CHAPTER THREE

SCIENTIFIC APTITUDE - ABILITIES SELECTED

Scientific Aptitude

What is the basic constitution of a scientific aptitude ? what abilities are to be included under scientific aptitude ? One has to arrive at a convenient and workable list of abilities that might be regarded as proofs of possessing the 'scientific aptitude(by a student.

Conceiving scientific aptitude to be a compound of abilities Zyve developed exercises to measure eleven of those components including (1) ability to suspend judgment (2) to detect fallacies and inconsistencies, (3) to reason logically and originally and to draw correct inductions and deductions. It provides one indication of aptitude for the various branches of engineering, chemistry, physics and biology and other work in which success depends in part upon the ability to profit by training in scientific method.

Questionnaire and Its analysis

The questionnaire is an important instrument in any normative survey research, being used to gather information from widely scattered sources. It was thought worthwhile to prepare a questionnaire as regards the abilities to be included under 'scientific aptitude'. The idea is to arrive at a convenient

and workable list of abilities that might be regarded as proofs of possessing the 'scientific aptitude' by a student.

An analysis of some of the selected abilities comprising a 'scientific aptitude' has been presented with a view to ascertain their opinion. Science teachers are requested to go through the list of abilities presented and tick off the ones with which they agree and add other abilities that they think are important in the space provided. While preparing the questionnaire, the purpose of the questionnaire was made as explicit as possible and unnecessary specification or details were excluded from its purview. It was given to some selected science teachers and lecturers of science department (numbering 120). Personal contacts with the science teachers were also made explaining the purpose of the questionnaire with the hope that it would give them better understanding of the contents of the questionnaire and facilitating its answering. The opinions expressed by teachers and lecturers of science have been analysed. Besides expressing their opinion in favour of the abilities presented, a few more have been suggested, some of which overlapped with the ones presented.

The ability to observe critically has not been included separately as other abilities selected give considerable scope for critical observation. It forms a common denominator since

it is inextricably associated with other abilities.

The ability to infer from an experimental data is found to be a basic ability that should have precedence over other abilities that we come across in a scientific method. The ability to formulate a hypothesis, suggesting means of verifying a hypothesis and to generalise from a given set of hypotheses though not less important depend in the final analysis on the ability to draw correct inferences from an experimental data. Hence its inclusion in the list of selected abilities constituting a 'scientific aptitude'.

As the test items to be constructed under each of these abilities are not to be based on fixed or particular curriculum or course and to free the test items from the stigma of calling them achievement test items, some of the abilities suggested in the questionnaire have not been included. To illustrate the point the abilities suggested like (1) ability to draw diagrams and scientific apparatus and level them, (2) ability to handle and set apparatus, (3) ability to draw neat and accurate diagrams, etc. have been deleted. These could be better tested through an achievement test.

The number of abilities thus far selected has been limited only to seven, lest the inclusion of a few more may unduly lengthen the test battery and the time required for answering the items. Th overstrain caused to the students in turn may bring in the fatigue factor and thus come in the way of achieving the

desired objectives. The test items are constructed carefully under each of these abilities bearing in mind the various principles of test construction. (The questionnaire form is given in Appendix I, Page No. 209)

For the present purpose to understand the relative fitness of a pupil with regard to the possession of certain basic abilities that speak of scientific aptitude, the following seven abilities have been selected. The list of abilities has been arrived at after taking into consideration the opinion of a number of science teachers, lecturers and people interested in Science :

1. Numerical ability
2. Spatial ability
3. Reasoning ability
4. Inter-relationship
5. Mechanical ability
6. Cause and effect relationship
7. Infer from an experimental data

Numerical Ability

The human mind can seldom accept completely abstract ideas. They must be derived from or illustrated by concrete examples. Tangible objects are to be provided which will bring that necessary contact with reality into the symbolic world of mathematics. Mathematics is often regarded as the

bread and butter of science if the butter is omitted the result is indigestion, loss of appetite or both. For proper understanding and grasp of the content matter mathematics is to be used. Science ceases to have any meaning without mathematics in its higher realms. As the queen of sciences, mathematics makes a powerful impact on each and every aspect of science. Actually it is a realm of knowledge entirely by itself and one of considerable scope; the word mathematics stems from a root which means 'learnable knowledge.' Mathematical knowledge is commonly deemed to have a high degree of validity.

It is fair to say that mathematics is the language of science in a deep sense. It is an indispensable medium by which and within which science expresses, formulates, continues and communicates itself.

A prime demand on mathematics is that it be deductively vigorous and a traditional model for intended vigour is Euclid's presentation of mathematical assertions in theorems.[1]

The numerical ability items are designed to test understanding of numerical relationships and facility in handling numerical concepts. The few problems framed in this type could come under 'arithmetic reasoning' when the language elements have been avoided as far as possible. The item

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[1] McGraw Hill Encyclopaedia of Science and Technology. Vol.8, p.176.

computational or manipulative skills have been carefully framed so as to avoid its contamination with reading ability of the pupils.

The numerical ability test is a measure of the student's ability to reason with numbers to understand numerical relationships; to deal intelligently with quantitative materials. It teams with other tests as a measure of general learning ability. Educationally it is important for prediction in such fields as mathematics, physics, chemistry, engineering and other curricula in which quantitative thinking is essential. Numerical ability to different degrees is required in areas specially related to science courses.

The frequency and difficulty of the demands made upon arithmetic in attacking problems in other subjects, suggest that instruction in arithmetic can make important contributions to facilitating the work in those areas. The evidence from many investigations, which have been recently completed, although dealing with limited areas, indicates that there is a large number of arithmetic abilities and number concepts which are so commonly and persistently needed that the student should have them in stock of examples consistently reported.

The pupil at the beginning of his number thinking, handles objects that are concrete in ways that are objective. We guide him in doing this as the means to stimulate and control his thinking. But the way the pupil must think and pay attention is

not at all concrete or objective. The pupil's thinking at the outset gives drive and direction to his later thinking. Each phase of his thinking becomes so intimately and part of succeeding ones that the pupil is equipped to move into a new phase as he approaches it. To illustrate when the pupil can recognise the sequence of numbers having a common difference, he can recognise the number sequence having any other established order.

In the present test, the following items have been included under numerical ability :

i) Identifying the correct number in sequence after a study of a given number series containing fractions, numbers with common difference, common multiples, decimals, cubes, etc.

ii) Expressing fractions in percentages.

iii) Finding out the cube root of a number given its cube value,

iv) Interpolating values from a given data,

v) Reading and interpreting graphs

vi) Substituting numerical values correctly in an equation defining two quantities.

vii) Finding the values of an expression from a given established order of relation.

It is an accomplished fact that there is heavy incidence of mathematical concepts and terms in the study of science. As

such, the numerical ability constitutes one of the basic abilities in the scientific aptitude, and hence there is enough justification for its inclusion in the test battery.

Spatial Ability

Physically space is that property of the universe associated with extension in three mutually perpendicular directions. Space may contain matter but space exists apart from matter. Through usage the term 'space' has come to mean generally outer space or the region beyond earth.

Geophysically space is that portion of the universe beyond the immediate influence of earth and its atmosphere. From the point of view of flight, space is that region in which a vehicle cannot obtain oxygen for its engines or rely upon an atmospheric gas for support (either by buoyancy or by aero-dynamic effects).

Astronomically, space is a part of the space-time continuum by which all events are uniquely located. Biologically, one characteristic of space in the flight sense is that positional acceleration that is comparable to gravitational acceleration. Perceptually space is sensed indirectly by the objects and events within it. Thus a survey of space is more a survey of its contents.

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[1]McGraw-Hill Encyclopaedia of Science and Technology, Vol.12, p.537.

The space relation test represents a combination of two approaches to a measurement of this ability. The ability to visualise a constructed object from a picture of a pattern has been used frequently in tests of structural visualisation.

Similarly the ability to imagine how an object would appear if rotated in various ways has been used effectively in the measurement of space perception.

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 2 dimensional space alone is important. The patterns and drawings are made large and clear, no premium is placed on visual discrimination. Perception of differences is easy, the task is conceived solely with judgments of how the objects would look if constructed or cut, paper models look like when opened, objects assume shapes when rotated about an axis. A subject's answer will be correct if he has the ability to imagine the object and its appearance after rotation about a particular axis.

The space relation test is a measure of ability to deal with concrete materials through visualisation. The ability to manipulate things mentally, to create a structure in one's mind from a plan is what the test is designed to evaluate.

It is an ability needed in science with regard to the rotational aspects of figures in two and three dimensional space. The following aspects of the spatial items have been included in the test :

i) Identifying the correct shape of a paper model when opened;

ii) Identifying the correct line of cutting along which a figure is cut into its two constituent parts;

iii) Locating the correct figure that would form from the superimposition of a figure or pattern over the other;

iv) Identifying the correct shape of a paper left out after the removal of the 4 sectors from the four corners of a square;

v) Identifying the correct shape of a given form of wire that would assume when rotated about its X and Y axes;

vi) Matching the half figuresgiven on one side with the remaining halves given on the other side.

Reasoning Ability

Reasoning is defined as a process of thinking the end terms of which are tested by their logical necessity rather than by their concurrence with observed facts - the process

of solving a problem by means of a concept or general principle."[1]

Reasoning test is a term somewhat loosely applied to mental tests in which the testee is required to draw conclusions from stated conditions or to check the best reason among several presented to explain a statement.

Here the reasoning test is intended as a non-verbal measure of the student's reasoning ability. The matrices and series presented in each item requires the perception of an operating principle in the changing diagrams. In each instance, the student must discover the principle or principles governing the change of figures and give evidence of his understanding by designating the diagrams which should logically follow.

In this type of test items some matrices are used which is understood and defined in the following way :

A matrix is a rectangular array of numbers or other elements of the form[2]

$$A = \begin{matrix} a_{11} & a_{12} & \cdots\cdots & a_{1n} \\ a_{21} & a_{22} & \cdots\cdots & a_{2n} \\ a_{31} & a_{32} & \cdots\cdots & a_{3n} \\ \cdot & \cdot & \cdot\cdot & \cdot \\ a_{m1} & a_{m2} & \cdots\cdots & a_{mn} \end{matrix}$$

[1]Warren, Harward C. Dictionary of Psychology (New York: Houghton Mifflin Company), 1933.

[2]McGraw Hill Encyclopaedia of Science & Technology, Vol.8, p.175.

The above array A is an m by n matrix with m rows and n columns and the size of A is said to be m by n. The rows of a matrix are always numbered from the top down and the columns from left to right. The position of each element in the array is given by its subscripts that is a_{ij} is the element in the i^{th} row and j^{th} column.

Rows and columns are to be studied carefully in a matrix and the correct number or symbol is to be indicated that should logically follow in a sequence. Care was exercised to prevent any visual discrimination factor from contaminating the measurements obtained. The designs and diagrams have been selected so that all drawings are large and clear and the difference between successive diagrams are obvious. Complexity is obtained from increasing conceptional difficulty. The differences are apparent, discerning why the patterns differ, is the intellectual exercise.

Interrelationship

The interrelationship test items are designed to make pupils properly perceive the different relationships between diagrams, situations, concepts, patterns, presented and give evidence of his having perceived and understood the relationship between them by suggesting a figure with similar identical relationship. The test items here are made non-verbal and selected from the analogy type.

In science the ability to inter-relate phenomena, principles, situations is quite important. More formally stated, science is a study of natural environment and a study of problems that pop into children's minds as they live and grow from one day to the next. As the pupils grow and gain knowledge of their environment, their perception deepens about the things they see and observe. Even the scientific method involves a proper study of the data and facts in all its relations and aspects before arriving at a tentative hypothesis. That being so, the ability to interrelate a given situation, things one observes becomes a pre-requisite to a student of science before drawing conclusions.

In the analogy type of items included, the pupils are to study carefully the relationship between the first two given diagrams or figures out of the three given, then they are to suggest a fourth diagram that bears the same relationship with the third as the second bears with the first. The ability to compare and contrast of the things and objects presented is also included in the ability to interrelate.

The analogy type contains two aspects of the item included. One is the observational aspect and the other is the applicational aspect of the item. What the pupil observes and perceives in the first part, he has to apply that knowledge

and understanding of relationship in the latter part of the item. The similarities and dissimilarities observed in the first two figures, patterns or symbols are to be identified in the second two figures, patterns or symbols.

Mechanical Ability

Machine is a combination of rigid or resistant bodies having definite motions and capable of performing useful work. The term mechanism is closely related but applies only to the physical arrangement that provides for the definite motion of the parts of a machine.

Machines vary widely in appearance, function and complexity from the simple hand operated paper punch to the ocean liner which is itself composed of many simple and complex machines. No matter how complicated in appearance, every machine may be broken into smaller and smaller assemblies until an analysis of the operation becomes dependent upon an understanding of a few basic concepts most of which come from elementary physics.

> Machine is an arrangement of moving and stationary mechanical parts used to perform some useful work or to provide transportation. By Means of a machine an applied force is increased, its direction is changed or one form of motion or energy is changed into another form. Thus defined such simple devices as the lever, the pulley, the inclined plane, the screw, the wheel and the axle are called machines. They are classed by engineers as the fundamental

> mechanical powers of which more complicated machines are merely combinations. Of the five, the lever, the pulley and the inclined plane are primary, the wheel, the axle and the screw are secondary.[1]

Machines are designed as a rule by the operations they perform and the complicated devices used for sawing, planing and turning for example are known as sawing machines, planing machines and turning machines respectively and as machine tools collectively.

Cutting Tools. Single or multiple point cutting tools, including broaching tools, milling cutters, honing stones, abrasives and saw blades are common forms of cutting devices. Although varied in configuration, the basic cutting action performed by each is much the same. Some tools remove material in large chips, shavings or large pieces, others such as the saw, honing stone or abrasive grits remove stock by cutting away small particles.

The machines which hold the cutting tools and in some cases the work pieces and furnish the power for cutting, vary greatly in size and configuration. Machines vary from small hand held or grinding devices to large automatic, multi-operation tools. Machining operations commonly performed are turning, facing, boring,milling, sawing,

[1]The Columbia Encyclopaedia (New York: Columbia University Press), 1963, Vol.III, p.1271.

broaching, shaping, plaining, drilling, threading, tapping, the various types of gear cutting, grinding, honing, lapping super finishing, buffing and nibbling. Some of these overlap each other.

The various machining operation that employ cutting tools use either a rotating or a traversing motion. During some machining operations the work-piece moves, in others only the cutting tool moves.

Basically in any machining operation in which a cutting tool is used one or more relative motions between the work piece and the cutting device are essential.

The most common example of a machine element is a 'gear' which fundamentally is a combination of the wheel and the lever to form a toothed wheel. The rotation of this gear on a hub or shaft drives other gears which may rotate faster or slower depending on the number of teeth on the basic wheels. The material from which the gear is made establishes its strength and hardness of its surface determines its resistance to wear. Knowledge of the forces on the gear makes possible the determination of its size. Changes in its shape allow modification in its use.

Mechanical ability is the proficiency in manipulating formboards, various devices, work samples, understanding the processes and techniques in simple machines. Tests of mechanical

ability often include measures of speed of work, accuracy or precision, hand eye coordination, manual dexterity and structural visualisation. It deals with concrete, practical ability to deal with tangible materials such as various articles to be assembled or with tools.

The following aspects of the mechanical ability items are included in the test :

(i) Identifying the cutting tools using either rotating or traversing motion;

(ii) Identifying the direction of rotation of gears when two or more of them operate simultaneously;

(iii) Identifying certain other simple machines based on the learning experiences of pupils.

Cause and effect Relationship

Hobbes defined a cause as the " aggregate of all the accidents both of the agents how many so ever they may be and of the patients, put together which when they are all supposed to be present it cannot be understood but that the effect is produced at the same instant and if any one of them is wanting, it cannot be understood but that the effect is not produced. " The word accident is used here in a technical sense in which it is roughly equivalent to quality.

"Cause effect reveals the relation of uniform co-existence and sequence between phenomena, the feeling of expectation or tendency to anticipate a consequent when an antecedent is given."[1]

Causation is the process of transition or transformation of phenomena, objects, events, etc., when the earlier stages are regarded as the conditions of the later stages that is if in the absence of the earlier phenomena, or their equivalents the later phenomena never occur.

In the sciences, explanations are mostly of the type known as "hypothetico - deductive" according to which observation suggests a generalization or law from which consequences can be deduced. The consequences can then be verified or falsified by controlled experiment or where this is impossible by observation. In the theoretical sciences generalization and laws usually take the form of functional correlations between variables and the idea of efficient cause does not appear. Any set of laws which saves the phenomena is considered legitimate but since a given set of phenomena can be saved by any of an infinite number of alternative sets of laws it is necessary to provide criteria for choosing one set rather than another. The usual criteria are mathematical simplicity (which is largely a matter of

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[1]Howard, C.Warren. Dictionary of Psychology (New York:Houghton Mifflin Company, 1933),p.39.

taste) comprehensiveness and predictive fruitfulness. The concept of efficient cause still appears within the frame work in these sciences which depend largely on qualitative analysis and especially in the practical sciences.

The scientific conception that given stimuli under controlled conditions must inevitably produce standard results is generally accepted by philosophers. Systems vary however in the degree of emphasis that they place on the role of chance in changing a situation.

From a study of the given situation the pupils should be able to give the correct cause of a situation. The logic underlying the causal comparative method was set forth as early as 19th century by John Stuart Mill[1] in his first and third canons of logic. Mill called these canons, the principle of agreement and the principle of double agreement. The first and third canons may be stated as follows :

> If two or more instances of the phenomenon under investigation have only one circumstance in common that circumstance may be regarded as the probable cause (or effect) of the phenomenon. The third canon points out that in order to isolate factors which are probably causes one must find these which are absent when the phenomenon(result) does not occur.

It is not necessary at the present moment to get into the various details of the canons and the logic behind it. Suffice it to say that after a close scrutiny and analysis

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[1]Good,Carter V, Bar,A.S.,Scates,Duglas E. The Methodology of Educational Research (New York: Appleton-Century Crofts), 1936,p.538.

of data, the pupils should be in a position to explain from the list of statements given, the cause and effect relationship in a given situation. Lastly a prediction of the consequences of a given situation would enable students to control the results, thus laying a proper emphasis on the precautionary measures to be adopted.

"Systems vary however in the degree of emphasis that they place on the role of chance in changing a situation. Hume felt that in causal relations we have no evidence of any power exerted by the cause on the effect. Kant thought the notion of cause a fundamental category of understanding while others argue a strictly mechanical theory of causality. (The introduction of the principle of indeterminacy into modern physics has necessitated a modification of traditional concepts."[1]

Infer from an Experimental Data

The progress of science is marked not only by an accumulation of facts but by the emergence of the scientific method and of the scientific attitude. The first step included in the scientific method is the gathering of data by the observation of phenomena. By inductive reasoning a hypothesis or preliminary generalisation is inferred from the data. The inference is drawn after a proper analysis and the study of the data gathered.

[1]The Columbia Encyclopaedia (New York: Columbia University Press), 1963, p.364.

Seven steps are recognised and defined as constituting scientific procedure :

a) The location and definition of a problem

b) Survey of the already available data

c) The formulation of a hypothesis

d) The development of the hypothesis

e) The collection of new additional data

f) The analysis, classification and summarisation of data

g) Generalisation.

Before the formulation of a tentative hypothesis one has to carefully survey the available data and infer from that, valid conclusions. The inference of certain valid results precedes the formulation of a hypothesis. Again before the generalisation, the new additional data gathered is analysed and classified and results inferred before the hypothesis is elevated to a law. The validity and reliability of the hypothesis formulated depend upon the results inferred from the collected data.

In the present test, the experimental data or facts are given and the pupil will have to infer correctly from the given statement of facts.
