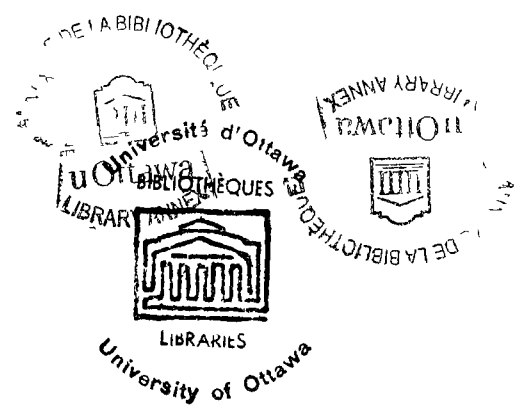


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**TWO SPATIAL FACTORS IN TWO-DIMENSIONAL AND
THREE-DIMENSIONAL SPATIAL APTITUDE**

by Raymond R-S. Molomo

Thesis presented to the School of
Psychology and Education of the
University of Ottawa as partial
fulfillment of the requirements
for the degree of Master of Arts
in Education



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CURRICULUM STUDIORUM

Raymond Rydwell-Sadson Molomo was born on the 9th of January, 1930, in Mochudi, Bechuanaland Protectorate, South Africa. He received the Bachelor of Arts degree in Philosophy from Pius XII College, University of South Africa, Pretoria, in 1956. He received the Graduate University Education Diploma from Fort Hare College, Rhodes University, Grahamstown, in 1960.

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INTRODUCTION

Spatial ability has always been considered to be an important segment of the vast area of aptitudes. Many tests of this ability have been devised for use in education and industry. There are the various paper-and-pencil, apparatus, and psychomotor tests of spatial ability. Surface development, paper-and-pencil, apparatus, form boards, rotated figures, mechanical movements, complex coordination, and paper folding are some of the most familiar spatial tests.

Whether a single unitary spatial ability or several different abilities are essential to describe the process of spatial perception is the question that has arisen persistently. Many researchers have grappled with the perplexing problem of how we orient ourselves geographically and spatially. A person might be considered to be located in a spatial-reference matrix with himself at the origin of the coordinates. As he moves about in space, he uses this matrix to locate objects and points within his spatial environs.

The problem of orientation became more complicated as man took to the air and positions that deviated consistently from the customary vertical occurred as, when in flight, his aircraft ascended, banked, and performed other unusual manoeuvres. Orientation with regard to the self is only one aspect of the spatial problem. We have to deal

often with spatial relationships in which we are not located at the centre, or that are not present and, therefore, have to be imagined or visualized. When we design a structure that is not yet built, or analyse what is wrong with a car engine from its sputterings without opening it up and separating the parts, we visualize the spatial arrangement and movement of the parts relative to one another. We form a visual spatial pattern and exercise our imaginative powers to this unreal and yet useful visual pattern without which we could not have a concept of an architectural or mechanical structure before it existed. Without it, invention would be impossible.

The tactualists held that we obtain our perception of the shape and arrangement of objects in space through the touch sensation and kinaesthesia. For the visualists, our percepts of spatial relations are obtained through sight. The other point of view which could be regarded as integrative or eclectic maintained that each of the senses is capable of space perception and that the senses are all involved in the process of space perception.

The concept of a measurable spatial ability was brought to attention primarily as a result of factor analyses of intellectual abilities. Like the other concepts born of factor analysis, the concept of spatial ability was developed through the inductive approach in which statistical

evidence is the basis of deriving a new psychological concept. Factor analysis has, further, broken down the spatial ability into three specific and almost unitary factors, spatial relations and orientation, spatial visualization, and kinaesthetic imagery. British and American psychologists have tended generally to disagree about the number and significance of the different spatial factors that can be isolated in various graphic tests. The British point of view that there is only one spatial factor seems to be better supported by studies of the spatial abilities of children while the American concept of several spatial factors is borne out to a large extent by studies of adults. It has been established that spatial abilities are not yet fully mature before the age of fifteen years. The extent to which each of the several factors is related to a composite spatial aptitude has not yet been adequately assessed.

This project is concerned with investigating relationships between two-dimensional and three-dimensional spatial aptitude and two spatial factors, spatial relations and orientation, and spatial visualization. Its importance lies in the practical implications that might accrue with respect to the application of spatial tests in prediction of success in industrial occupations and academic pursuit. It is essential that spatial ability should be fully mapped

out and spatial tests thoroughly analysed if they should be employed with success to measure appropriate functions.

The first chapter surveys the literature with emphasis on those aspects which are relevant to the problem. An approximately chronological treatment of factor analyses of spatial tests is handled in this chapter. The experimental design of the study is presented in the second chapter. It covers the presentation of the problem, the formulation of the hypothesis, and descriptions of the sample, the psychometric instruments and the procedures followed in the accumulation of data. The last chapter presents the results, discussion and interpretations of the findings. Areas of research and problems that might call for further investigation have been suggested in the summary and conclusions. The annotated bibliography at the end of this study gives an inkling towards the major sources on which the review of the literature is based. Finally, the appendices present the distributions of the raw scores on the four tests, and the abstract of the thesis.

CHAPTER I

REVIEW OF THE LITERATURE

While this chapter will be devoted to a survey of relevant research in the domain of spatial abilities, it is essential that the problem be announced at once if the review of the literature should be appreciated in the light of the principal concern of this investigation. The problem of this study is to investigate the difference between two-dimensional spatial aptitude and three-dimensional spatial aptitude in terms of the two cognitive factors, spatial relations and orientation, and spatial visualization.

This chapter is divided into five sections. A more or less chronological presentation is followed, though not quite strictly in some cases. Almost exclusively, factor analysis has been the technique used in investigations concerning spatial abilities. The first section deals with earlier factor analyses of spatial tests, the second reviews factor analyses of the Aviation Psychology Programme, the third discusses the directional discrimination and continuum hypotheses, and the fourth summarizes the findings of the Space and Visualization Committee. Uhlaner's study on the differences between two-dimensional and three-dimensional spatial relations abilities was the only one of its nature that the writer came across. In view of its extreme

importance for this investigation, it has been treated as a distinct part of the review of the literature. It constitutes the fifth section.

1. Early Factor Analyses of Spatial Tests.

Angell¹ reporting for the American Psychological Association committee that was set up early in this century for the purpose of recommending tests for practical applications, discussed the then objective tests of mental imagery. He held that tests of geometrical forms such as visualizing what a cube or a geometrical figure would look like if it were cut up in certain specified ways, were peculiarly successful in throwing visual imagery into the foreground and that the tests possessed no significance other than the introspective evidence gained through them. Fernald² attempted to measure imagery but did not find reliable measures for it. She concluded that there were several independent variables determining the quality of imagery, and that the type of imagery used by a subject varies with the character of the test. Her other conclusion was that symbolic

1 J.R. Angell, et al., "Report of the Committee of the American Psychological Association on the Standardization of Procedures in Experimental Tests", in Psychological Monographs, Vol. 13, No. 1, 1910.

2 M.R. Fernald, "The Diagnosis of Mental Imagery", in Psychological Monographs, Vol. 14, 1912, p. 1-69.

imagery, especially verbal, is often effective in meeting the demands of a given form of test. Spelling backwards, memorization of homophones, and memorization of Roman and Arabic numerals were some of the objective tests of imagery that were suggested.

The introduction of the factor analytic technique into the study of the relationships among tests has made it possible to isolate spatial factors in many studies. Spearman³ cited evidence in favour of and against the existence of a group factor connected with spatial relations. In his study of the abilities of man he reported a correlation of .79 between "g" and the relation of space. Spearman states, further, that "in this class of relations, then, we are examining the very basis of a person's stimulation by and reaction to his material environment".⁴

Kelley⁵ reported having found in a number of studies a factor referred to as manipulation of spatial relations which was different from another factor that involved sensing and retention of visual forms. He concluded from his investigations with primary school pupils that there were two

³ C. Spearman, The Abilities of Man, Macmillan and Company Limited, London, 1932.

⁴ Ibid., p. 175.

⁵ T.L. Kelley, Crossroads in the Mind of Man, Stanford University Press, 1928.

spatial factors, one involving a sensing and retention of geometric forms, and another involving manipulation of geometric forms. He indicated that facility with verbal material, manipulation of spatial relationships, and memory are independent categories of mental life from very early age. On the basis of this finding he added:

The manipulation of spatial relationships is clearly a large independent factor entitled to its own psychology. It probably does not play as large a part in school work as do the verbal, arithmetical and memory factors, but it may play even a greater part than these three in adult activity represented by trades and engineering.⁶

Thurstone⁷ included among his seven primary mental abilities a factor that he labelled S, and characterized as "facility in spatial and visual imagery".⁸ He likened this factor to the spatial or visual group factor found by Kelley in an earlier investigation. Following the lead of Brown and Stephenson,⁹ El Koussy¹⁰ set out to investigate the spatial factor by putting together a battery of twenty-eight

6 Kelley, Op. Cit., p. 136.

7 L.L. Thurstone, "Primary Mental Abilities", in Psychometric Monographs, No. 1, Chicago University Press, 1938.

8 Ibid., p. 80.

9 Wm. Brown and Wm. Stephenson, "A Test of the Theory of Two Factors", in the British Journal of Psychology, Vol. 23, 1933, p. 352-370.

10 El A.A. H.Koussy, "An Investigation into the Factors in Tests Involving the Visual Perception of Space", in the British Journal of Psychology, Monograph Supplement, Vol. 7, No. 20, 1935.

variables consisting of eight reference tests, two of Cox's mechanical tests, two so-called scholastic abilities tests and sixteen tests involving visual perception fundamentals of a spatial nature. When "g" was partialled out, eight of the sixteen a priori spatial tests had an average specific correlation of about .25. The specific correlations for the eight tests satisfied the tetrad criterion, indicating that there was in them over and above "g" one group factor. El Koussy called this factor the K factor. His description of K leaves no doubt about its visual-spatial content:

The K factor receives a ready psychological explanation in terms of visual imagery. Observations as well as introspection from adults as well as children show in those tests involving the K factor, it is necessary to obtain, manipulate and utilize visual spatial imagery.¹¹

Wolfle¹² summarized factorial results to 1940 and found that the spatial factor, second to the verbal factor only, was the most frequently identified factor. He stated that it appeared prominently in tests that required the subject to react to spatial relations, to read plans or blueprints, to distinguish or identify similarities between graphical representations of opposite or the same sides of such asymmetrical figures as flags. For him the same factor seemed to be involved in dealing with both

11 El Koussy, Op. Cit.

12 Dael Wolfle, "Factor Analysis to 1940", in the Psychometric Monographs, No. 3, 1940.

two-dimensional and three-dimensional space. This was in agreement with the current view that there are no significant differences between two-dimensional and three-dimensional spatial visualization abilities. The latter was said to be a gradual application of the former ability. Super and Crites¹³ still support this view, with a reservation though:

It may be that in working with two-dimensional objects, one actually works in three dimensions, mentally turning objects around and over, so that there is no real difference between the two types of tests; but this has not yet been demonstrated to be the case.¹⁴

Using Thurstone's centroid method, Harrell¹⁵ analysed the intercorrelations between thirty-seven variables including the Minnesota battery of mechanical ability tests, the seven McQuarrie tests of mechanical ability, O'Connor's Wiggly blocks, and the Stenquist picture-matching test. Among the five factors that he isolated were the spatial and the perceptual, both of which were prominent in the so-called mechanical ability tests. The single significant weight of the spatial factor in the Minnesota form boards was .52.

¹³ D.E. Super and J.O. Crites, Appraising Vocational Fitness, New York, Harper and Brothers, 1962, v-688 p.

¹⁴ Ibid., p. 286.

¹⁵ W. Harrell, "Factor Analysis of Mechanical Ability", in Psychometrika, Vol. 5, No. 1, issue of March, 1940, p. 17-33.

Wittenborn,¹⁶ in his investigations of the nature of the mechanical ability, found that the spatial factor was a principal factor. Twenty per cent of the variance of the Minnesota Spatial Relations test was due to this factor. Thirty-five per cent of the variance of the Paper Form Board test was attributable to the spatial factor. The Assembly test was found to be largely a measure of spatial ability and called for the dexterity factor to a negligible degree. Contrary to its name, the Assembly test calls for the visualization of the relations of parts rather than the ability to excel in the manual process of assembling parts. Wittenborn concluded that the hypothesis that "a high order of spatial ability is necessary for personally gratifying performance in any mechanical operation"¹⁷ may be offered. He hypothesized, further, that persons who are deficient in spatial ability may in general tend to avoid mechanical work or participate with little zeal and consequently neglect the development of many purely manual facilities with which they might have started in life.

It is quite obvious already that spatial ability has occupied a very important position even in factorial studies

16 J.R. Wittenborn, "Mechanical Ability, Its Nature and Measurement 1. Analysis of the Variables Employed in the Preliminary Minnesota Experiment", in Educational and Psychological Measurement, Vol. 5, No. 3, issue of Autumn, 1945, p. 241-260.

17 Ibid., p. 257.

of other aptitudes, in particular the mechanical aptitude and intelligence. It could be mentioned in passing but as an important fact that nearly all the so-called non-verbal tests of intelligence have always been measures of spatial ability in one way or another.

Attention may now be directed towards analyses undertaken by the Army Air Force Psychological Program, now that a fair amount of what earlier research has accomplished has been pointed out and briefly discussed.

2. Factor Analyses of the Aviation Psychology Program.

In a brief description of the factors that were discovered by the Army Air Force psychologists in their endeavour to develop procedures for the selection and classification of aircrew trainees and aviation personnel, Guilford and Zimmerman¹⁸ indicate that factors similar to those that were isolated by Thurstone were discovered. Space 1 was one of the factors that was discovered by the aviation psychologists. Thurstone had defined spatial ability, which he had listed as one of his primaries, as if it were a visualization factor. Guilford and Zimmerman suggest that their space 1, probably in combination with visualization, composes

¹⁸ J.P. Guilford and W.S. Zimmerman, "Some A A F Findings Concerning Aptitude Factors", in Occupations, Vol. 26, No. 2, issue of December 1947, p. 154-159.

Thurstone's S factor. The factors seemed to explain the unexpected correlation between psychomotor and printed tests. Space 1 "seems to be an ability to perceive the spatial order or relationships among objects".¹⁹ In several psychomotor tests, the decision of the subject as to which way to move - right or left, up or down, forward or backwards, depended on a correct appraisal of the visual stimulus arrangement. This ability, probably, outweighed all others in the pilot criterion. It may be a prominent prerequisite in many machine-operating jobs that require decisions as to direction of movement that depends on signals.

On analysis of Thurstone's Hands, and a combination of Flags, Figures, and Cards, Guilford and Zimmerman found a cleavage among these tests. A second factor, space 2, was discovered. It carried with it two tests which, although loaded with space 1, had an additional common variance. Space 3 appeared in one analysis only. As very little is known of it, it is mentioned with reluctance. Visualization was verified in a number of analyses. The tests most heavily saturated with it seemed to involve a visual manipulative ability. It would appear that the ever-present danger of introducing reasoning variance makes it difficult to construct a pure measure of the visualization ability. Many mechanical tests such as mechanical movements and mechanical principles of the Bennett type have loadings

¹⁹ Guilford and Zimmerman, Op. Cit., p. 157.

on it, but also even higher loadings on another factor, mechanical experience. Guilford and Zimmerman express this uncertainty as to the number of spatial factors thus:

(...) it would appear that either there are several factors or, if only one, it is this special manipulative type (...). The inventor of mechanical devices probably depends heavily upon it, but the extent is still to be determined.²⁰

British psychologists have isolated a factor that they called "practical". This factor loads mechanical and spatial tests. In addition to the "g" factor postulated by Spearman, The "practical" factor is needed to account for the common variance when mechanical and spatial tests are included in a battery. Burt²¹ divided the "practical" factor into two sub-factors: mechanical and spatial. He defined the space sub-factor as the ability to perceive, interpret or mentally rearrange objects as spatially related. A further distinction was made between two space sub-factors: a factor for static spatial relations and a factor for kinetic spatial relations. The static-relations factor was subdivided further into the abilities to perceive and visualize objects in two dimensions only, and in three dimensions. Whether or not there are real differences between

20 Guilford and Zimmerman, Op. Cit., p. 157.

21 C. Burt, "The Structure of the Mind: A Review of the Results of Factor Analysis", in the British Journal of Educational Psychology, Vol. 19, 1949, p. 178-199.

the two abilities, as Burt implied, has not yet been conclusively demonstrated.

Several spatial factors were isolated in the Aviation Psychology Program.²² Spatial relations and visualization were the two that were best established. The visualization factor was described as involving visual manipulative ability. In solving the problems that tested for this, it was necessary for the examinee to move, turn, twist, or rotate an object or objects and to recognize a new pattern or position after the prescribed manipulation has been effected. Surface development, mechanical comprehension, paper folding and verbal cubes were the types of test that had loadings on this factor. No certainty of the nature of the spatial-relations factor was established. One speculation was that it represented the ability to determine and understand a systematic relationship between spatial order in the stimulus and spatial order in the response. Tests such as a paper-and-pencil test in which the direction of flight and altitude of an airplane must be determined from a set of instrument dial readings, and a psychomotor test in which a pattern of lights must be matched to another pattern by knowing in which directions to move a stick and rudder exemplify tests that were loaded with this factor.

²² J.P. Guilford, Printed Classification Tests, A A F Report No. 5, Washington, D.C., United States Government Printing Office, 1947, iii-919 p.

The Army Air Force psychologists reported repeated analyses in which two factors were found, one having to do with awareness of appreciation of spatial relations and the other with mental manipulation of objects in space. This was later verified by Thurstone²³ in his study on visual thinking. The third factor was ill-defined and infrequent in the examined studies. In their analysis of the A.A.F. Sheppard Field Battery of thirty-nine experimental printed aptitude tests and seven reference tests taken from the A.A.F. Air Classification Battery, Fructer, Guilford and Zimmerman²⁴ identified two factors as spatial relations and visualization, and visual imagery. Zimmerman²⁵ re-analysed Thurstone's Primary Mental Abilities and designated spatial relations and visualization as two distinct factors. Of greater importance, however, was Thurstone's isolation of three factors²⁶ that he claimed were connected with visual orientation in space. He labelled them S_1 , S_2 , and S_3 . The

23 L.L. Thurstone, Some Primary Abilities in Visual Thinking, Chicago, University of Chicago Psychometric Laboratory Report No. 59, 1950.

24 J.P. Guilford, et al., "Factor Analysis of the A.A. Forces Sheppard Field Battery of Experimental Aptitude Tests", in Psychometrika, Vol. 17, No. 1, issue of March, 1952, p. 45-68.

25 W.S. Zimmerman, "A Revised Orthogonal Rotational Solution for Thurstone's Original Primary Mental Abilities Test Battery", in Psychometrika, Vol. 18, No. 1, issue of March, 1953, p. 77-93.

26 Thurstone, Some Primary Abilities in Visual Thinking, Op. Cit.

first, S_1 , was said to represent the ability to recognize the identity of an object when it is seen from different angles. It is, further, the ability to visualize a rigid configuration when it has been moved into different positions. S_2 represented the ability to imagine the movement or internal displacement among the parts of a configuration that one is thinking about. It was measured by Mechanical Movements and Surface Developments. Obviously, this was the same factor that he had spoken of in 1938. "The space factor is found in tests which require the subject to manipulate an object imaginatively in two or three dimensions."²⁷ S_3 was said to represent the ability to think about those spatial relations in which the body orientation of the observer is an essential part of the problem. Thurstone did not mention specific tests for this factor. He, however, indicated that it was not limited to tests in which there is gross bodily movement in relation to the object or the environment. It was also involved in tasks in which there is hand-and-eye coordination with a moving object, and in tasks in which the subject must locate a point in a coordinate system or in reading instruments. He surmised that kinesthetic imagery might be

²⁷ L.L. Thurstone, "The Perceptual Factor", in Psychometrika, Vol. 3, No. 1, issue of March, 1938, p. 1-17.

involved in S₃. In a later study,²⁸ a fourth factor which Thurstone identified as a kinesthetic imagery factor was isolated. It was measured by the Hands, and the Bolts tests.

Three factors, space, spatial orientation, and visualization were listed by French²⁹ in a compilation and summary of the results of a number of studies. He described the space factor as the ability to perceive spatial patterns accurately and to compare them with each other. It was said to include the perception of two-dimensional as well as three-dimensional space. According to French, the orientation factor seemed to involve a person's ability to remain unconfused by the changing orientations in which a spatial pattern may be presented. The visualization factor was considered to be the ability to comprehend imaginary movements in three-dimensional space, or the ability to manipulate objects in imagination.

To test the validity of two apparently correlated hypotheses that purported to represent the differences in the psychological attributes of the spatial relations

28 L.L. Thurstone, Analysis of Mechanical Aptitude, University of Chicago Psychometric Laboratory Report No. 62, 1951.

29 J.W. French, "The Description of Aptitude and Achievement Tests in Terms of Rotated Factors", in the Psychometric Monographs, No. 5, 1951.

factors, Michael et al.³⁰ used a sample of 360 high school male students, the spatial tests of the Guilford-Zimmerman Aptitude Survey, and the spatial tests of the Thurstone battery. Orthogonal rotation was used. The spatial relations factor was hypothesized to be the ability to comprehend the arrangement of elements within a visual stimulus pattern, primarily with reference to the human body. In Thurstone's Cubes test the subject is asked to recognize whether the designs on the sides of a second cube can hold the same relationship to one another as they do on the first cube. By noticing within each cube the left-right, top-bottom, and front-back interrelationships of the faces, the subject is able in each item to refer the positions of three designs on three exposed faces of one cube to the positions of designs on the faces of the other cube. Guilford and Zimmerman's Spatial Orientation test places a premium on the examinee's ability to maintain the correct relationships of objects to one another in a background scenery that has been viewed twice from a motor-boat, before and after the prow has moved up or down and/or left or right. The subject must ascertain the relative amount of direction of movement of the boat

³⁰ W.B. Michael, et al., "An Investigation of Two Hypotheses Regarding the Nature of the Spatial-Relations and Visualization Factors", in the Educational and Psychological Measurement, Vol. 10, No. 2, Issue of Summer, 1950, p. 187-213.

corresponding to changes in the two views of the background setting.

The factor of visualization was hypothesized to be the ability that requires the mental manipulation of visual images. Unlike the factor identified by some studies as visual memory, which appears to be a static or reproductive form of visualization, visual manipulation is dynamic. This ability appears to be present in the solution of problems in which the examinee must mentally move, rotate, twist, turn or invert one or more objects to comprehend fully the field of spatial relations. He should be able to recognize new positions, location or changed appearances. The spatial relations factor was said to be automatic and the visual factor more deliberate and less automatic. Hence, time should not matter much in the assessment of the latter as it is a measure of power and not of skill. Verbal comprehension, numerical facility, perceptual speed, reasoning, visualization, and spatial relations were the factors that were identified in the orthogonal system.

In a subsequent study³¹ by the same researchers using a high school sample of 151 boys and 139 girls and a battery of fifteen tests and Thurstone's centroid technique,

³¹ W.B. Michael, et al., "An Investigation of the Spatial-Relations and Visualization Factors in Two High School Samples", in the Educational and Psychological Measurement, Vol. 11, No. 4, issue of Winter, 1951, p.561-577.

their previous results were confirmed. For both groups the same six orthogonal factors were identified. This could be regarded as positive evidence for the tenability of the two hypotheses regarding the spatial relations and visualization factors.

Zimmerman,³² in an intensive study of the measurement, isolation, and definition of spatial abilities, sought to answer the following questions:

1. How many spatial factors are there?
2. What is the influence of item difficulty upon the factor composition of a test in this area?
3. Were spatial factors other than those announced by Thurstone measured by some of his 56 tests?
4. What form of test will measure the spatial-visualization factor or factors best?
5. If other factors can be identified in Thurstone's data, from what source will they originate?

He reported ample evidence of two spatial-visualization factors, spatial relations and visualization, and also confirmed that both the spatial relations and the visualization factors were present in Thurstone's original primary mental abilities test battery despite the fact that the first published solution accounted for one of them only.

³² W.S. Zimmerman, The Isolation, Definition, and Measurement of Spatial and Visualization Abilities, unpublished Ph.D. thesis, University of South Carolina, 1949.

He concluded, further, that

Although the spatial factor is yet not clearly defined, some earlier hypotheses can be eliminated on the basis of the findings. Apparently in measuring spatial ability, it is necessary to present problems requiring something more than simply a discrimination of up-down, right-left, or backward-forward movement. It seems to be necessary for the examinee to project himself empathically into a spatial situation and to determine the relationships of external objects relative to his own body (...). The individual must be motivated to empathize instead of placing himself in position remote from the problem where he is more inclined to manipulate the external object visually.³³

From the above citation it would appear that, for Zimmerman, spatial ability involves ability to project oneself psychologically into the spatial stimulus. But this demand on the part of the subject depends on the complexity of the spatial situation, as we shall see later when the continuum hypothesis is discussed.

The Aviation psychologists established the existence of two spatial factors, spatial relations and spatial visualization. The former was said to be automatic while the latter was said to be deliberate and less automatic. In conjunction with these concepts, two hypotheses were postulated.

33 Zimmerman, Op. Cit., p. 192.

3. Directional Discrimination and Continuum Hypotheses.

1) For a while the idea of the space factor being one of directional discrimination had strong appeal for the aviation psychologists. They constructed tests to emphasize this aspect of spatial ability. It was thought that spatial ability did not comprise anything more than the ability to distinguish direction of movement, ability to discriminate between up and down, backward and forward, in and out, left and right.

Degan,³⁴ for instance, influenced by the appeal of the directional discrimination theory of the spatial ability defined it as the facility of discriminatory decision in which the decision relates to the potential direction of movement. He maintained that this ability was a function of the Complex Coordination test, a measure of psychomotor ability. The tests that were constructed based on this hypothesis did not reveal the factor that was isolated by the Air Force Spatial Relations test. The directional discrimination hypothesis has, therefore, been unacceptable insofar as it applied to the Air Force spatial relations factor.

³⁴ J.W. Degan, A Re-Analysis of the A A F Battery of Mechanical Tests, Chicago, University of Chicago Psychometric Laboratory Report No. 58, 1950.

ii) The continuum hypothesis states that space and visualization are differentiated by their relative positions on a continuum of complexity or difficulty. It implies that by varying item complexity or difficulty a single kind of test could be made to emphasize each factor in succession, perceptual speed, spatial relations, visualization, and reasoning. Zimmerman investigated this hypothesis by using different forms at different levels of difficulty of the Visualization of Maneuvers test. He found that the Visualization of Maneuvers test measured visualization optimally at a moderate level of difficulty and that the less difficult items tended to measure perceptual speed.

The results of the analysis supported the hypothesis for the first three factors but not for the fourth. The easier, more speeded form of the test gained by far the highest loading on Perceptual Speed, the test of medium difficulty led the others on Space, although not as convincingly, and the most difficult of the three led the others with a heavy weight in Visualization. Whether an even more difficult form of the same test would sample reasoning could not be inferred from the data.³⁵

These findings were a confirmation of, and even an improvement on, what Zimmerman had found out earlier when he concluded that the continuum hypothesis holds for perceptual speed and visualization only.

³⁵ W.S. Zimmerman, "The Influence of Item Complexity Upon the Factor Composition of a Spatial Visualization Test", in Educational and Psychological Measurement, Vol. 14, No. 1, issue of Spring, 1954, p. 119.

Thus, the only factor continuum that can be readily demonstrated to be due to difficulty variations in the test involves the two factors of perceptual speed and visualization.³⁶

The continuum hypothesis seems, therefore, to be tenable, at least tentatively. Its importance resides in its implications. It suggests that the rigidity versus flexibility, and the involvement of the total configuration, are incidental to and merely functions of the degree of complexity involved. An acceptance of this hypothesis would mean that the difficulty of any item will differ among the subjects, and that the points on the continuum where each factor enters will, therefore, vary among subjects. While one would use the spatial relations factor or ability to solve a problem, another might use the visualization factor. The problem might still be so simple for another that he might use perceptual speed only. Zimmerman points out that:

For distinct separations to be made, the analysis might need to be based on homogeneous populations in which the individuals shift from one factor to another on or near the same points on the difficulty continuum.³⁷

³⁶ Zimmerman, The Isolation, Definition, and Measurement of Spatial and Visualization Abilities, Op. Cit.

³⁷ -----, "Hypotheses Concerning the Nature of the Spatial Factors", in Educational and Psychological Measurement, Vol. 14, No. 2, issue of Summer, 1954, p. 400.

It has been explained that a person encountering a problem in which he can project himself empathically will solve it spatially. If an individual, for instance, is viewing a house whose foundation is oblique and he tends to orient himself by bringing his own body into alignment with the house, he is "spatializing", whereas if he mentally rotates it back into normal position, he is "visualizing". Orientation by spatializing is not possible when objects are too far out of alignment. In such circumstances the viewer will form a mental image, if he is capable of visualizing, and manipulate it. Zimmerman clarifies this point thus:

When only a slight degree of turning or rotation is required for an individual to orient himself with an external object, he is more likely either to move himself or feel himself adjust empathically to the stimulus situation.³⁸

The more automatic response, then, is to spatialize; but when this does not accomplish the desired end, dependence is placed upon the more intellectualized visualization.³⁹

4. Findings of the Space and Visualization Committee.

In 1951, the Educational Testing Service sponsored a seminar at Princeton in which individuals interested in factor analytic methods and their applications took part.

³⁸ Zimmerman, The Isolation, Definition and Measurement of Spatial and Visualization Abilities, Op. Cit., p. 149.

³⁹ -----, "Hypotheses Concerning the Nature of the Spatial Factors", Op. Cit., p. 400.

The Space and Visualization committee was one of the committees that was formed for the purpose of formulating hypotheses concerning the nature of various aptitudes. This committee reviewed the findings of previous investigators in the domain of spatial abilities. Their endeavour was to cite the various factors in the spatial-visualization domain which had been suggested by Thurstone, by the Army Air Force psychologists, and by French, to present an adequate description of the nature of those spatial-visualization abilities which seem to be reasonably established and, finally, to furnish an outline of the similarities and differences in the psychological processes describing what now appear to be better defined abilities of this domain.

Michael, Guilford, et al.⁴⁰ undertook this task and produced a systematic description and presentation of the major studies of the spatial factors. Comprehensive descriptions of the psychological processes characterizing the main factors, spatial relations, visualization, and kinesthetic imagery, were successfully attempted. The descriptions were based on introspection and observation of the conduct of examinees during solution of test problems.

40 W.B. Michael, J.P. Guilford, et al., "The Description of Spatial Visualization Abilities", in Educational and Psychological Measurement, Vol. 17, No. 2, issue of Summer, 1957, p. 185-199.

Comparisons were made so that differences and/or similarities could be pointed out distinctly.

It would seem plausible from what was discovered by the Space and Visualization committee that the general trend has been to isolate two factors, sometimes three although the third factor has always been a dubious one. Although French discovered three factors, the kinesthetic factor was not among them. His first two factors were of the nature of the factor referred to in this study as spatial relations and orientation. Thurstone's S_1 and S_3 are not very different from French's first two factors; hence they too correspond to the spatial relations and orientation factor. Brief descriptions of the factors considered in this study will follow. These descriptions are based on the findings of the Space and Visualization committee and their own descriptions of the factors.

1) Spatial Relations and Orientation.- This factor is said to represent the ability to comprehend the spatial relationships or the arrangement of elements within a visual stimulus pattern with respect to the subject's body as the frame of reference. In a typical test of the factor, as the whole configuration changes position, the elements within the pattern retain their essential relationships to one another. The implication is that global perception of a visual stimulus pattern is accompanied by a recognition

of the relative positions of the elements with respect to their being high or low, farther or nearer than others, or whether a particular element is to the left or right of another. Michael, Guilford and their co-workers have this to say in connection with orientation as a spatial equilibrium, balance or alignment between the subject and object of visual perception:

It does not seem plausible at the present time to think of the perception of the arrangement of the elements in the stimulus pattern without referring to the position of these elements with respect to the location of the examinee. There is the suggestion of component of balance on the part of the examinee, since he is frequently observed to lean in one direction or another, to cock his head, or to move his shoulders in order to 'right' or 'align' himself with the stimulus pattern. This empathic participation of the examinee through manifestation of bodily movements is usually apparent to him when he is asked to introspect about his responses to test items that are considered to be representative of the SR-0 factor.⁴¹

Michael and his co-researchers hypothesized, further, that the difference between spatial relations and visualization is that in the former ability the subject constitutes an origin, a point of reference more or less at the center of the area represented by the visual stimulus pattern. In the latter ability he appreciates spatial arrangements that to him seem to be at some distance "at least as far as his fingertips".⁴²

⁴¹ Michael, Guilford, et al., Op. Cit., p. 190.

⁴² Ibid., p. 190.

ii) Spatial Visualization.- In spatial visualization the examinee appears to be somewhat "detached" from the stimulus pattern and to manipulate parts of the visual pattern imaginatively

(...) as if he were located at a control point that furnishes not only an overall view of the stimulus complex, but also the operational base for effecting the required sequence of movements of certain elements of the pattern.⁴³

The examinee has to rotate, turn, twist or invert one or more objects, or parts, of a configuration in accordance with relatively explicit directions with respect to the nature and organization of manipulations to be effected. To imagine the arrangement, spatial relationships and direction of motion among parts of a machine is an example of the ability referred to as visualization.

iii) Kinesthetic Imagery.- The nature of this factor is still uncertain. It has, however, been tentatively described simply as the ability to distinguish direction of movement in terms of the left and the right hands. The only tests so far known to measure this ability are Thurstone's Bolts and Hands tests. The Space and Visualization committee described this factor as:

43 Michael, Guilford, et al., Op. Cit., p. 191.

(...) a left-right discrimination with respect to the location of the human body, so that the left and right hands seem vicariously or tentatively to move in response to a single visual stimulus.⁴⁴

Spatial ability, as research has shown, is not unitary but multiplex. This discovery is in agreement with the theory of unique traits championed by well-known experts like Hull, Kelley, Thurstone and others. The tenets of this theory are that all variability in human behaviour may be expressed as a function of a limited number of independent, elemental abilities and that these abilities may be discovered and suitable instruments designed to measure them. Three spatial factors have been isolated and fairly adequately identified. They have already been described. This concludes the fourth section of the review of the literature which comprises factor analytic studies in the domain of spatial abilities.

5. Summary of Uhlaner's Study.

Bingham,⁴⁵ Tiffin,⁴⁶ and Greene⁴⁷ are all agreed that the spatial relations aptitude is a very important

44 Michael, Guilford, et al., Op. Cit., p. 192.

45 W.B. Bingham, Aptitude and Aptitude Testing, New York, Harper Brothers, 1947, p. 137 and 172.

46 Joseph Tiffin, Industrial Psychology, New York, Prentice Hall Inc., 1948, p. 57.

47 E.B. Greene, Measurement of Human Behaviour, New York, The Odyssey Press, 1941, p. 343.

aptitude for many types of work such as mechanical and related industrial trades, drafting, engineering, architecture and other related occupations. Job analyses of these occupations reveal that three-dimensional spatial relations aptitude may certainly be as significant a factor as two-dimensional spatial relations aptitude. In other words, workers in these occupations are required to perceive solid objects and to think correctly about their relationships. If the relationship between two-dimensional spatial relations aptitude and three-dimensional spatial relations aptitude is not very high, then, the two-dimensional spatial relations tests used in vocational guidance, personnel selection in industry, and academic prediction are not adequate measures of three-dimensional spatial relations aptitude which seems to be the one more associated with the jobs, vocations or academic training for which considerations are often made.

In response to Super's⁴⁸ statement that "whether there is any fundamental difference between ability to visualize in two dimensions and in three dimensions has not yet been demonstrated"⁴⁹ Uhlaner⁵⁰ endeavoured to investigate

48 D.E. Super, The Dynamics of Vocational Adjustment, New York, Harper Brothers, 1942.

49 J. Uhlaner, Relationship Between Two Dimensional and Three Dimensional Spatial Relations Aptitude, Ph.D. thesis, New York University, 1947, p. 3.

50 Ibid.

the relationship between two-dimensional and three-dimensional spatial relations aptitude and to develop a reliable performance scale based on the principle of the Chinese puzzle. Uhlaner defined two-dimensional spatial relations aptitude as the ability to perceive plane geometric patterns and to think correctly about their relationships, and three-dimensional spatial relations aptitude as the ability to perceive solid objects and to think correctly about their relationships. It would appear that Uhlaner's definition is not complete as it does not include perception and understanding of graphical representations of three-dimensional solids and their relationships. The difference in content between a spatial performance test and a three-dimensional paper-and-pencil spatial test is that in the former the subject deals with the real parts of a visual structure whose totality only can be visualized before, and can be actually seen after the assembly has been completed, and in the latter the process is completely imaginative; that is, the subject visualizes the parts from the graphic representations, from the visualized relationships of the parts in the completed assembly, and from the mental gestalt of the assembled object.

On examination of the existing instruments that purport to measure three-dimensional spatial relations aptitude, Uhlaner was convinced that there were no reliable

measures of this spatial ability. The Spatial Relations Performance Scale⁵¹ was developed by Uhlaner for the purpose of reliably measuring three-dimensional spatial relations aptitude. It consists of a series of blocks each of which consists of a number of similar pieces of wood cut with some wavy or other irregular edges which when fitted together after the fashion of a jigsaw puzzle, form a solid block. The construction of the blocks was based on the principle of the Chinese puzzle. There are six test blocks. The odd number blocks have each four pieces while the other, even number, blocks have each six pieces. Satisfactory test-retest reliability coefficients were obtained for each test block.

Bingham considers the O'Connor Wiggly Blocks test, despite its low reliability, a measure of aptitude for visualizing three-dimensional structures. The rationale of the Spatial Relations Performance Scale is that a test that measures spatial ability through manipulation of dissociated parts of a solid structure to compose the structure measures three-dimensional spatial relations aptitude. This being the principle on which the O'Connor Wiggly Blocks were constructed, this test supports the case for the reliability of the Spatial Relations Performance Scale. It should be,

⁵¹ For a fuller description of this, the reader is referred to Uhlaner's thesis, p. 20-87.

further, supported by the rationale of the Mellenbruch Block Curve Series and the Crawford Structural Visualization tests.

Since the Revised Minnesota Paper Form Board (AA) measures two-dimensional spatial relations aptitude and the Spatial Relations Performance Scale measures three-dimensional spatial relations aptitude, the relationship, as found by Uhlaner and for the subjects he employed, between two-dimensional and three-dimensional spatial relations aptitude was relatively low. A test-retest reliability coefficient of the Spatial Relations Performance Scale for the research population was found to be .80. Uhlaner used the penalty - for-chance attack technique in the administration of his performance scale and discovered that greater variability of the scores was achieved by this method than was obtained by the use of the conventional or standard technique of administration. His results, as already indicated, showed that differences in three-dimensional spatial relations aptitude as measured by the Spatial Relations Performance Scale, and possibly by any other similar instrument, could be detected more readily by means of the penalty-for-chance attack technique than by means of the standard technique of administration in which time is the only variable or criterion for differentiation. Uhlaner concluded:

The relationship between two dimensional spatial relations aptitude and three dimensional spatial relations aptitude was found to be relatively low. In order to investigate this relationship the results of the Revised Minnesota Paper Form Board (Form AA) were compared with the results of the Spatial Relations Performance Scale. This comparison yielded a raw correlation coefficient of .27 which, when corrected for attenuation yielded a correlation coefficient of .32.⁵²

Bingham describes the Revised Minnesota Paper Form Board as able to furnish:

(...) an indication of ability to discriminate geometrical patterns in two dimensions and mentally to manipulate such figures. It measures without the use of apparatus somewhat the same abilities as are sampled by means of the Minnesota Spatial Relations boards and other form boards.⁵³

Uhlaner indicates that he did not use the O'Connor Wiggly Blocks test because of its very low reliability coefficient. Remmers and Sholl⁵⁴ reported a reliability coefficient of .35 for this test. Nevertheless, it is one of the tests that measure the spatial relations aptitude through the manipulation of solids without reference to a form board. It consists of solving a Chinese puzzle, fitting together nine irregular pieces of wood to form a rectangular solid. The speed with which this is done is taken as a

52 Uhlaner, Op. Cit., p. 93.

53 Bingham, Op. Cit., p. 312-313.

54 H.H. Remmers and J.W. Sholl, "Testing the O'Connor Wiggly Block Test", in the Personnel Journal, Vol. 12, No. 3, issue of October 1933, p. 155-159.

measure of ability to visualize structure in three dimensions. The other test that Uhlaner considered was the Reeds Midget Wiggly Block test for measuring mechanical ability. He found it unsuitable, in spite of a high reliability coefficient of .80, because of the inconvenient size of the pieces and the interlocking joint element in it that could introduce other variables than the three-dimensional spatial relations aptitude.

This has been a resumé only and not intended to be a comprehensive report on Uhlaner's unique study. No other studies than Uhlaner's were encountered by the writer that attempted to show that there are no significant differences between two-dimensional and three-dimensional spatial relations aptitude or to prove the contrary in support of Uhlaner. However, the literature abounds in statements that imply a great deal of uncertainty on this issue and solicit research in the general problem. Some of these statements have already been cited, the most significant of which are those by Super and Crites.

In one way or another, this investigation into the interrelationships of two spatial factors with special attention to their roles as components of two-dimensional and three-dimensional spatial aptitude should validate or disprove Uhlaner's conclusions. If spatial relations and orientation, and spatial visualization are components of

both two-dimensional and three-dimensional spatial aptitude, and there are no significant differences between their relationships with these two spatial aptitudes, we could logically infer that there are no significant differences between two-dimensional and three-dimensional spatial relations aptitude, at least in terms of these factors.

CHAPTER II

DESIGN OF THE STUDY

The statement of the problem and formulation of a hypothesis, description of the instruments of measurement and justification of their employment, description of the sample, and description of the procedures followed in the accumulation of data are the four sections composing this chapter.

1. Statement of Problem and Formulation of Hypothesis.

From the review of the literature it would seem abundantly evident that there is no single spatial ability but that there are at least three or more specific abilities in this domain. The interrelationships or interaction of these factors, as far as the writer knows, have not yet been assessed either in terms of their roles as unitary abilities or as components of a composite spatial ability measured by a non-univocal spatial test. Roff, however, has reported a correlation of .75 between two primaries that were identified as orientation, a factor analogous to the spatial relations and orientation factor, and visualization.

Spatial tests have widely been used in educational prediction, vocational counselling, and personnel selection in industry. It would appear that psychometrists in these fields have not yet bothered themselves with the matter of

considering the distinctions between measures of a two-dimensional spatial aptitude and measures of a three-dimensional spatial aptitude and the possible practical implications of such distinctions. The reason for this attitude should be found in the assumption, without demonstration, that the differences between the two aptitudes are negligible and insignificant.

Super and Crites discussing the relationships between the Revised Minnesota Paper Form Board and three-dimensional performance spatial tests indicate that:

No data have been seen concerning relationship between scores on this two-dimensional test of spatial relations and such presumably three-dimensional tests as the Wiggly Block and the Crawford Spatial Relations Test, although it would seem to be very important to ascertain the relationship between ability to judge relationships of two-dimensional objects and ability to think in terms of three-dimensional space. It may be that, in working with two-dimensional objects, one actually works in three dimensions, mentally turning objects around and over, so that there is no real difference between the two types of tests; but this has not yet been demonstrated to be the case.¹

Estes² administered the Revised Minnesota Paper Form Board, Crawford Spatial Relations, Wiggly Block, and American Council on Education Psychological Examination (L and Q)

¹ D.E. Super and J.O. Crites, Appraising Vocational Fitness, New York, Harper and Brothers, 1962, p. 286.

² Stanley Estes, "A Study of Five Tests of Spatial Ability", in the Journal of Psychology, Vol. 13, issue of April 1942, p. 275-271.

to a group of engineering freshmen and factor analysed his data. One common factor was revealed, perhaps, owing partly to the very small number of tests, a definite inadequacy for a factor analytic experimental design. Estes concluded that two- and three-dimensional spatial tests measure the same function using different media.

The implication, if correct, is that two- and three-dimensional tests of spatial judgment measure the same spatial factor, although imperfectly because of the different media. Until further evidence is available, it seems legitimate to conclude that the Revised Minnesota Paper Form Board measures spatial relations, perceptual ability, and inductive reasoning, in that order, and that although it measures spatial judgment by means of two-dimensional media, this ability is the same as that measured by three-dimensional means.³

Thus for Estes there is no difference between the two abilities in question. Very little had been done in factor analysis of the spatial ability when Estes conducted his study. Psychologists were still grappling with the problem of making distinctions between spatial visualization and visual imagery or memory. Hence very little distinction, if not none at all, was made between spatial relations and spatial visualization.

Users of tests like the O'Connor Wiggly Blocks and the Crawford Structural Visualization seldom discriminate between what they measure and what is measured by the paper-and-pencil tests that are often regarded, probably very

³ Estes, Op. Cit., p. 270.

erroneously, as their equivalents. The value of a test has been assessed in terms of its cost and time for administration; not in terms of its actual function. The Space Relations test of the Differential Aptitude Tests is often interchanged with the Revised Minnesota Paper Form Board just because both are paper-and-pencil spatial tests. The test items of the former are geometrical drawings representing three-dimensional solids while the test items of the latter consist of two-dimensional geometrical figures only representing no solids. To go further, it could be asked: Does the Space Relations test of the Differential Aptitude Tests, a three-dimensional paper-and-pencil spatial test, measure the same function as the O'Connor Wiggly Blocks, a three-dimensional performance spatial test? Could the answer that they are only different measures of the same ability be satisfactory? Admittedly, both involve three-dimensional spatial visualization but in the former the subject deals with representations of three-dimensional solids while in the latter the subject deals with real three-dimensional solids, the blocks, so that their relative positions after assembly only are visualized. It would appear that the former involves a visualization of a visualization, a more complex operation. While in the former all the different positions have to be visualized and also the fittings, in the latter one can turn the blocks with one's

hands, compare the actual visible contours, imagine the fitting, and go on like that until the correct solution has been achieved. The writer is inclined to think that Uhlaner had noticed this weakness that is likely to be found with any performance spatial test administered under conventional procedures when he decided to employ the penalty-for-ohance attack technique in scoring his performance scale.

The above are some of the observations and problems that the writer has encountered in the domain of spatial abilities. Michael advises that:

Particular attention should be directed toward ascertaining whether the spatial relations and visualization abilities are correlated. In the three empirical studies undertaken by the writer, the amount of correlation has appeared to be negligible.⁴

The purpose of this study is not to attempt to answer all the questions that have been raised or to solve all the problems that have been encountered. Central in this investigation is the question: Are there significant differences between two-dimensional and three-dimensional spatial abilities? To avoid a meaningless yes or no answer as the final outcome of this study, it has been deemed more appropriate to include the terms of reference or bases of

⁴ W.B. Michael, "The Nature of Space and Visualization Abilities: Some Recent Findings Based on Factor Analysis Studies", in the Transactions of the New York Academy of Sciences, Vol. 11, 1949, p. 275-281.

comparison. Hence, the enlarged question: Are there significant differences between two-dimensional and three-dimensional spatial abilities in terms of the two spatial factors, spatial relations and orientation, and spatial visualization? The kinesthetic imagery factor was excluded because of the unavailability of tests to measure it.

It might be redundant to marshal further justification for a study of this nature in the light of what has already been said. Nevertheless, a very important point of view which substantiates the value of a study like this is expressed by Michael in his declaration that:

Once the spatial domain has been adequately mapped, greater emphasis can be placed upon a program of test development in which relatively pure tests can be constructed to measure the abilities identified.⁵

The main assumptions in this study, therefore, are that two-dimensional spatial relations aptitude is distinct from three-dimensional spatial relations aptitude, and also that the two spatial factors discussed before together compose each of the two spatial aptitudes. The null hypothesis to be tested in this investigation may be formulated thus:

There is no significant difference between two-dimensional spatial aptitude and three-dimensional spatial aptitude in terms of spatial relations and orientation, and spatial visualization.

⁵ Michael, Op. Cit.

Sub-hypotheses could be formulated with respect to the relationships of the two aptitudes considered by themselves and in relation each to each spatial factor but this is omitted for the sake of brevity. Reference to these comparisons and their outcome will be made in the presentation of the results of the investigation.

2. Instruments of Measurement.

From the nature of the hypothesis stated in the preceding paragraph, it should be clear that a study such as this cannot be undertaken without the use of statistical techniques in the final analysis. Accordingly, an appropriate experimental design involving the use of psychometric tools has been adopted. Four measures were required to measure three-dimensional spatial aptitude, two-dimensional spatial aptitude, ability to understand spatial relations and orientation, and ability to visualize spatially. Consequently, the description and justification of the tools employed in this study is four-fold and follows the above enumeration of the functions in a respective order.

1) The Space Relations Test of the DAT.⁶ The fact that it has not yet been resolved whether or not three-

⁶ George K. Bennett, Harold G. Coashore, and Alexander G. Weaman, Manual for the Differential Aptitude Tests, The Psychological Corporation, New York, 1959.

dimensional spatial aptitude differs from two-dimensional spatial aptitude, the central problem of this study, makes it very difficult to tag labels to spatial tests to distinguish them in this regard. Nevertheless, the Space Relations Test of the DAT was found by the writer to be the best available measure of three-dimensional spatial aptitude because of the nature of its items and what it purports to measure.

Its test items are of the type that represent a combination of two previous approaches to assessment of the spatial ability: the ability to visualize from a picture of a pattern a construction or constructed object, a chief aspect of structural visualization tests, and the ability to imagine how an object would appear if rotated in various ways. Obviously, this test should be more highly saturated with the visualization factor than with the spatial relations and orientation factor in spite of its name.

The test consists of forty patterns which can be folded into figures that represent solid structures. For each pattern five figures are shown and the examinee must decide which of the figures can be made from the pattern shown. The most important aspect of the items, as the authors of the test would testify, is the fact that the figures are two-dimensional representations of three-dimensional solid objects.

A feature inherent in these items is that they require mental manipulation of objects in three-dimensional space. Item forms which refer to only two dimensions are less useful, since there are relatively few occasions when perception of two-dimensional space alone is important.⁷

The patterns and other drawings are large and clear. No premium is placed on visual acuity or discrimination. Perception of differences is very easy; the task is concerned principally with judgments of how the objects would look after construction and rotation. A subject's answers are correct if he has the ability to imagine the constructed object and its appearance after rotations. The test is, therefore, designed to measure the ability to manipulate three-dimensional objects mentally, to create a structure. This ability is needed in such fields as drafting, dress-designing, architecture, art, engineering, die-making, solid geometry, decoration, or wherever there is need to visualize objects in three dimensions.

a) The Validity of the Space Relations of the DAT.- Validation studies of the DAT have been stimulated by the authors since 1947. The result has been the yield of "several thousand validity coefficients and some other evidences of validity".⁸ These can be found in the professional

⁷ Bennett, et al., Op. Cit., p. 7.

⁸ Ibid., p. 38.

literature on the DAT and in detail in supplements to the original manual. The researches have embraced prediction of course grades, prediction of achievement tests results and prediction of vocational and educational success based on follow-up studies of students into their post-high school educational and vocational careers. Predictive values of the DAT were obtained by comparing the test scores of persons who were about to begin a new job or a particular type of educational course against criteria such as supervisors' ratings, production records, sales volume, school grades, courses or standardized examinations, or simple division into "pass" or "fail". The coefficient of correlation between test scores and criterion scores constitutes the validity coefficient.

The manual of the DAT indicates the difficulty with which adequate criteria for the Space Relations test are available. It is suggested that tests of this type have a general utility in the prediction of success in engineering and mechanical design.

Although advanced mechanical drawing can be expected to require spatial ability, the beginning courses usually stress motor skills and the learning of symbols to a considerable extent, obscuring the relationship which exists in later stages when greater demands are made on visualization.⁹

⁹ Bennett, et al., Op. Cit., p. 38.

It is, further, pointed out in the manual that the Space Relations test can be quite valuable in specific instances such as prediction of plane geometry and in the results from the American Institute of Specialized Watch Repair who reported a fairly high validity coefficient of .69 using 111 students.

b) The Reliability of the Space Relations of the DAT.- The comprehensive tables in the manual "indicate that the goal of adequate reliability has, in general, been achieved".¹⁰ Split-half correlation coefficients, corrected by the Spearman-Brown formula because the speed factor is of little importance in the DAT have been computed as indexes of reliability. These reliability coefficients were based on data from homogeneous and meaningful groups. The manual reports average reliability coefficients of .93 and .90 for boys and girls respectively. Since correlation coefficients are not to be averaged, the mean correlation coefficients were obtained by converting each correlation to its Fisher's z function, weighting each by its appropriate number of cases, averaging the values and re-converting. High single form internal consistencies and alternate forms consistencies have been reported for populations as high as 1064.

¹⁰ Bennett, et al., Op. Cit., p. 65.

Doppelt and Bennett¹¹ conducted a longitudinal study of the DAT battery using the Mount Vernon, New York, high school pupils from grade 9 to grade 12. Referring to the whole battery they concluded:

The important fact is that this series of tests in eight meaningful areas shows a stable degree of long-term consistency. The counselor whose decisions are based, to some extent, on test scores will be more confident in his judgment when he knows that the tests are measuring relatively stable functions rather than capricious variables.¹²

To reiterate what has already been said when the content of the Space Relations was discussed, additional corroboratory statements by other authors may be cited as more justification for the use of this test in this study. Super and Crites,¹³ in their description of the DAT battery point out that the Space Relations subtest is the most ingenious of them all:

The Space Relations Test (Thurstone's S) is the most ingenious in the series, although embodying familiar principles. These are ability to visualize a constructed object from a pattern (structural visualization in three dimensions), and ability mentally to manipulate a form in order to judge its appearance after rotation in various ways. By combining these two principles in items which require the mental folding of cut or partly shaded patterns a test of spatial visualization has been developed which promises to be superior to any so far developed.¹⁴

11 J.E. Doppelt and G.K. Bennett, "A Longitudinal Study of the Differential Aptitude Tests", in the Educational and Psychological Measurement, Vol. 11, 1951, p. 228-237.

12 Ibid.

13 Super and Crites, Op. Cit., v-688 p.

14 Ibid., p. 541.

The Space Relations test of the DAT has, therefore, been found to be the best measure of three-dimensional spatial aptitude and/or visualization (a number of authors regard spatial visualization as synonymous with three-dimensional spatial ability). It is for these reasons that this test was chosen as one of the tools of this study.

ii) The Revised Minnesota Paper Form Board (Series AA).¹⁵ The original form of the Minnesota Paper Form Board was developed by Paterson et al.¹⁶ and used in the Minnesota Mechanical Ability Project. It was a completion test based on the Geometrical Construction subtest of the Army Beta. Owing to the laboriousness and subjectivity of the scoring of completion items a need arose to convert the Minnesota Paper Form Board into a multiple-choice test. Likert and Quasha undertook this task and produced the revised test that was used in this study.

A series of two dimensional diagrams cut into separate parts constitute the test. There are sixty-four items altogether. Each item is made up of a stem and five possible choices from which the examinee selects an answer.

¹⁵ W.H. Quasha and R. Likert, "The Revised Minnesota Paper Form Board Test", in the Journal of Educational and Psychological Measurement, Vol. 28, 1937, p. 197-204.

¹⁶ D.G. Paterson, R.M. Elliot, et al., Minnesota Mechanical Ability Tests, University of Minnesota Press, Minnesota, Minneapolis, 1930, p. 586.

The stimulus diagram, distinctly situated towards the top of the left corner of the item area, consists of disarranged geometrical figures which can be fitted together to form a geometrical pattern. Five possible fittings are placed towards the right and bottom of the item area. The subject has to choose the one figure which is composed of the exact parts which are shown in the stimulus diagram. While the main problem in each case is to select the figure that corresponds to the assembled parts, sometimes the subject merely pushes the parts mentally together in order to make the appropriate whole and sometimes turns them mentally around or over.

a) The Validity of the Revised Minnesota Paper Form Board (henceforth referred to as the RMPPFB).- Scores on this test have been found to have predictive value for achievement in mechanical fields such as engineering, design and drafting in which spatial perception plays a very significant role.

Of all the tests used in the Minnesota Mechanical Ability Battery, the Minnesota Paper Form Board Test was the only paper and pencil test to give satisfactory correlations with a criterion of mechanical ability.¹⁷

Although this test has been referred to as a measure of concrete non-verbal intelligence, it does measure

¹⁷ Quasha and Likert, Op. Cit., p. 197.

abilities that are relatively independent of intelligence, as usually defined by intelligence tests. The Revised Minnesota Paper Form Board has been demonstrated by many studies to be a measure of two-dimensional spatial aptitude, though an imperfect one like many others. It has been found in three studies by Morris,¹⁸ Murphy,¹⁹ and Estes²⁰ that this test measures also perceptual ability, ability to discover patterns or a rule of procedure (induction), speed of hand and eye-coordination, and visualization or mental manipulation of spatial relations.

These weaknesses cannot be eliminated in this study. It would seem that as long as the continuum theory stands and demarcation points between perceptual speed and spatial relations, between spatial relations and visualization, and between visualization and inductive reasoning have not been ascertained, no spatial test can be thought of that does not involve one, some or even all these factors. Despite the methodological problems pointed out regarding the RMPFB,

18 C.M. Morris, "A Critical Analysis of Certain Performance Tests", in the Journal of Genetic Psychology, Vol. 54, 1939, p. 85-105.

19 L.W. Murphy, "The Relation Between Mechanical Ability Tests and Verbal and Non-Verbal Intelligence Tests", in the Journal of Psychology, Vol. 2, 1936, p. 353-366.

20 S.G. Estes, "A Study of Five Tests of 'Spatial' Ability", in the Journal of Psychology, Vol. 13, 1942, p. 265-275.

it has been demonstrated by Uhlaner²¹ that this test measures two-dimensional spatial aptitude as distinct from three-dimensional spatial aptitude measured by the Space Relations of the DAT or a performance spatial test like Uhlaner's Spatial Relations Performance Scale.²² Four studies have reported significantly low correlations between the RMPFB and five spatial tests that purport to measure three-dimensional spatial aptitude. Uhlaner, as already indicated, found a correlation of .27 between the Revised Minnesota Paper Form Board and his Spatial Relations Performance Scale. Estes²³ found correlations of .26 and .31 between the RMPFB and the Crawford Spatial Relations and the O'Connor Wiggly Blocks respectively. Morrow²⁴ reported a correlation of .33 with the Minnesota Spatial Relations. A still lower correlation was reported by Jacobsen²⁵ between the RMPFB and the Crawford Spatial Relations. These low correlations should be pointers to the negligible relationship

21 Julius Uhlaner, Relationship Between Two Dimensional and Three Dimensional Spatial Relations Aptitude, Ph.D. thesis, New York University, 1947.

22 Ibid.

23 Estes, Op. Cit.

24 R.S. Morrow, "An Analysis of the Relations Among Tests of Musical, Artistic, and Mechanical Abilities", in the Journal of Psychology, Vol. 5, 1938, p. 253-263.

25 E.E. Jacobsen, "An Evaluation of Certain Tests in Predicting Mechanic Learner Achievement", in the Journal of Educational and Psychological Measurement, Vol. 3, 1943.

which this test bears to three-dimensional spatial tests. Bingham refers to it as a measure of "ability to discriminate geometrical patterns in two dimensions and mentally to manipulate such figures".²⁶ He adds that the Revised Minnesota Paper Form Board assesses:

Ability not only to perceive the spatial relations of objects but to think correctly about these relations is obviously an important factor in mechanical aptitude.

Indeed, it is so essential for many kinds of work that numerous blanks and forms have been developed for use in measuring this kind of ability. One of the most convenient of these is the geometrical construction test known as the Minnesota Paper Form Board recently revised by Likert and Quasha (see page 312). This is essentially a test of speed in recognition of forms and space relations.²⁷

Ghiselli²⁸ found a validity coefficient of .57 between the Revised Minnesota Paper Form Board and the job criterion of inspector-packers and concluded that measures of the ability to perceive spatial relations such as is given by the Minnesota Paper Form Board test will be extremely valuable in the prediction of success of inspector-packers of the type considered in his study.

²⁶ W.D. Bingham, Aptitudes and Aptitude Testing, New York, Harper and Brothers, 1937.

²⁷ Ibid.

²⁸ E.E. Ghiselli, "Tests for the Selection of Inspector-Packers", in the Journal of Applied Psychology, Vol. 26, 1942, p. 469-476.

The high validity obtained with the Minnesota Paper Form Board test is extremely interesting. This test has primarily been used by counselors and employment officers as an indicator of mechanical aptitude. However, the results of the present investigation, together with recent findings that scores on the test show fairly good correlations with measures of job success among power sewing machine operators, and can and merchandise packers, indicate that its range of usefulness is not confined to mechanical jobs.²⁹

Jurgensen³⁰ reviewing the test in the Fourth Mental Measurement Year Book indicates that the test has frequently been found to be predictive of academic success in courses such as art, aviation mechanics, dentistry, drafting, engineering and geometry. In another review by Katzell,³¹ it was pointed out that the test has been used extensively and many validity coefficients obtained.

The extensive use of this test over a number of years has produced information on its validity in a variety of educational and vocational situations. Twenty-five studies which include validity data on the test are summarized in the manual. These studies cover the following types of personnel: engineering and technical students, arts students, dental students, mechanics, sewing machine operators, inspectors, factory supervisors, and several other types of factory jobs. The test has shown appreciable validity in most of these areas.³²

29 Ghiselli, Op. Cit., p. 475.

30 Clifford E. Jurgensen, The Fourth Mental Measurement Year Book, New Jersey, The Gryphon Press, 1953, p. 762.

31 R.A. Katzell, The Fourth Mental Measurement Year Book, New Jersey, The Gryphon Press, 1953, p. 763.

32 Ibid., p. 763.

The fact that success in professional engineering curricula as well as in many engineering and mechanical occupations is considered to depend upon the extent to which the persons involved possess ability for perceptual thinking with the spatial aspects of relationships of objects, an ability which is probably a specialized form of abstract thinking, explains the choice of the Revised Minnesota Paper Form Board for use in this study in spite of the validation studies on this test being mostly related to job criteria.

b) The Reliability of the Revised Minnesota Paper Form Board.- An uncorrected reliability coefficient based on the intercorrelation of the two revised forms of the test was reported to be .79. The split-half reliability, corrected, was found by Likert and Quasha to be .92. Ebert and Simmons³³ attempted to establish the reliability by the retest method using children aged ten to fourteen years.

For ten-year olds retested at eleven, the reliability coefficient was .87, at the age of 12, .86; for 12-year olds retested at 13 and 14, the reliability coefficients were .87 and .80 respectively. It can be safely assumed, then, that the reliability is actually in the .80's and sufficiently high for individual diagnosis. The instability of the

33 E. Ebert, and K. Simmons, "The Brush Foundation Study of Child Growth and Development I. Psychometric Tests", in Monograph of Social Research in Child Development, Vol. 2, 1943.

reliability coefficients, as they may be observed to decrease with increase in age, may be explained by the fact that it has been suggested by experts in the field of spatial abilities that although the point where the plateau actually starts has not yet been located, they are not fully developed before the age of sixteen. The studies referred to above were undertaken during the formative years.

It would appear that, despite a large number of studies on or with the Revised Minnesota Paper Form Board, there is a paucity of published reliability data for the Minnesota Paper Form Board test.

iii) The Card Rotations Test.³⁴ This test is one of the many reference tests for cognitive factors that were developed by the different committees established by the Educational Testing Service in 1951. These tests were developed to represent each of the better established factors in the cognitive area.

The tests for each factor were selected so as to be: (...) three in number (...) such as to provide for covering as much of the range from sixth grade through college as possible, (...) as factorially pure as possible for the intended factor, (...) as different as possible to balance out uniqueness, and (...) reasonably easy to administer by paper-and-pencil methods.³⁵

³⁴ J.W. French, Ruth B. Ekstrom, and L.A. Price, Manual for Kit of Reference Tests for Cognitive Factors, Educational Testing Service, Princeton, New Jersey, 1963, p. 40.

³⁵ Ibid., p. 2.

The Card Rotations test answers to these descriptions. It is modelled on Thurstone's Cards test. Each item gives a drawing of a card cut into an irregular shape. Six other drawings of the same card, sometimes merely rotated by different amounts and sometimes turned over to produce an entirely different orientation, are placed to the right of the stimulus card. The task of the examinee is to indicate by marking (+) the cards that show the card rotated either clockwise or anti-clockwise and mark (-) those that represent the card turned over.

a) The Validity of the Card Rotations Test.- The manual for the reference tests for cognitive factors indicates that the tests are distributed for research purposes only and that they should not be used for counseling or other operational purposes. The purpose of the tests is to "provide research workers with a set of tests for defining each of the factors".³⁶ The intention is to facilitate interpretation and the confident comparison of one factor study to another, to eliminate need for cross-identification of factors in studies by means of psychological interpretation alone and, hence, to eliminate this kind of subjective identification. The tests are intended to provide a common ground for the objective comparison of factors.

36 French, Ekstrom, and Price, Op. Cit., p. 1.

The result of this approach has been a complete absence of validation studies of these tests. The Card Rotations test, therefore, has not been validated by means of an external criterion. It should, however, be noted that this test was developed through factor analysis. The fundamental rationale of the concept of validity is provided by the theory of factor analysis. Briefly stated, the rationale of validity is that the communality of a test, which is given by the common-factor variance, accounts for the correlation of that test with others.

The larger the factor loadings in factors that the tests have in common, the larger their inter-correlation. This same equation applies to the correlation of a test with a practical criterion. The criterion measure can also be expressed in terms of factors and factor loadings.³⁷

Most commonly, the degree of validity is indicated by some correlation coefficient. The preceding argumentation is an attempt to point out that although a practical criterion has not been used to establish the validity of the Card Rotations test, its method of development already involves a validation procedure. In other words, this test was found to have significant weights in the spatial orientation factor in common with other tests like the Cube Comparisons Test, and the Spatial Orientation of the

³⁷ J.P. Guilford, Psychometric Methods, New York, McGraw-Hill Book Company, Inc., 1954, p. 356.

Guilford-Zimmerman Aptitude Survey. These clusters are all measures of the spatial relations and orientation factor. It should be justifiable, after these explanations, to infer that what the Card Rotations test measures, its validity, has been established.

b) The Reliability of the Card Rotations Test.- As already indicated no standardization studies have been undertaken to establish the validity and reliability of the reference tests for the cognitive factors. These tests are intended for use in factor analytic research and not in ability assessment and prediction. The manual is, therefore, completely devoid of any information on or about reliability coefficients of the reference tests.

This manual does not provide the usual reliability, norming, validation, or other information ordinarily expected in a test manual. Such information has not been included because these tests are suggested for the single purpose of factorial research.³⁸

A redeeming feature of the tests is that they have been adapted to make proper estimation of test reliability possible. Almost all of the reference tests for cognitive factors have two separately timed parallel parts. The Card Rotations test has two parallel parts and its reliability for this study has been estimated by regarding each part as a separate equivalent of the other. The procedure

³⁸ French, Ekstrom and Price, Op. Cit., p. 2.

employed in the estimation of the reliability of this test for this study shall be described in the next chapter.

iv) The Surface Development Test.³⁹ Like the Card Rotations test, the Surface Development test is one of the reference tests for the cognitive factors developed factor-analytically by the Educational Testing Service. This test has been adapted from Thurstone's Surface Development, a slightly different test going by the same name. Drawings or patterns of solid structures that could be constructed with card board or sheet metal are presented. For every drawing there is a diagram showing how the material might be cut and folded in order to make the complete three-dimensional solid form. Dotted lines show where the material is folded. One part of the diagram is marked with a cross to correspond to a surface in the drawing marked in the same way. The task of the examinee is to indicate which lettered edges in the drawing correspond to numbered edges or dotted lines in the diagram.

a) The Validity of the Surface Development Test.- What was said previously about the validity of the Card Rotations test applies to this test. It, too, was developed through factor analysis and has been used in factor-analytic studies. It has been found to have a significant weight in

39 French, Ekstrom and Price, Op. Cit., p. 48.

spatial visualization in common with the Paper Folding test, and the Form Board test.

b) The Reliability of the Surface Development Test.-

This test consists of two separately timed equivalent parts which may be used to estimate its reliability. The procedure used in the estimation of this reliability shall be described in the next chapter.

This concludes the second section of this chapter, description and justification of the tools of measurement employed in this study. The description of the sample used in this investigation constitutes the third section and the next task.

3. Description of the Sample.

a) Age.- In view of the trend that spatial abilities are not fully mature before the age of fifteen years, the writer elected to use an older sample in which developmental variations with regard to spatial abilities would be eliminated as much as possible. The population used in this study had an average age of seventeen years and fell within the range of $15\frac{1}{6}$ years and $18\frac{5}{6}$ years.

b) Grade.- Three groups of Grade XII boys of St. Patrick's High School in Ottawa were used as subjects for this study. The average size of the groups was thirty-nine boys. Grade XII was deemed the best academic level for

these tests as the standardization procedures of some of the tests had been based on Grade XII populations. Furthermore, the reference tests for the cognitive factors used in this study could have perhaps been a little too difficult for a lower grade and a little too easy for a higher grade. Still, a group from a lower grade level could perhaps not have qualified for use as subjects in this study as the average age could easily have been lower than fifteen years. The importance of age level has already been discussed.

c) Intelligence.- The guidance department of the school had already administered the Henmon-Nelson Test of Mental Ability (Revised Edition Grades 9 - 12) to the three groups when they were in Grade XI in 1963. Their average I.Q. on this test was 108. The average I.Q. of this group on the Otis Group Intelligence Scale administered in February 1964, was 110. The I.Q. ranges were very small thus evidencing a fair degree of homogeneity in this group with respect to intelligence.

d) Language.- All the individuals in this sample were either English-speaking only or bilingual, speaking English and French or English and another European language. This had to be ascertained to ensure that all the examinees would understand the instructions fully. The counseling and guidance department of the high school and also class teachers of these groups confirmed the linguistic

characteristics of this sample as given by the students themselves.

4. Accumulation of Data.

The sample described in the preceding section of this chapter had taken tests before so that the testing situation was not a novelty to them. The guidance and counseling department of St. Patrick's High School administers a battery of tests every year to all the students to appraise their different abilities and aptitudes. This is usually done during an appropriate period that has been earmarked for guidance and testing. The testing program for this study had to be fitted into the guidance schedule of the school to avoid a disruption of the school time-table and also to avoid creation of an atmosphere that would be different from the one already established by the guidance program. In the opinion of the writer the guidance program had already established the necessary climate, rapport, and the necessary attitudes, on the part of the students, towards psychological testing.

An elaborate explanation of the purposes and usefulness of the testing program to the students could have interfered with the motivation that had already taken effect. All the testing was done ostensibly as part of the testing program. The writer, who administered most of

the tests, was introduced to the students as an assistant of the guidance master. Care was taken to avoid arousal of curiosity and sensation that might have had adverse effects on the performance of the students on the tests. To make the sessions as ordinary as possible the writer acted as proctor occasionally while the guidance master was the chief administrator. This approach ensured interest in the testing program. No incidents of a lackadaisical attitude were observed during the testing process.

All the testing was done in the guidance lecture room which was commodious enough to seat forty individuals in one session. The room was adequately lighted and ventilated. It was devoid of all possible sources of visual distraction such as pictures on the walls and the like. The columns were three feet while the rows were about two feet apart. A large time-piece was hung on the front wall where it could be seen by everybody during the administration of the tests for the cognitive factors. The room is situated on the far end of one wing of the school so that it is detached from the usual school bustle that is likely to be found near the central rooms. In a nutshell, this room had been selected by the guidance department for the purpose of using it permanently as a guidance and testing room.

The testing procedures followed the protocol suggested by Super and Crites⁴⁰ and there is no reason to suspect that errors which could add some unwanted variance to the scores occurred during the process of administration of the tests. Descriptions of how each test was given will now follow.

a) Administration of the RMPFB (Form AA).--

i) Procedure.- This test was administered to the three groups separately. The procedure was that laid down in the manual⁴¹ and also on the first page of the test booklet. The directions were read as articulately and audibly as was suitable for the group and place of administration on each of the three occasions. Time was allowed for the practice problems. As the manual does not indicate that the examinees should be informed of the length of the test, this was not done. However, at the end of twenty minutes, the examinees were instructed to cease working immediately. Strict vigilance against surreptitious continuation after announcement of end of time was maintained for all the groups. Answer sheets were collected immediately on expiration of working time.

40 Super and Crites, Op. Cit., p. 56-68.

41 Likert and Quasha, Op. Cit., p. 4-5.

ii) Scoring.- Scoring was done by hand. The appropriate scoring key supplied with the manual was used. As this test is a multiple-choice test, correction for chance was provided for by the use of the formula, $R - \frac{W}{5}$, which is given in the manual. The accuracy of the scoring procedures was checked by the guidance department of the school.

b) Administration of the Space Relations of the DAT.-

i) Procedure.- This test had already been administered to the three groups by the guidance department of St. Patrick's High School. The guidance master is a qualified school psychologist. The desire to avoid practice effect coupled with the confidence that the writer had in the guidance master made only one more administration of this test adequate for the purpose of estimating reliability by the test-retest technique. This administration was done about two months after the first administration by the guidance department. The protocol laid down in the manual was followed without any modification. The examinees were not told how long the test would take as the manual does not indicate whether or not this should be done. As laid down in the manual the actual test was done in thirty minutes. Invigilation was alert and strict.

ii) Scoring.- The scoring key for the A form was used for hand scoring. The formula suggested in the scoring key, $R - W$, (total of rights minus total of wrongs) was employed to assess the final score on this test.

c) Administration of the Card Rotations and the Surface Development tests.-

i) Procedure.- Since the times for the administration of these two tests are quite short, it was found feasible to have one testing session for both of them. For all the groups, without exception, the Card Rotations test was administered first. Instructions were clearly read and the examinees would not be instructed to begin as long as there were still questions on the instructions. Enough time was given for practice problems. Four minutes were allotted to each of the two parallel parts of the test as stipulated in the manual. The examinees were aware of the time in which the test had to be done and also of the formula used in scoring their answers. This information appears in the instructions that were read to them. It is surmised that the intention is to minimize the tendency to guess and also the possibility of doing very little within the four minutes allowed as a result of ignorance of the amount of the available time and not as a result of inability to do more within this period. The breathing space between the administration of the Card Rotations test and the administration of the Surface Development test had to be short

enough not to allow attenuation of motivation and long enough to avoid the element of fatigue and the resultant decrease of efficiency in performance. Four minutes served the purpose.

The remarks made with respect to the administration of the Card Rotations test apply to the administration of the Surface Development test with the one exception - the latter test was allotted six minutes for each of the two parallel parts. Again the subjects were aware of the strictly limited and short time allowed for the test and also of the warning not to sacrifice accuracy for speed as "Your score on this test will be the number of correct letters minus a fraction of the number of incorrect letters".⁴²

ii) Scoring.- The formula used for scoring the Card Rotations test was the one suggested in the instructions for the administration of the test, $R - W$, (total of rights minus total of wrongs). Immediately conspicuous in the above quotation is the ambiguity of the scoring formula for the Surface Development test. It is not indicated as to how much the "fraction" of the number of incorrect responses that is to be subtracted should be. The problem of deciding on a formula to be used in the scoring of this test was inescapable.

⁴² Surface Development Test, Educational Testing Service, Princeton, N.J., 1952, p. 1.

The matter of the effect of chance on test scores will not be discussed here. Suffice it to say that a multiple-choice test restricts the range of effective measurement by a test. A priori formulae have been derived to correct for chance. The formula used for scoring the Surface Development test is:

$$S = R - \frac{W}{k - 1}$$

where S = formula score

R = number of correct answers

W = number of wrong answers

K = number of alternatives for each item

This formula and others like it rest on the assumption that the examinee either knows the answer or he responds at random.⁴³

Since the Surface Development test has five alternative responses to each item, the above equation becomes

$$S = R - \frac{W}{4}$$

If S came out with a fraction, it was rounded off to the next higher integer in accordance with Lyerly's⁴⁴ recommendation.

43 Guilford, Op. Cit., p. 448.

44 S.B. Lyerly, "A Note on Correcting for Chance Success in Objective Tests", in Psychometrika, Vol. 16, 1951, p. 21-30.

CHAPTER III

PRESENTATION AND DISCUSSION OF RESULTS

This chapter comprises presentation, interpretation, and discussion of the findings of this study. The first section presents the reliability coefficients of the tools of measurement as obtained; the second deals with the correlations between the variables considered in this study; the third presents statistical hypotheses and tests for their acceptance or rejection; and, finally, the last section constitutes discussion of the findings.

1. Reliability of the Tools of Measurement.

The Space Relations of the Differential Aptitude Tests (Form A), the Revised Minnesota Paper Form Board Form AA, the Card Rotations Test, and the Surface Development Test are the psychometric instruments that were used in this study. The reliability of each will be presented as it was found for the sample extracted from the St. Patrick's High School twelfth grade population.

a) The Space Relations of the DAT.- Reliability coefficients, some as high as .93, have already been reported for this test by other researchers. Most of these were split-half coefficients. For this study a test-retest reliability coefficient was obtained by administering the

test twice to one hundred students and finding the product-moment correlation between scores from the first administration and scores from the second. A Pearson r of .88 with a standard error of estimate (henceforth referred to as SE) of .03 was obtained.

b) The Revised Minnesota Paper Form Board (Form AA).-

The odd-even method of splitting was used to compute a split-half reliability coefficient of this test for the sample used in this investigation. As the test items are arranged in order of difficulty, the scores on the odds, generally, were perceptibly higher than the scores on the evens. Differences between these scores were found and Rulon's formula,

$$r_{tt} = 1 - \frac{\sigma_d^2}{\sigma_t^2} \quad \text{where}$$

r_{tt} = coefficient of reliability

σ_d^2 = variance of the differences

σ_t^2 = variance of the whole test

was used. A reliability coefficient of .94 with an SE of .02 was obtained.

c) The Card Rotation Test.- As indicated in the second chapter, this test consists of two separately timed parts which might be regarded as equivalent or parallel. The sum of the scores on the two parts constitutes the final score on the whole test. The differences between the scores

on the two parts were used as above and a reliability coefficient estimated. A value of .89 with an SE of .02 was found.

d) The Surface Development Test.-- Differences between the scores on the two separately timed parts of the test were obtained and reliability estimated by Rulon's formula. A reliability coefficient of .90 with an SE of .02 was found.

On the whole, satisfactory reliability coefficients were obtained. Some of them could have been better considering the fact that some authorities place the minimum at .94. Table I gives a better summary of the reliability coefficients obtained in this investigation and also the number of subjects used for each test.

2. Correlations between Variables.

The purpose of this study is to find out whether or not significant differences exist between two-dimensional and three-dimensional spatial aptitude in terms of spatial relations and orientation, and spatial visualization. The converse, whether or not spatial visualization differs significantly from spatial relations and orientation in terms of two-dimensional and three-dimensional spatial aptitude, is an important corollary, a subsidiary problem that could not be overlooked. Hence, this section will

Table I.-

Summary of Reliability Coefficients Computed from Data Used
in this Investigation.

Test	r_{tt}	SE	Method of Computation	N
Space Relations	.88	.05	Pearson r	100
RMPFB	.94	.02	Rulon's	100
Card Rotations	.89	.02	Rulon's	97
Surface Development	.90	.02	Rulon's	97

present six correlations which will be used in the investigation of significant or non-significant relationships and difference between these four variables. The null hypothesis, $H_0: r_{xy} = 0$, where x and y are the correlated variables was tested at the .01 level of significance in each of the six cases to decide as to whether an obtained correlation was statistically significant or not.

a) Correlation between Space Relations and the Revised Minnesota Paper Form Board (signified as 3D and 2D).-- The scores on the two tests were divided into appropriate class intervals and tallied on a scatter diagram. The chart devised by Lawrence Dayhaw, a professor of the School of Psychology and Education of the University of Ottawa, was used to determine all the correlations computed in this study. Tables IV and V, Appendix 1, show the intervals and frequency distributions of the scores on the two tests respectively. The basic statistics are also shown. The formula used for the computation of the Pearson correlation coefficients between these two tests was:

$$r_{xy} = \frac{N \sum xy - \sum x \sum y}{\sqrt{N \sum x^2 - (\sum x)^2} \sqrt{N \sum y^2 - (\sum y)^2}}$$

where x and y are scores on the Revised Minnesota Paper Form Board (Form AA) and the Space Relations of the DAT respectively. An r of .55 significant at the .01 level was obtained. The above formula was used in all the computations and will not be repeated in the subsequent cases.

b) Correlation between the Revised Minnesota Paper Form Board (Form AA) and the Card Rotations Test.- A procedure similar to the one described in (a) was used. A correlation coefficient of .55 significant at the .01 level of confidence was obtained. Of all the 120 subjects to whom the tests were administered, only 88 had their scores used for the computation of this statistic. Many were eliminated because they had not taken one or more of the tests. Others were disregarded because of improper identification which was essential for the process of correlation of scores. Table VI, Appendix 1, shows the basic statistics and the distribution of scores on the Card Rotations Test. The distribution of the scores of the eighty-eight subjects used for this computation did not differ much from that of the scores of one hundred subjects with respect to the RMPFB test. These scores, therefore, did not warrant inclusion in the appendices. The distribution is similar to that in Table V, Appendix 1.

c) Correlation between the Revised Minnesota Paper Form Board (Form AA) and the Surface Development Test.- The scores of eighty-eight individuals on the RMPFB were correlated with the scores of the same individuals on the Surface Development test. The same procedure used in the previous computations was used. A correlation coefficient of .57 significant at the .01 level of confidence was the yield.

The distributions of the raw scores on the Surface Development test appear in Table VI, Appendix 1.

d) Correlations between Space Relations and Card Rotations.- A correlation coefficient of .44 significant at the .01 level was obtained by using corresponding scores of eighty-eight individuals on the two tests. The precautions observed in the procedures described before apply here as well.

e) Correlation between Space Rotations and Surface Development.- Corresponding scores of eighty-eight individuals on the two tests were used to compute this correlation. A fairly high value of .74 significant at the .01 level of confidence was found. This was the highest correlation obtained in this investigation and thus showed the highest relationship to exist between three-dimensional spatial aptitude and the spatial visualization factor.

f) Correlation between Surface Development and Card Rotations: As finding the interrelationships between the two cognitive factors, spatial relations and orientation, and spatial visualization, is a subsidiary problem in this study, it was necessary to determine the correlation between these two tests. A fairly low correlation of .45 significant at the .01 level of confidence was obtained.

The results have been presented again in Table II to facilitate speedy reference.

Table II.-
Summary of Correlations between Variables.

Variables	r	SE
2D - 3D	.55	.074
2D - SR-0	.55	.074
2D - Vz	.57	.072
3D - SR-0	.44	.086
3D - Vz	.74	.048
Vz - SR-0	.45	.086

These correlations were all significant at the .01 level of confidence.

3. Tests of Hypotheses and Significance.

To investigate the interrelationships of the variables involved in this study and also make comparisons between certain relationships with a view to accepting or rejecting the principal hypothesis six statistical hypotheses were formulated and tested.

i) The correlation between two-dimensional spatial aptitude and the spatial relations and orientation factor does not differ significantly from the correlation between three-dimensional spatial aptitude and the spatial relations and orientation factor.

ii) The correlation between two-dimensional spatial aptitude and the spatial visualization factor does not differ significantly from the correlation between three-dimensional spatial aptitude and the visualization factor.

iii) The correlation between the spatial relations and orientation factor and two-dimensional spatial aptitude does not differ significantly from the correlation between the spatial visualization factor and the two-dimensional spatial aptitude.

iv) The correlation between the spatial relations and orientation factor and three-dimensional spatial aptitude does not differ significantly from the correlation between the spatial visualization factor and three-dimensional spatial aptitude.

v) The correlation between two-dimensional spatial aptitude and the spatial visualization factor does not differ significantly from the correlation between three-dimensional spatial aptitude and the spatial relations and orientation factor.

vi) The correlation between three-dimensional spatial aptitude and the spatial visualization factor does not differ significantly from the correlation between two-dimensional spatial aptitude and the spatial relations and orientation factor.

Hypotheses i and ii were employed to compare two-dimensional spatial aptitude with three-dimensional spatial aptitude using the cognitive factors as criteria. Hypotheses iii and iv were used to compare the cognitive factors using the spatial aptitudes as criteria. Hypotheses v and vi were used to investigate differences between two independent relationships in which a common variable was not involved.

a) Hypothesis 1.- The statistical test used for this hypothesis was the Critical Ratio. The standard error of the difference between $r = .55$ and $r = .44$ was estimated by the use of the formula:

$$\sigma_{dr} = \sqrt{\sigma_{r_{12}}^2 + \sigma_{r_{34}}^2 - 2r_{12} r_{34} \sigma_{r_{12}} \sigma_{r_{34}}}$$

As one variable was common, the spatial relations and orientation factor, the correlation factor in the covariance term had to be estimated by using the formula:

$$\Delta r_{12r_{13}} = r_{23} - \frac{r_{12}r_{13}(1-r_{23}^2 - r_{12}^2 - r_{13}^2 + 2r_{12}r_{13}r_{23})}{2(1-r_{12}^2)(1-r_{13}^2)}$$

The formula for the standard error of the difference then became:

$$\sigma_{dr} = \sqrt{\sigma_{r_{12}}^2 + \sigma_{r_{13}}^2 - 2r_{12}r_{13}\sigma_{r_{12}}\sigma_{r_{13}}}$$

The Critical Ratio was then obtained by dividing the difference between the two correlations by the standard error of the difference. This difference was not significant at the .05 level.

b) Hypothesis ii.- A procedure similar to the one used to test the first hypothesis was followed to find out if $r = .57$ differs significantly from $r = .74$. The common variable in this case was the spatial visualization factor. A fairly high Critical Ratio of 2.40 was obtained.

c) Hypothesis iii.- This hypothesis was tested by ascertaining whether or not the difference between $r = .55$ and $r = .57$ was significant. The obtained Critical Ratio of .23 indicated a high degree of non-significance.

d) Hypothesis iv.- The difference between $r = .44$ and $r = .74$ was tested for significance and a Critical Ratio of 3.52 denoting significance beyond the .01 level was obtained.

e) Hypothesis v.- The correlations compared here do not include a common variable. Hence, the estimation of the standard error of the difference between the two correlations was done without the use of the covariance term in the formula. This might have increased the standard error of the difference and consequently decreased the Critical Ratio unduely. The difference between $r = .57$ and $r = .44$ was not significant at the .05 level.

f) Hypothesis vi.- This hypothesis, like the one immediately preceding it, does not involve a common variable. The covariance term was excluded because the $\sqrt{r_{12}r_{34}}$ factor was not obtained. Hence, the formula used to compute the standard error of the difference between the two correlations was:

$$\sigma_{dr} = \sqrt{\sigma_{r_{12}}^2 + \sigma_{r_{34}}^2}$$

A Critical Ratio of 2.15 was found for the difference between $r = .74$ and $r = .55$. This difference was significant at the .05 level of confidence.

Table III.-

Summary of Results of Tests of Significant Differences
between Correlations.

Variables	r	D	\hat{D}	CR	Level of Significance
2D - SR-0	.55				
3D - SR-0	.44	.11	.084	1.30	-
2D - Vz	.57				
3D - Vz	.74	.17	.079	2.40	.05
2D - SR-0	.55				
2D - Vz	.57	.02	.086	.23	-
3D - SR-0	.44				
3D - Vz	.74	.30	.085	3.52	.01
2D - Vz	.57				
3D - SR-0	.44	.13	.095	1.36	-
2D - SR-0	.55				
3D - SR-0	.74	.19	.088	2.15	.05

4. Discussion and Interpretation.

a) Hypotheses i and ii.- A definite but moderate relationship between two-dimensional spatial aptitude and three-dimensional spatial aptitude was shown by a correlation of .55. To confirm this finding, a hypothesis of independence between the two aptitudes was tested by the chi-square technique yielding a value of 28.10 which was significant beyond the .01 level. This could be accounted for by the compositeness of the spatial aptitude. If spatial aptitude consists of all the three factors described in the first chapter of this study, there will always be this dependence between spatial aptitudes and hence significant correlations between spatial tests.

The test items of both the Space Relations and the Revised Minnesota Paper Form Board tests are arranged in order of difficulty. According to the continuum theory that was discussed in the first chapter, the easiest items could be measuring perceptual speed while the easier ones measure spatial relations and orientation; the difficult ones might be measuring spatial visualization while the most difficult measure inductive reasoning. Possibly, not all these factors along the continuum are involved but this could be determined by a comparative item analysis of the two tests - a prodigious task beyond the scope of this study.

It would appear, therefore, that before comparison between two-dimensional spatial aptitude and three-dimensional spatial aptitude can be made on the bases of the two spatial factors considered in this research, an a priori relationship exists between the two aptitudes and is accounted for by the inherent presence of the very criteria in the tests. It could also be accounted for by the continual overlap of function that, nevertheless, differs from individual to individual.

Spatial visualization was found to correlate more with three-dimensional spatial aptitude than with two-dimensional spatial aptitude. While both the Surface Development and the Space Relations tests deal with three-dimensional materials, their face validity would not suggest a possible duplication of function. That the correlation between two-dimensional spatial aptitude and spatial visualization was significant at the .01 level, although significantly lower than that between the same factor and three-dimensional spatial aptitude, might support Super and Crites' view that in working with three dimensions one actually works progressively with two dimensions. Even if it were so, the writer feels that a piecemeal two-dimensional attack on a three-dimensional spatial problem situation would not produce the same results as a global approach in which the totality of the situation is apprehended simultaneously. It should be

emphasized that a whole is more than a mere summation of its parts. A three-dimensional structure, whether it be a concrete object or its graphical representation on a two-dimensional substratum is much more than a sum of individual solids or geometrical figures. If three-dimensional spatial aptitude were simply a summation of many similar two-dimensional spatial aptitudes, a test of the former would produce the same results as a test of the latter if three times as much time allowed for the latter is provided. Since the Space Relations and the Surface Development tests are not speed tests, it is very improbable that tripling times given for the tests would produce results that would correlate very highly with the results of a two-dimensional spatial test such as the Revised Minnesota Paper Form Board.

The correlation between two-dimensional spatial aptitude, as measured by the Revised Minnesota Paper Form Board, and three-dimensional spatial aptitude, as measured by a performance spatial test, was found by Uhlaner to be .27 - a value much lower than the one obtained in this study. This does not necessarily disprove Uhlaner's findings. The matter of possible differences between a three-dimensional performance test and a three-dimensional paper-and-pencil spatial test has already been dealt with and will not be repeated here. In any case, if these differences do exist, they could account for this disagreement. Still, this

difference might not be statistically significant. No test for this was attempted because at writing, the number of individuals that Uhlaner used, was not available for determining the standard error of his correlation.

It was found in this study that the correlation between three-dimensional spatial aptitude and spatial visualization, as expected, was fairly high, much higher than the correlation between the same cognitive factor and two-dimensional spatial aptitude. The implication of this is that since two-dimensional spatial aptitude is part of three-dimensional spatial aptitude, a three-dimensional spatial test would, in addition to assessing ability to deal with solid objects in space, measure ability to handle two-dimensional problems such as determining the relationships of figures in plane or descriptive geometry. Visualization seems to be the one operation mostly involved in perceiving objects spatially in ordinary day-to-day experience. This ability is, therefore, much more important than spatial relations and orientation and seems to be a sine qua non of spatial perception.

Spatial relations and orientation correlated more with two-dimensional spatial aptitude than with three-dimensional spatial aptitude. Nevertheless, this correlation was not significantly higher. The distribution of the raw scores on the Space Relations and the Revised Minnesota Paper

Form Board were slightly positively skewed. Astonishingly, too, the distribution of the raw scores on the Surface Development test were positively skewed. These tests might have been slightly easy for the average twelfth grade pupil of St. Patrick's High School. This could have made the correlations slightly spurious - one of the reasons why an attempt was not made to correct the correlations for coarse grouping.

From the aforesaid, the first hypothesis has to be accepted while the second is rejected at the .05 level. The implication with regard to the main hypothesis is that it can neither wholly be accepted nor rejected. According to the circumstances of this study, two-dimensional spatial aptitude has been found to differ significantly from three-dimensional spatial aptitude in terms of the spatial visualization factor only, and not in terms of the spatial relations and orientation factor.

b) Hypotheses iii and iv.- The second approach to the problem has been to use the aptitude tests as criteria and the cognitive factors as the objects of comparison. While the comparison here is focussed on the cognitive factors, a subsidiary concern in this study, this provides another angle for investigating the differences between two-dimensional spatial aptitude and three-dimensional spatial aptitude. In fact, as far as the writer is concerned, it

does not matter which pair is used as reference criteria. That is, stating that visualization differs significantly from orientation with respect to the three-dimensional spatial aptitude only but not with respect to the two-dimensional spatial aptitude would not convey any more or less than the converse. The same relationship exists between the two statements as would be found between a mathematical proposition and its converse.

It will be observed that the correlation between spatial visualization and three-dimensional spatial aptitude was significantly higher, at the .01 level, than the correlation between the same spatial aptitude and the spatial relations and orientation factor. This confirms what was noted under hypotheses i and ii. Here again, the third hypothesis has to be accepted while the fourth is rejected at the .01 level. Superficially, this might appear to be a tautology in view of what was postulated in and concluded for the first two hypotheses. A little more careful examination of the thinking involved and also the figures used in Table III might achieve the crucial perspective at this point. As expected, again, there was more agreement of three-dimensional spatial aptitude with spatial visualization than with spatial orientation. The principal hypothesis is, therefore, accepted in terms of the spatial relations and orientation factor and rejected in terms of the spatial visualization factor.

Another striking result was the almost equal correlations between two-dimensional spatial aptitude and spatial relations and orientation and between the same aptitude and spatial visualization. These correlations were .55 and .57 respectively. One would expect two-dimensional spatial aptitude to correlate more with spatial relations and orientation than with spatial visualization in conformity with what has already been observed and discussed. This somewhat irregular result might partly be accounted for by the slightly skewed distributions of the raw scores on the Surface Development and on the Revised Minnesota Paper Form Board tests, as may be observed from Tables V and VII, Appendix 1. This result might mean that a two-dimensional spatial test could be a better predictor of the two factors simultaneously than a three-dimensional spatial test which would emphasize the visualization function at the expense of the spatial relations and orientation factor. Whether or not this would have a practical value would depend on job analyses in terms of these factors, on whether in practical situations both ability factors are used or, in accordance with the continuum hypothesis, visualization is used in the more complex spatial situations, and also on whether the same individual could consciously or unconsciously alternate orientation with visualization in due proportions according to the nature of the spatial

perceptual challenge. It might still, as Super and Crites suggest, depend on whether an individual meagrely endowed with spatial visualization would progressively utilize orientation for three-dimensional problems, or when it is vice versa a lower effort level would be employed to solve orientation problems with the visualization ability. All these possible explanations have not yet been fully explored.

c) Hypotheses v and vi.- The third approach to the problem was to compare the relationships between two-dimensional spatial aptitude and three-dimensional spatial aptitude with the cognitive factors when each is correlated with the other cognitive factor. These comparisons do not involve a common variable. The significance of these tests does not go beyond comparing degrees of relationship. The fifth hypothesis was accepted because the correlation between two-dimensional spatial aptitude and spatial visualization did not differ significantly from the correlation between three-dimensional spatial aptitude and spatial relations and orientation. The last hypothesis was rejected above the .05 level of significance. This demonstrates once more that any comparison that involved a relationship between visualization and three-dimensional spatial aptitude yielded a significant difference.

Three of the six hypotheses have been accepted and the other three have been rejected. The general trend, as

has already been pointed out, has been that the correlation between three-dimensional spatial aptitude and spatial visualization has consistently been significantly higher than any other correlation compared with it. A definitely high relationship between spatial visualization and three-dimensional spatial aptitude is evident. The main hypothesis of no difference between two-dimensional spatial aptitude and three-dimensional spatial aptitude in terms of the two spatial factors has to be accepted in part and rejected in part. In terms of their relationships with spatial visualization two-dimensional spatial aptitude has differed from three-dimensional spatial aptitude.

All the correlations have been significant at the .01 level. Definite but moderate relationships were indicated in most cases. Of great importance are the inter-correlations between the cognitive factors and between the spatial aptitudes. A correlation of .45 between spatial visualization and spatial relations and orientation is a pointer to lack of uniqueness in the reference tests for the cognitive factors. Between the two there could be overlap of function or there could be another factor that explains the fair amount of common variance to the two tests. It is even doubtful whether even semi-complete orthogonality between these factors was achieved in the factor-analytic development procedures by which they were constructed and

classified as fairly univocal. The factors, as measured by the tools used in this study, are not independent, so that whatever spatial test correlates significantly with the one must of necessity correlate with the other. The extent to which each factor loads two-dimensional and three-dimensional spatial tests can be determined through factor analysis.

The correlation between two-dimensional and three-dimensional spatial aptitude was found not to be high enough to warrant substitution of a test of the one function by a test of the other in a counseling or prediction situation. It would appear, however, that a three-dimensional spatial test like the Space Relations of the DAT could be used much more beneficially in a counseling or prediction situation than a two-dimensional spatial test like the Revised Minnesota Paper Form Board.

SUMMARY AND CONCLUSIONS

Three-dimensional spatial aptitude has been found to differ significantly from two-dimensional spatial aptitude in terms of their relationships with spatial visualization. No significant difference was found between them when spatial relations and orientation was used as a criterion. Nevertheless, fairly large differences, in some cases, approaching the .05 level of significance were obtained. It is very probable that they could be significant at least at the .05 level in another sample. Further inquiry into these issues might produce better results.

Many questions have been raised in this study. They have almost all remained unanswered. Only a few are enumerated here.

- i) Does a three-dimensional spatial performance test measure the same function as a three-dimensional paper-and-pencil spatial test?
- ii) What are the interrelationships between perceptual speed, spatial orientation, spatial visualization, and inductive reasoning? Do they really lie on one continuum?
- iii) What part is played by somesthesia and kinaesthesia in spatial perception? Is the kinaesthetic imagery factor real?

- iv) Is three-dimensional spatial aptitude simply a summation of two-dimensional spatial aptitude?
- v) Would a three-dimensional spatial test make a better predictor of satisfactory performance in industry or academic achievement than a two-dimensional spatial test?
- vi) Does chance attack in performance spatial tests introduce error variance?

A great deal of uncertainty still exists in this domain. Not enough research has been done in this field in spite of the indisputable importance of spatial tests in industry, mechanical technology, and academic achievement and prognosis. The writer feels that a good deal is left to be unravelled and a correspondingly large amount of ability is left unassessed because inadequate tools are used to measure spatial aptitude. This is due to the fact that spatial tests have not yet been fully mapped out. Overlap and deficiency are still rampant. Sometimes spatial tests are used to assess mechanical ability or intelligence. This might be done with a measure of success because of concomitance between spatial aptitude and mechanical ability. However, concomitance should not mean determination. Appropriate instruments should produce more meaningful results in terms of the quality and quantity of the aptitude under investigation.

It has been found in this study that three-dimensional spatial aptitude might and might not differ from two-dimensional spatial aptitude depending on the basis of comparison. Spatial visualization did not show high correlation with either two-dimensional spatial aptitude or spatial relations and orientation. Therefore, a three-dimensional paper-and-pencil spatial test might be employed to assess spatial ability in general without maximum benefit but with more accuracy than a two-dimensional spatial test used alone. While this domain is still being explored it might be advisable always to use a three-dimensional spatial test. For more specific assessments, the reference tests for the cognitive factors used in this study should provide the best service.

By combining the test items of a spatial visualization test and the test items of a spatial relations and orientation test according to the appropriate procedures of test construction, a test that could measure both factors simultaneously could be constructed. Such a test could be used to find out whether certain individuals would tend to do the orientation items while others would tend to evade the orientation items to do the visualization items. Whether individuals who score high on an orientation test would select the orientation items in a jumbled test in preference to the visualization items and whether those who score high

on a visualization test would generally choose the visualization items in preference to the orientation items would be an interesting investigation and another approach to the continuum theory of spatial factors.

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APPENDIX 1

DISTRIBUTION OF SCORES

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Table IV.-

Distribution of Scores on the Space Relations
of the Differential Aptitude Tests.

Score	Frequency
90 - 99	4
80 - 89	11
70 - 79	16
60 - 69	13
50 - 59	16
40 - 49	15
30 - 39	5
20 - 29	7
10 - 19	5
0 - 9	6
-10 - -1	2

N = 100
M = 53.10
 σ = 25.20

Table V.-
Distribution of Scores on the Revised Minnesota
Paper Form Board (Form AA).

Score	Frequency
60 - 64	2
55 - 59	5
50 - 54	10
45 - 49	19
40 - 44	19
35 - 39	17
30 - 34	11
25 - 29	10
20 - 24	3
15 - 19	2
10 - 14	1
5 - 9	1

$N = 100$
 $M = 39.90$
 $\sigma = 10.60$

Table VI.-
Distribution of the Scores on the Card Rotation
Test.

Score	Frequency
220 - 239	1
200 - 219	1
180 - 199	3
160 - 179	7
140 - 159	12
120 - 139	21
100 - 119	21
80 - 99	12
60 - 79	8
40 - 59	1
20 - 39	0
0 - 19	1

$N = 88$
 $M = 121.55$
 $\sigma = 36.12$

Table VII.-
Distribution of Scores on the Surface
Development Test.

Score	Frequency
60 - 64	4
55 - 59	10
50 - 54	10
45 - 49	10
40 - 44	11
35 - 39	8
30 - 34	10
25 - 29	7
20 - 24	7
15 - 19	3
10 - 14	3
5 - 9	3
0 - 4	2

$N = 88$
 $M = 38.00$
 $\sigma = 15.33$

APPENDIX 2

ABSTRACT OF

Two Spatial Factors in Two-Dimensional and
Three-Dimensional Spatial Aptitude

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Two Spatial Factors in Two-Dimensional and Three-Dimensional Spatial Aptitude

Three spatial factors: spatial relations and orientation, spatial visualization, and kinaesthetic imagery have been isolated as components of two-dimensional and three-dimensional spatial aptitude. Although many factor-analytic studies of spatial tests have been undertaken, the literature exhibits a dearth of research in the nature of composite spatial aptitude. The tendency has been to assume that two-dimensional spatial aptitude does not differ from three-dimensional spatial aptitude.

This study has concerned itself with determining whether or not two-dimensional spatial aptitude differs significantly from three-dimensional spatial aptitude. Two spatial factors, spatial relations and orientation, and spatial visualization were used as criteria. The Revised Minnesota Paper Form Board (Form AA) was used to measure two-dimensional spatial aptitude, the Space Relations of the Differential Aptitude Tests was used to measure three-dimensional spatial aptitude, the Surface Development Test

1 Raymond R-S. Molomo, master's thesis presented to the School of Psychology and Education, University of Ottawa, Ontario, 1964, ix-105 p.

and the Card Rotations Test, both from the Kit of Reference Tests for Cognitive Factors, were employed to measure spatial visualization, and spatial relations and orientation respectively. The kinaesthetic imagery factor was not included in this study because no instrument was available for its measurement.

Coefficients of correlation between the variables were computed by using the scores of 120 Grade XII boys to whom the four tests were administered. Six statistical hypotheses were formulated and tests for significant differences between correlations applied using the Critical Ratio. Three of the hypotheses were accepted while the other three were rejected. The main hypothesis was correspondingly accepted in part and rejected in part. Two-dimensional spatial aptitude was found to differ significantly from three-dimensional spatial aptitude with respect to the spatial visualization factor which correlated highly with the latter. No significant difference was found with respect to the spatial relations and orientation factor.