p. 8) and "to imagine how an object would appear if rotated various ways." (Sec. 1, p. 8) Thus, "mental manipulations of objects in three-dimensional space" (Sec. 1, p. 9) are involved in this test. These tests were administered in shortened forms due to testing session time limitations. This shortening was accomplished by telling the subjects not to answer the first five questions in each test, thus leaving the

Space Relations test with 35 questions (requiring 84 correct answers) and the Verbal Reasoning test with 45 questions (requiring 45 correct answers). The reasons allowing for these length modifications were the relative simplicity of the first questions in each test and the extent of ages and intellects of the subjects. Other than these changes and the resultant testing time reductions, each test lasting 25 instead of the standard 30 minutes, standardized procedures were followed.

The split-half reliabilities, corrected by the Spearman-Brown formula, for the Space Relations and Verbal Reasoning tests, from grades 8 through 12, range from 0.89 to 0.95 and 0.87 to 0.94, respectively.

In order to have an independent measure of problem solving abilities, two equivalent forms (A and B) of a test made up of written, "story-type" problems were developed (See Appendix A). The tests were composed of 16 problems requiring 18 multiple choice answers and each was divided into three sections containing three different types of problems. These were: Logical Reasoning Problems, which were syllogistic types of problems requiring deduction of a correct "therefore" statement; Complex Thinking Problems, which were a mixture of direction-location and story-form problems somewhat similar to syllogisms; Time, Rate, Distance Problems, which required dealing with rates of travel, distances, time, proportions, etc., to arrive at a correct answer. These problems did not require more than very basic mathematic skills. The testing instructions (See Appendix A) were similar to those of many group tests, being modeled after several.

The test problems were subjectively evaluated as to level of difficulty, ranked, and randomly assigned to one test form or another, thus contributing to form equivalency. Also, overall level of difficulty of the problems was checked and assessed by independent testing on a small population similar in major characteristics to the population under study.

Testing Procedures

DAT Space Relations and Verbal Reasoning

Testing with the Space Relations and Verbal Reasoning tests was conducted on the morning of April 30, 1968, in a large classroom at Utah State University with all subjects attending. The Space Relations test was administered first with the Verbal Reasoning test immediately following. Total testing time was one hour. Standardized procedures were followed except for the previously mentioned modifications. Three proctors were used.

Problem Solving Tests (Forms A and B)

The Problem Solving Tests were taken in the small group laboratory situations which occurred once a week for 50 minutes for each subject. Four laboratories were scheduled per week with approximately 35 members in each. Each subject was a member of one laboratory only. The two test forms were distributed alternately in pre- and post-testing sessions to control for possible difference in form difficulty. Each subject eventually took both test forms. One proctor was used during this testing. The instructions, test forms, and an answer sheet are included in Appendix A.

Subject ranking and matching

The scores on the DAT tests were converted into t scores (See Appendix B), and the subjects were ranked according to their converted verbal scores. A subject's converted spatial score was then subtracted from his converted verbal score to permit a relative comparison of the two. This resultant value was represented by a plus or minus score, such as +10 or -3. Extremes in these scores, subjects relatively high or low in the Space Relations factor, were then matched for Verbal Reasoning ability, thus making a pair of a relatively high plus number and a relatively high minus number, such as +15 and -5. The average difference in Space Relation scores, the difference between the high plus and high minus numbers, for all matched pairs was 20.56, which is over two standard deviations difference. The average difference for these same matched pairs in Verbal t scores was only 1.39, which kept the factor of Verbal Reasoning differences controlled. The matching procedures resulted in 18 pairs of subjects, the pairs being distributed throughout the range of verbal scores.

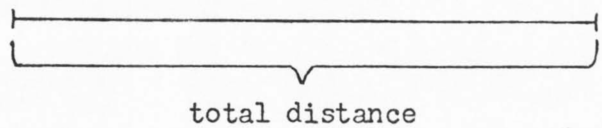
Problem Solving Instructions

Nine pairs of subjects, whose verbal t scores were dispersed throughout the range of verbal t scores, served as a control group taking pre- and post-Problem Solving Tests only. The remaining nine pairs, whose verbal t scores were similarly dispersed, took a pre-test, received instructions on "paper and pencil" methods to solve the types of problems on the problem-solving tests, and then took a post-test. The instructions were given directly before the post-test, and there was ample time for all to complete the test. The verbal instructions were as follows (with the instructor diagramming on a blackboard):

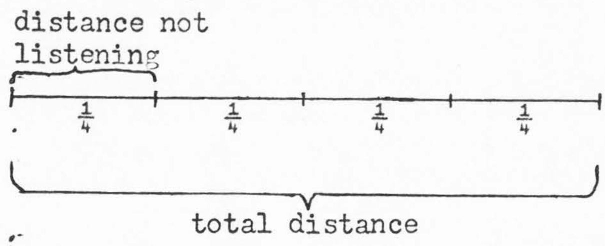
You students have been asked to be here so that we can give you some ideas which might help you solve problems similar to those that were on the test you took.

On that test there were three main types of problems; they were Time, Rate, Distance Problems; Logical Reasoning Problems; and Complex Thinking Problems.

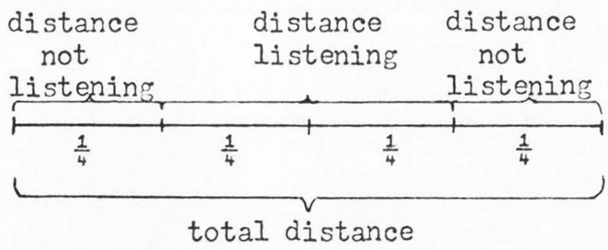
On the first of these types, the Time, Rate, Distance Problems, we have found it helpful to represent the distances traveled as lines on a paper. For instance, if a man started listening to a radio one-fourth the way to his destination and quit when there remained one-half the distance he had traveled while listening and you want to find out what part of the total distance was traveled while listening to the radio, you could represent the entire distance traveled as one line such as this and label the line total distance.



Next, you could mark off and label on this line the distance traveled before listening. To do this you would first need to divide the line in half and then divide each half in half again, or, in other words, divide the line into fourths. The quarter farthest on the left would then be labeled distance not listening or something similar and each quarter would be labeled.



After doing this, it would be important to remember that of the three-fourths of the line remaining there is a distance which was spent listening and a distance spent not listening, and that the distance spent not listening was one-half of that spent listening, or one part was "not listening" and two parts were "listening." In other words, the remaining three-fourths of the trip after first turning on the radio, was made up of three parts and that two-thirds of these parts, were spent listening. Once this is realized, these parts should be labeled like this.



It can be seen that they are already marked off. It can also be seen that the part of the distance spent listening is two-fourths or one-half of the total distance, which is the answer to the problem.

Now let us all try another problem which is a little bit different. You try it first on your paper, and then I'll try it on the board. Remember, to help you solve this problem, use a line to represent the distance traveled.

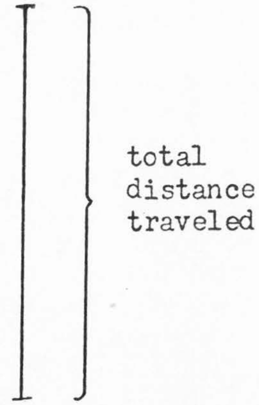
The problem is: On the first floor of a skyscraper, a man entered an elevator to go up to a desired floor. He fell asleep after going up one-half of the stories to his destination. Upon awakening he still had to go up one-fourth of the distance he had traveled while awake. What part of the total trip was taken by his sleep?

Please put your pencils down when you're finished.

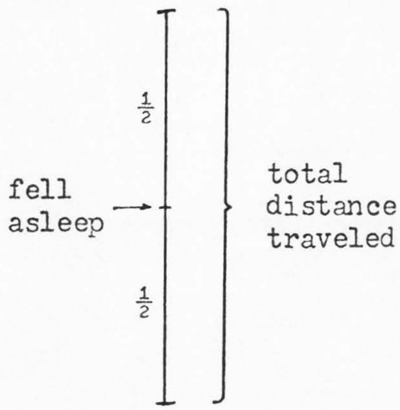
(Working time)

Is everyone through?

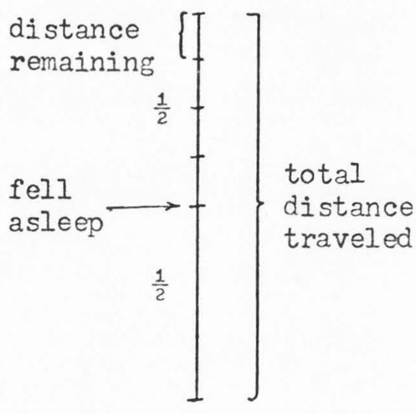
Here's how I would solve this problem if I were to work it. I would let one vertical line represent the total number of floors or total distance traveled, like this.



Next, I would mark and label the point at which the man fell asleep. In doing this I would be dividing the line in half since the man fell asleep after going up one-half of the stories to his destination. The line would now look like this.



The next thing to do would be to remember that the man had one-fourth of the distance he had traveled before falling asleep remaining to travel. And since he had traveled one-half of the total distance before falling asleep, we could now divide the upper half of the line (since it's equal to the first half) into fourths and label the last one-fourth "distance remaining." We do this so that we can more easily "see" the parts "sleeping" and "not sleeping" of the last half of the trip.



Now that we know that the last fourth of the second half of the trip is the part of the trip which was remaining after he woke up, we can easily see that the other three parts of the second half is the part of the total distance spent sleeping. But since the problem wanted to know what part of the total distance was spent sleeping, we must remember that one-fourth of half the distance is the same as one-eighth of the total distance and that three-fourths of half the distance is the same as three-eighths of the total distance. Therefore, three-eighths of the total distance was the part taken by sleep.

Now you may have noticed that although this method using a line might not have been entirely necessary to solve this problem, it did make it easier.

On the second type of problem, that involving logical reasoning, we have found that if we use circles we can solve them easier. The circles are used to represent the factors in the problems and where we draw the circles on a paper is determined by the relationships among the factors represented by them. Usually with this type of problem there will be three factors related to the solution, and thus we will use three circles in solving most of them.

I think an example using this method to solve a logical reasoning problem will help you to understand. The problem we will use is:

All men are mortal;
Socrates is a man;
Therefore ________________.

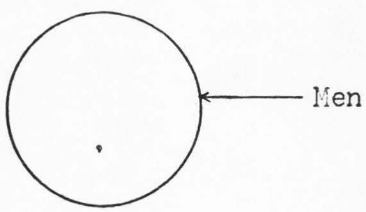
Fill in the blank with the correct statement. The answers that we have to choose from to complete this problem are:

(a) Socrates is mortal.
(b) Socrates is not mortal.
(c) Socrates may be mortal.

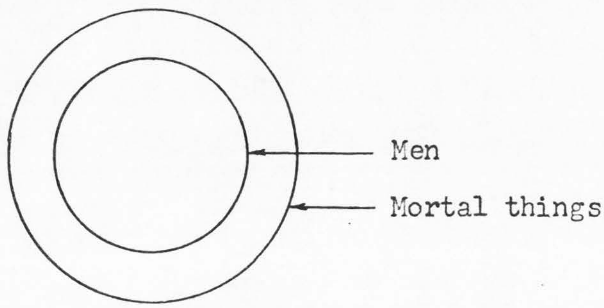
The first step in solving this problem, I think, would be to decide on the three factors stated in the problem which are necessary for solution. In other words, what we need now are the three specific factors which we will represent by circles on paper and which are necessary for solution. These three factors are represented by the words, mortal, man, and Socrates, and we know this because in reading the problem we can see that the problem deals with man's mortality and its relationship to Socrates.

Now that we have decided on the three factors, we must next decide how to represent these by circles and put them together so that their relationships will be correctly represented and so that from the arrangement of these circles we can find a solution.

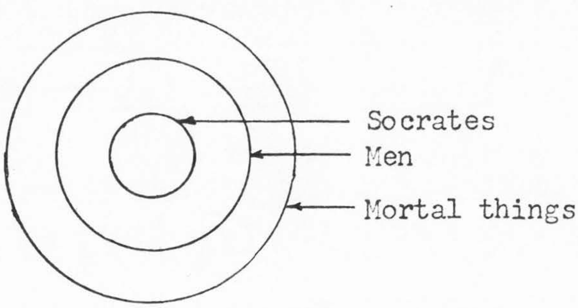
To represent the first factor in the problem, that of men in general, we need only to draw a circle, let the inside of it stand for all men, and label it "men." We would do it like this.



Next we must determine the relationship between this factor of men and the factor of mortality. We can represent the factor of mortality, or all things that are mortal, by a circle, and now we need to figure out how to draw it to represent its relationship to the factor of men. Since things other than men can be mortal, or could be mortal, it seems that the "mortality" circle should be bigger than the "men" circle, and also, since all men are mortal, it seems that we should put the "men" circle inside of the "mortality" circle since all mortal things are represented inside of this circle. The second circle would then be drawn around the first like this. It should also be labeled.



Now we need to represent the third factor, Socrates, by a circle. Since it is stated that Socrates is a man, we can represent Socrates the man as a small circle inside of the larger circle containing all men. Now our diagram would look like this.



Now from this diagram we can go through our answers and choose the correct one. The first answer, (a)"Socrates is mortal," can be checked by recalling that Socrates is a man, by seeing that he is in the circle representing all men and by realizing that the circle representing all men is inside the circle containing all mortal things, so that Socrates is inside of the circle containing all mortal things and that he then must be mortal. Therefore the first answer is correct.

Let's try a second problem of this type now. Let's also use this method of diagramming with circles to represent the factors presented in the problem to help find the solution.

The problem is:

All football players are wrestlers;
Some wrestlers lift weights;
Therefore ______________________.

The answers provided are:

(a) All wrestlers are football players.
(b) All wrestlers are weightlifters.
(c) Some football players may be weightlifters.

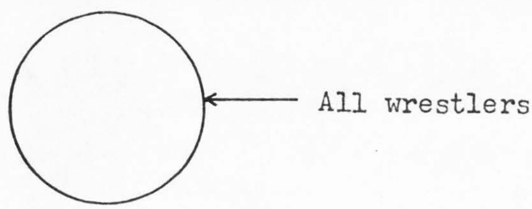
Now each of you try to solve this problem using circles to diagram for assistance, and put your pencil down when you are through.

(Working time)

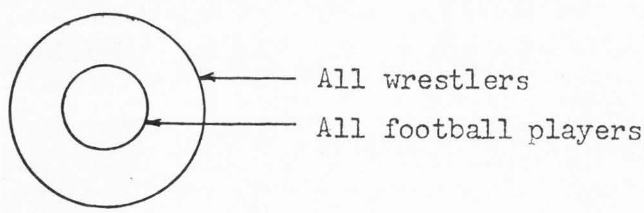
Is everyone through now?

Here's how I solved the problem, and your method of solution should have been something like it.

First I represented all wrestlers by a large circle, like this.

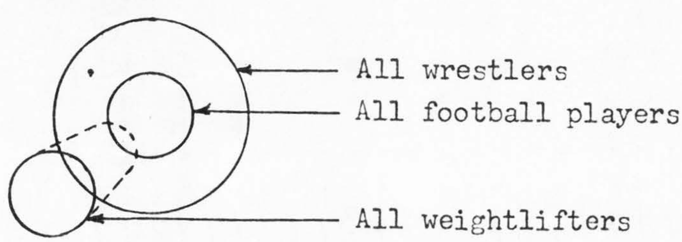


Next I represented all football players with a circle inside of all of the wrestlers, like this.



I did this because all football players are wrestlers.

Next I represented all the weightlifters. I could do this by two different circles which I combined so that I could get a clearer picture of the possible answers. The diagram looks like this now.



I represented the wrestlers who lift weights by the solid part of the circle representing all weightlifters, which overlaps the circle representing all wrestlers. I also represented the possibility that some football players may lift weights by the dotted part of the circle which overlaps the circle representing all football players. I did this because the relationship between football players and weightlifters was not stated.

Now, using my diagram, I can go through the answers and decide which is correct.

The first answer, (1) "All wrestlers are football players," judging from the diagram, is obviously incorrect.

The second answer, (b) "All wrestlers are weightlifters," is also incorrect as determined by the diagram.

The third answer, (c) "Some football players may be weightlifters," should therefore be correct. However, this should be checked on the diagram. From the diagram it can be seen that it is possible for some football players to be weightlifters. Therefore, the third answer is correct.

In this example of problem-solving using this "circle-diagram" method, it would have been easy to reject the first two answers, without the diagram, but to decide on the correctness of the third answer would have been difficult. In this case, our method helped to decide on the correctness of one answer.

In solving the third type of problems, which we call Complex Thinking Problems, we have found it helpful to represent the given, whether it be persons, items, or characteristics, and the relationships stated, as figures and lines which make up a diagram.

As an example using this method, I will solve this problem.

I don't like sea voyages, and I don't like the seaside. I must spend Easter either in France, or among the Scottish hills, or on the south coast. Which shall it be?

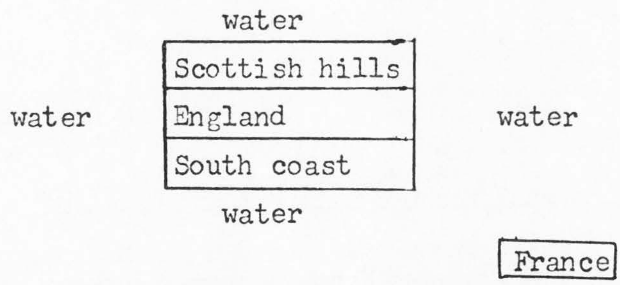
The answers given are:

(a) The south coast.
(b) France.
(c) The Scottish hills.

To solve this problem I would first have to realize that the person is in England. Next I would represent England as some sort of figure--like this.

England

After this, I would represent the other information, locations in this case, given in the problem by diagramming them in their proper relation to the location of England. The diagram would look like this now.



I put the south coast and the Scottish hills next to England since, in reality, they are, and I put France away from England since England is on an island and is a good distance from France. Also since England is on an island with the south coast and the Scottish hills, there would be water surrounding it. I labeled these areas "water."

Now to find the correct answer to this problem, all I need to do is go through the answers and decide, by checking with my diagram and the person's likes and dislikes as stated in the problem, which choice is appropriate.

The first answer is the south coast. Keeping in mind the person's dislike for seasides, it can be counted as incorrect.

The second answer, France, is also incorrect. This is so because if you look at the diagram you will realize that England and France are separated by water and the person does not like sea voyages.

The third answer, the Scottish hills, should be the correct one. This can be checked by our diagram. It can be seen that the person will not have to take a sea voyage nor will be on the seaside, therefore the Scottish hills is the correct answer.

This method of diagramming, while not completely necessary all of the time, is a help in solving this type of problem. It helps you "see" the relationships and items involved.

Now let's try a second problem of this type. You try to solve it first, using figures, lines, etc., as I did in the first problem, and then I'll try it.

The problem is: Four girls are standing in a row: Janice is taller than Mary; Ann is taller than Janice; Rose is shorter than Mary. Out of this group who is taller than two people but shorter than one?

Your answers are:

(a) Mary
(b) Ann
(c) Rose
(d) Janice

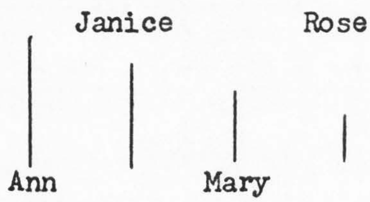
Alright, now you try to solve this one and put your pencils down when you're through.

(Working time)

Everyone finished?

Here's how I would solve this problem. Your method should be something similar.

The first step to take, I think, is to decide on what the problem wants. In this case it wants to know who is taller than two people but shorter than one. Therefore, I would represent the girls' heights, as stated in the problem, by lines. My diagram would look like this.



I represented each girl's height by a line which is the correct length in relation to the others. For example, look at the line representing Ann's height. It is longer than the line representing Janice's height as stated in the problem.

The next step in solving this problem is to re-read the part of the problem which states what is wanted and decide on an answer. This part of the problem is "Out of the group who is taller than two people but shorter than one?" The answer, judging from the diagram, is, of course, Janice, since the line representing her height is longer, or taller, than two other lines but shorter than one.

In this case, as in most, our method of solution, though not really necessary, made it easier to solve the problem. (All instructions quoted from author's private works.)

RESULTS AND DISCUSSION

It was hypothesized that the ability to mentally solve "story-type" problems, those presented in the form of sentences, having to do with time-distance and object-relationship interactions is significantly related to one's spatial reasoning ability. This is an ability which, however, can be compensated for by training in and the use of overt "paper and pencil" manipulations, when tested by such "story-type" problems. In testing this hypothesis, two forms of a test composed of "story-type" problems served as an index of problem solving ability; whereas the DAT Space Relations Test and Verbal Reasoning Test provided measures of spatial reasoning ability and verbal reasoning ability, respectively. This latter ability was a variable held constant. A table will be presented showing the results of these lastly mentioned tests.

A correlation will be presented to indicate the relationship between the ability to mentally solve "story-type" problems, represented by pre-test scores on the problem-solving test, and spatial reasoning ability, represented by scores on the Space Relations Test.

Differences in test score improvements for the groups will be presented to reveal the effects of instruction upon problem-solving abilities. This will indicate the possibility for compensating for a weakness in spatial reasoning ability by utilizing "paper and pencil" manipulations. Also, differences in improvement for the instructed groups, according to problem type, as related to spatial reasoning ability, will be presented. This will be done to reveal the specific relationships between problem type, spatial reasoning ability, and exposure to problem-solving methods.

Below are presented the results of the administration of the Space Relations and Verbal Reasoning tests to the original subject population. The maximum scores, means, and standard deviations are given.

Table 1. Means and standard deviations on the DAT Verbal Reasoning and Space Relations tests. N = 146.

Test	Maximum score	Mean	Standard deviation
Verbal Reasoning	45	25.8 ($t = 48.6$)	8.6
Space Relations	84	52.2 ($t = 56$)	17.1

The average percent correct of the maximum possible on the Verbal Reasoning test was 57.3 and on the Space Relations test was 62.1. The mean on the Verbal Reasoning test was 25.8 with an accompanying standard deviation of 8.6. The mean on the Space Relations test was 52.2 with an accompanying standard deviation of 17.1.

The correlation of problem-solving ability, represented by scores on the pre-test of the problem-solving tests, with spatial reasoning ability, as measured on the Space Relations test, was computed, using a Pearson correlation by the scattergram method, to be 0.56 ($p < 0.001$). This correlation indicates that there exists a moderately high relationship between the ability to mentally manipulate objects and to solve "story-type" problems involving interactions among the involved constructs. With the factor of verbal reasoning held constant, a partial correlation of 0.34 was found between the above-mentioned mental manipulation ability and success in solving the above-mentioned "story-type" problems.

In Table 2 below are presented the average test score improvements for the four groups (non-instructed, high and low in spatial reasoning ability; instructed, high and low in spatial reasoning ability), the differences in improvement for the high and low spatial reasoning groups receiving instructions and not receiving instructions, the average improvements for the instructed and non-instructed groups, and the difference in this average.

The group low in spatial reasoning that received instruction had a pre-test average score of 12.12 and a post-test average score of 14.67. These resulted in an improvement of 2.55. The high-space instructed group had averages of 15.00 and 14.89 with a -0.11 improvement. The difference in improvement for these groups was 2.66. Using the test of significance of the difference between means when the data are correlated, this difference was found to be significant at the 0.01 level. The group low in spatial reasoning that was not instructed had a pre-test average score of 12.22 and a post-test average score of 12.67. These resulted in an improvement of 0.45. The high-space non-instructed group had averages of 14.33 and 13.67 with a -0.66 improvement. The difference in improvement for these groups was 1.11. This difference, using the same test of significance as stated above, was not significant at the 0.05 level. The average improvements for the instructed (high and low space) group and the non-instructed (high and low space) group were 1.22 and -0.11, respectively. The difference in these averages, which was 1.33, was significant at the 0.05 level.

Table 2. Average pre- and post-test scores, net improvements, and differences within instructed and non-instructed groups; average instructed and non-instructed group improvements and improvement differences.

Group		Pre-test score	Post-test score	Score improvement	Improvement difference	Average instructed and non-instructed group improvements	Average instructed and non-instructed group improvement difference
Instructed	Low space	12.12	14.67	2.55	2.66 ($p < 0.01$)	1.22	1.33 ($p < 0.05$)
	High space	15.00	14.89	-0.11			
Non-instructed	Low space	12.22	12.67	0.45	1.11 ($p < 0.05$)	-0.11	
	High space	14.33	13.67	-0.66			

The post-test scores indicate the respective total effectiveness of the four groups in dealing with the problems presented in the tests, and the difference in improvement between the low-space instructed and non-instructed, which was 2.10 in favor of the instructed, indicates the effects of instructions on problem-solving ability for those low in spatial reasoning ability. This 2.10 difference was significant at the 0.05 level.

The group showing the greatest average improvement was the low-spatial instructed. This is just as was hypothesized. The group showing the least improvement was the high-spatial non-instructed. The difference in improvements for these groups was 3.21 which was found to be significant at the 0.01 level. This finding seems logical in that the high-spatial non-instructed group's basic method of dealing with the problem-solving measures probably remained the same throughout both tests while the low-spatial instructed group's solving methods were altered and improved. The group high in spatial ability and receiving instructions showed a lack of improvement with the second test, thus verifying a correlary to the hypothesis. The fact that this group was high in the spatial factor and that the instructions were a method of teaching devices for compensating for a weakness in this ability, seems to explain this finding.

The post-test scores also substantiate the hypothesis that a weakness in spatial reasoning ability, an ability needed to solve certain types of problems, can be compensated for by "paper and pencil" manipulations. The post-test average of the low-spatial instructed group is 1.00 greater than that of the high-spatial non-instructed group. This difference is not significant at the 0.05 level and indicates that the post-test scores of the two groups are not significantly different. Thus, after instructions, the low-spatial and high-spatial ability groups were equally competent in solving the problems administered.

The difference in average improvement of 2.66 problems correct for the high- and low-spatial instructed groups reveals the effects of the utilization of the instructed problem-solving methods for those low in spatial reasoning ability. The scores for the high-spatial instructed group seem negatively affected by the problem solving instructions.

The non-instructed group's average improvement difference of 1.11 ($p > 0.05$) reveals the lack of significant positive improvement by either group from the pre- to post-test.

The average instructed and non-instructed groups' improvement difference of 1.33 ($p < 0.05$) indirectly reveals the positive effect of instructions on the low-spatial instructed group. The 1.22 average instructed group improvement results totally from the low-spatial group in that the high-spatial group made no improvement at all. The 1.33 difference is an indirect means of revealing the effects of instruction on the subjects low in spatial reasoning ability.

In the table below are given the average improvements for the instructed groups, according to problem types, and the differences in improvements between the types, as related to spatial reasoning ability.

For the group low in the spatial factor, the following average improvements from pre- to post-test, according to the specific type of problems, resulted: Logical Reasoning Problems, 0.56; Complex Thinking Problems, 0.11; Time, Rate, Distance Problems, 1.78. The difference of 0.45 between the Logical Reasoning Problems and Complex

Table 3. Average improvement in number correct (of six possible) and differences in improvement, after instructions, according to problem type, as related to spatial reasoning ability.

	Logical Reasoning	Complex Thinking	Time, Rate, Distance	Difference in improvements
Low space	0.56	0.11	1.78	Log. Reas. vs. Comp. Think., 0.45 ($p>0.05$) Log. Reas. vs. Time, Rate, Dist., 1.22 ($p<0.05$) Comp. Think. vs. Time, Rate, Dist., 1.67 ($p<0.01$)
High space	-0.44	0.11	0.22	Log. Reas. vs. Comp. Think., 0.55 ($p>0.05$) Log. Reas. vs. Time, Rate, Dist., 0.66 ($p>0.05$) Comp. Think. vs. Time, Rate, Dist., 0.11 ($p>0.05$)

Thinking Problems was not significant at the 0.05 level, the difference of 1.22 between the Logical Reasoning Problems and Time, Rate, Distance Problems was significant at the 0.05 level, and the difference of 1.67 between the Complex Thinking Problems and the Time, Rate, Distance Problems was significant at the 0.01 level. For the group high in the spatial factor, the following average improvements from pre- to post-test, according to the specific type of problems, resulted: Logical Reasoning Problems, 0.44; Complex Thinking Problems, 0.11; Time, Rate, Distance Problems, 0.22. The difference of 0.55 between the Logical Reasoning Problems and the Complex Thinking Problems was not significant at the 0.05 level, the difference of 0.66 between the Logical Reasoning Problems and the Time, Rate, Distance Problems was not significant at the 0.05 level, and the difference of 0.11 between the Complex Thinking Problems and the Time, Rate, Distance Problems was not significant at the 0.05 level.

One can see that the type of problem apparently most influenced by the use of "paper and pencil" reasoning methods, especially in the case of those low in the spatial factor, was the Time, Rate, Distance. This suggests that this type of problem was most dependent upon spatial reasoning ability and most positively affected by methods which compensated for a weakness in it.

The other two types of problems seem only slightly affected by the "paper and pencil" diagramming methods, thus suggesting other factors, other than merely spatial, accounting for their successful solution. The possibility that the subjects could have used these problems as they were presented in the test booklets as parts of diagrams (more concretely presented), and thus not rely on their spatial reasoning abilities, seems a distinct possibility. Supporting this idea were the numerous marks, arrows, lines, and words added to the test booklet problems (especially the Complex Thinking and Logical Reasoning) during testing sessions and noted afterwards by this investigator.

SUMMARY

In this study it was hypothesized that the ability to mentally solve "story-type" problems, those presented in the form of sentences, having to do with time-distance and object-relationship interactions, is significantly related to one's spatial reasoning ability and that a weakness in this ability, when tested by the "story-type" problems, could be compensated for by training in and utilization of overt "paper and pencil" manipulations.

To test the hypothesis, three measures were used. These were the DAT Verbal Reasoning test—used to control the factor of verbal reasoning, the DAT Space Relations test—used to measure spatial reasoning ability, and two forms of a test composed of "story-type" problems of the above-mentioned variety—used to measure problem-solving ability.

A large group of college students (146) were first tested on the DAT tests and then 18 pairs were selected which were matched as nearly as possible on verbal reasoning abilities while keeping their spatial reasoning abilities as diverse as possible.

The 18 pairs were then tested and retested on the problem-solving tests with half of the pairs, whose spatial and verbal abilities were representative of the entire range tested, receiving problem-solving instructions in using "paper and pencil" manipulations prior to the retest.

Statistical analysis of the results confirmed the hypothesis in that it revealed a substantial positive correlation between spatial

reasoning ability and the ability to solve "story-type" problems having to do with time-distance and object-relationship interactions. Also, an analysis of the results showed, to a significant degree, that a weakness in spatial reasoning ability, when used to solve the type of problems being considered, can be compensated for by using "paper and pencil" manipulations involving graphic procedures.

The corollaries to the basic hypothesis, namely (a) that scores of the instructed group characterized by low spatial reasoning ability would significantly improve, after instructions in the use of specific diagramming techniques, on the second problem-solving test and (b) that scores of the instructed group characterized by high spatial reasoning ability would not significantly improve, after similar diagramming instructions, on the second problem-solving test, were also found to be true to a statistically significant degree.

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APPENDIX A

Problem Solving Instructions: This is a test containing 16 multiple choice problems. The results of your work with these problems will be used to study the effects of solving certain problems on solving other problems. You will not be graded on your work. You will have 45 minutes to work and will be told when 20 minutes remain, 10 minutes remain, and 5 minutes remain. Do not stop after each set of problems, but continue on to the next. Please do your best and try to finish. Please do not make any marks on this test booklet. Put your name, the date, and your lab number on your answer sheet. After you do this, you may begin.

Problem Solving Test
Form A

Logical Reasoning Problems

1. All hunters are hikers.
   All hikers are campers.
   Therefore, __________.

Ans: (Choose the only true statement.)
   a. no campers are hikers.
   b. all hunters are campers.
   c. some hikers are not campers.
   d. some hunters are not campers.

2. All industrialists are capitalists.
   Most industrialists are not representatives.
   Therefore, ____________.

Ans: (Choose the only true statement.)
   a. all representatives are capitalists.
   b. no capitalists are representatives.
   c. some capitalists are representatives.
   d. all capitalists are industrialists.

3. All hunters are shooters.
   No shooters are fishermen.
   All shooters are loaders.
   Therefore, ____________ and __________.

Ans: (Choose the two true statements.)
   a. some loaders are shooters.
   b. some hunters are fishermen.
   c. all hunters are loaders.
   d. all loaders are hunters.
   e. all loaders are fishermen.

4. All machinists are mechanics.
   No carpenters are mechanics.
   Some mechanics are welders.
   Therefore, ____________ and __________.

Ans: (Choose the two true statements.)
   a. no carpenters are machinists.
   b. all mechanics are machinists.
   c. some welders may be machinists.
   d. some carpenters may be machinists.
   e. some welders may be carpenters.

Complex Thinking Problems (Choose the correct answer.)

1. Three boys are sitting in a row: Harry is to the left of Willie; George is to the left of Harry. Which boy is in the middle?

Ans: a. Harry b. George c. Willie d. Cannot be determined by given information.

2. I am in town and want to go home. I know my house is south of town. It is morning and the sun is rising on my left. Which way would I have to walk to reach my house?

Ans: a. To my right. b. To my left. c. Straight ahead. d. Behind me.

3. I started from a church and walked 100 yards; I turned to the right and walked 50 yards; I turned to the right again and walked 100 yards. How far am I from the church?

Ans: a. 25 yards b. 50 yards c. 100 yards d. 150 yards

4. David is Robert's uncle. Jeff is Robert's brother. Alice is Jeff's daughter. Mary is Alice's sister. What is David's relation to Alice?

Ans: a. Grandfather b. Uncle c. Great-grandfather d. Great-uncle

5. Where the climate is hot, aloes and rubber will grow. Heather and grass will grow where it is cold. Heather and rubber require plenty of moisture. Grass and aloes will grow only in fairly dry regions. Near the Amazon river it is very hot and very damp. Which of the above will grow there?

Ans: a. Aloes b. Rubber c. Heather d. Grass

6. Where the climate is warm, cougar, antelope, and elk will live. Where the climate is cold, deer, bear, and moose will live. In mountainous areas, cougar, deer, and bear are inhabitants. In valleys, elk, antelope and moose reside. Deer, cougar, and moose live in wooded areas, while bear, elk, and antelope live in meadows. Near the state border, where the Davis mountain range is located, there is a huge forest which is always receiving snow. Which of the above animals would live in this forest?

Ans: a. Bear b. Cougar c. Deer d. One of the other animals

Time, Rate, Distance Problems (Choose the correct answer.)

1. A passenger fell asleep after he had traveled half-way to his destination. When he awoke there remained half the distance he had traveled while asleep. For what part of the way did he sleep?

Ans: a. 1/4 b. 1/3 c. 1/6 d. 1/5

2. A man had to carry 40 bricks 20 miles. However, after the first 4 miles he began to drop $\frac{1}{2}$ of the number of bricks he was carrying every 4 miles (except for the last 4 miles). How many bricks did he have left after the journey was over?

Ans: a. 0 b. 3 c. 5 d. 8

3. A man had to walk 12 miles to reach his home. After walking $\frac{1}{4}$ the distance, he was picked up in a car and accidently taken past his home twice as far as 1/3 the distance he had left to walk when he was picked up. How far did he now have to walk to reach his home?

Ans: a. 4 miles b. 5 miles c. 6 miles d. 8 miles

4. On the first floor of a skyscraper a man entered an elevator to go up to a desired floor. He fell asleep after going up 2/3 of the stories to his destination. Upon awakening he still had to go up 1/3 of the distance he had traveled while awake. What part of the total trip was missed by his sleep?

Ans: a. 1/6 b. 1/8 c. 1/9 d. 1/12

5. A man had to walk 10 miles to reach his home. He walked $\frac{1}{2}$ the distance and remembered he had forgotten to pick up a package $2\frac{1}{2}$ miles back, so he turned around and returned for it. He spent 1 hour visiting at the place where his package was and then set out for home at the same rate he had formerly traveled. It took him 4 hours to make the entire trip from start to finish. What was his average rate of travel?

Ans: a. $2\frac{1}{2}$ miles per hour b. 3 miles per hour c. $4\frac{1}{2}$ miles per hour d. 5 miles per hour

6. A man and his wife boarded a train together and traveled 15 miles to the first stop. The wife then accidently switched trains and had to go twice as far as her husband before they met again at the next stop. They arrived there at the same time, however, and continued on their journey for 15 more miles or 1/3 of their original journey. The whole trip lasted 1 hour. What was the average rate of speed of the train which the wife accidently boarded?

Ans: a. 75 miles per hour b. 80 miles per hour c. 85 miles per hour d. 90 miles per hour

Problem Solving Test
Form B

Logical Reasoning Problems

1. All brain surgeons must have steady nerves.
John cannot be a brain surgeon.
Therefore, ________________.

Ans: (Choose the only true statement.)
a. John must not have steady nerves.
b. John must have steady nerves.
c. John may not have steady nerves.
d. John does not have unsteady nerves.

2. Some discus throwers are tennis players.
All tennis players are runners.
Therefore, ________________.

Ans: (Choose the only true statement.)
a. no runners are discus throwers.
b. all tennis players are discus throwers.
c. no tennis players are runners.
d. not all discus throwers are tennis players.

3. All dancers are singers.
No singers are actors.
All singers are comedians.
Therefore, __________ and ___________.

Ans: (Choose the two true statements.)
a. some comedians are singers.
b. all comedians are dancers.
c. all comedians are actors.
d. some dancers are actors.
e. all dancers are comedians.

4. No zoologists are philosophers.
Some philosophers are psychologists.
All sociologists are philosophers.
Therefore, ____________ and ___________.

Ans: (Choose the two true statements.)
a. some zoologists may be sociologists.
b. some sociologists may be psychologists.
c. some zoologists may be psychologists.
d. all philosophers are sociologists.
e. no psychologists can be sociologists.

Complex Thinking Problems (Choose the correct answer.)

1. John is heavier than Bill but lighter than Dan. George is lighter than John but heavier than Bill. Who is the lightest of them all?

Ans: a. John b. Bill c. Dan d. George

2. There are four roads here. I have come from the south and want to go to Jacksonville. The road to the right leads to somewhere else. Straight ahead it leads only to a ranch. In which direction is Jacksonville?

Ans: a. South b. West c. East d. North

3. I started from school and drove 4 miles. I turned to the right and drove 2 miles. I turned to the left and drove 1 mile. I turned to the left again and drove 2 miles. How far am I from school?

Ans: a. 4 miles b. 5 miles c. 2 miles d. 7 miles

4. I have bought the following Christmas presents: a pipe, a blouse, some music, a box of cigarettes, a bracelet, a toy engine, a bat, a book, a doll, a walking stick, and an umbrella. My brother is 18; he does not smoke, nor play baseball, nor play the piano. I want to give the walking stick to my father and the umbrella to my mother. Which of the above shall I give to my brother?

Ans: a. the toy engine b. the book c. the pipe d. the music

5. Where the water is clean, bass and trout will live. Carp and suckers live in dirty water. Trout and suckers will live only where there is cold water. Carp and bass will live only in warm water. James Lake is noted for its cold, clear water. Which one of the above fish can live in this lake?

Ans: a. trout b. bass c. suckers d. carp

6. Where the climate is damp, moss, grass, and cattails grow. Where the climate is dry, cactus, sage, and marigold grow. Where there is a high altitude, moss, sage, and marigold grow. In low altitude areas, cattails, cactus, and grass grow. Where the spring is short, moss, marigold, and cactus grow. Where the spring is long, grass, cattails, and sage grow. Around Clark City, Washington, spring is short, it rains frequently, and the altitude is high. Which of the above mentioned plants grows there?

Ans: a. moss b. cactus c. cattails d. one of the other plants

Time, Rate, Distance Problems (Choose the correct answer.)

1. A man boarded a bus and after 1/3 of the trip fell asleep. When he awoke he had 1/3 of the distance he had traveled while asleep yet to go. For what part of the total trip did he sleep?

Ans: a. 1/6 b. 1/3 c. 1/2 d. 1/4

2. A man had 4 flights of stairs to walk up. The first and fourth flights were equal (20 steps apiece). The second flight was twice as long as the third, the third being equal to the fourth. When he was 3/4 of the way up all of the steps which flight was he on?

Ans: a. second b. third c. fourth d. he had walked up all of the stairs

3. A man entered a doctor's office, sat down to wait for his appointment, immediately picked up a magazine, and began reading it. Halfway through the total period he had to wait he stopped reading and started talking with an old friend. When he finished his conversation the time remaining to wait was $\frac{1}{4}$ the total time he had talked. What part of the total time that he had to wait did there remain?

Ans: a. 1/5 b. 1/6 c. 1/8 d. 1/10

4. On the third floor of a skyscraper a man entered an elevator to go up to a desired floor. He started talking to a friend after going up $\frac{1}{4}$ of the stories to his destination. When his friend left him he had twice the amount of floors remaining as he had traveled while talking. What part of the total trip did he have remaining?

Ans: a. 1/4 b. 1/2 c. 2/3 d. 3/4

5. A man had to walk 18 miles to his brother's home. After walking 1/3 of the distance he was given a ride 1/6 the distance he had left to travel. If he is met 5 miles from his brother's home how much farther does the man have to walk after his ride is over?

Ans: a. 2 miles b. 3 miles c. 4 miles d. 5 miles

6. A man had to travel 18 miles. He ran for a long distance, and when he finally started to walk he had 1/5 of the distance that he had run left to travel. If this part of the trip took twice as long as the first part, what is the ratio between the rate of running and the rate of walking?

Ans: a. 6 to 1 b. 5 to 1 c. 9 to 1 d. 10 to 1

Sample Answer Sheet

Name______________________________
Date______________________________
Lab Time_____________
Test Form_____________

Circle the correct answer(s).

Logical Reasoning Problems

1. a b c d
2. a b c d
3. a b c d e
4. a b c d e

Complex Thinking Problems

1. a b c d
2. a b c d
3. a b c d
4. a b c d
5. a b c d
6. a b c d

Time, Rate, Distance Problems

1. a b c d
2. a b c d
3. a b c d
4. a b c d
5. a b c d
6. a b c d

APPENDIX B

Individual t Scores on DAT Verbal Reasoning and Space Relations Tests. N = 146.

Subject number	Verbal t score	Spatial t score	Subject number	Verbal t score	Spatial t score
1	70	59	36	57	49
2	69	66	37	57	45
3	69	62	38	57	40
4	69	59	39	57	35
5	68	62	40	56	64
6	67	63	41	56	62
7	67	62	42	56	62
8	67	59	43	56	61
9	65	63	44	56	59
10	65	63	45	56	57
11	65	60	46	56	56
12	65	56	47	56	49
13	65	50	48	56	44
14	64	63	49	55	52
15	64	51	50	55	52
16	63	62	51	55	51
17	63	60	52	55	35
18	63	45	53	54	47
19	62	67	54	54	47
20	62	52	55	54	47
21	61	57	56	54	46
22	61	40	57	53	62
23	60	62	58	53	62
24	60	60	59	53	61
25	60	58	60	53	55
26	60	53	61	53	53
27	60	50	62	53	53
28	58	52	63	53	51
29	58	45	64	53	47
30	57	61	65	53	41
31	57	54	66	53	32
32	57	52	67	53	32
33	57	50	68	51	65
34	57	50	69	51	59
35	57	49	70	51	52

Individual t Scores (Continued)

Subject number	Verbal t score	Spatial t score	Subject number	Verbal t score	Spatial t score
71	51	48	109	44	51
72	51	62	110	44	50
73	51	55	111	44	43
74	51	55	112	42	55
75	51	52	113	42	49
76	51	46	114	42	34
77	51	40	115	42	26
78	51	40	116	41	41
79	51	25	117	40	56
80	49	59	118	40	53
81	49	53	119	40	42
82	49	53	120	40	29
83	49	49	121	39	59
84	49	49	122	39	49
85	49	46	123	39	48
86	49	35	124	39	47
87	48	63	125	39	38
88	48	58	126	37	46
89	48	56	127	37	28
90	48	54	128	37	18
91	48	50	129	36	62
92	48	44	130	36	54
93	48	43	131	36	50
94	48	42	132	36	41
95	48	40	133	36	35
96	47	50	134	35	43
97	47	45	135	34	50
98	47	29	136	34	41
99	46	59	137	34	36
100	46	55	138	33	56
101	46	54	139	33	55
102	46	54	140	33	31
103	46	53	141	30	34
104	46	49	142	29	44
105	46	48	143	28	57
106	46	32	144	28	46
107	44	62	145	27	47
108	44	52	146	27	32

Problem Solving Scores *

Instructed group		Non-instructed group	
Pre-test	Post-test	Pre-test	Post-test
15	17	16	18
17	17	14	14
12	15	16	14
18	17	15	14
15	13	14	14
17	17	17	15
12	14	10	9
16	14	13	11
12	16	12	10
13	14	16	14
8	14	12	12
12	12	14	14
12	14	8	8
14	12	13	14
8	11	6	11
11	14	11	12

* First member of each pair--low in spatial reasoning ability.