A STUDY OF COGNITIVE FACTORS WHICH CONTRIBUTE TO COMPETENCE IN THE BIOLOGICAL SCIENCES

by

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A B S T R A C T

The aim of this study was to investigate factors which might contribute to competence in the biological sciences.

Spatial skills are required for all biological studies which involve microscopy; form recognition, ability to recognise objects when their orientation is altered, ability to visualise from 2-D to 3-D, and in a 3-D to 2-D direction. Ability to abstract information from a background which contains irrelevant material is required in microscopy, and also for morphological studies where tissues and organs are embedded in organisms. In all sciences, ability to abstract information, to reorganise it and then use it, is required, i.e. the skill of analysis. The biological sciences differ from the physical sciences in that there are a great number of anomalies at structural, functional and developmental levels. The ability to review a range of similarities and differences, in order to consider possible inter-relationships, would probably be enhanced by the ability to think divergently.

The factors which were chosen were all of a cognitive nature - spatial ability, Field Independence, analytical skills and divergence.

The following tests were constructed.

Test A - Test of ability to visualise a 2-D section taken from a 3-D diagram.

Test B - Test of ability to visualise a 3-D object when given appropriate 2-D sections.

Test C - Test of ability to recognise a shape when its orientation was changed.

Test D - Test of ability to find a number of solutions to a problem using the technique of grouping items into like categories (sets). This was a test for divergence; those who gave the greatest number of responses were

judged to be more divergent than those who gave fewer answers.

Test E - Test of ability to abstract relevant information from a distracting background. This was a dual purpose test, testing for the spatial skill of form recognition, and also for the cognitive style of Field Independence.

Test F - Test of ability to abstract relevant information, to group characteristics which were similar but not identical, and to use it in a new situation. This was a test of analytical ability.

After a trial run, the tests were amended and the following samples were taken.

Primary 4/5 - primary school children aged 8-9 years

Primary 7 - primary school children aged 10-11 years

Secondary 2 - secondary school children aged 13-14 years

Secondary 4 - pupils aged 15-16 studying Scottish 'O' Grade Biology

Secondary 6 - pupils aged 17-18 studying Scottish 'H' Grade Biology or C.S.Y.S. in Biology.

Undergraduate Biology students - in a first year University Class of Biology I - most students were 18-19 years.

Post-graduate biologists made up of teachers, lecturers and research students.

Undergraduate students in the Arts and Divinity Faculties.

Post-graduate non scientists made up of teachers, lecturers, social workers and others.

All tests showed an age related trend, the young children having lower scores than the older pupils; the post-graduates performing better than the undergraduates. The different aspects of spatial ability did not develop at the same rate, the 3-D to 2-D skill taking the longest to develop. Analytical ability was poorly developed at the primary school level. There were more Field Independent individuals in the biology groups than in the non science groups.

Post-graduate biologists showed the following characteristics - they had good spatial ability, good analytical skills, and tended to be Field Independent. The biology students, and the S.6 (17-18 yrs) group also had these skills but to a lesser extent. The results of Test D for divergence were inconclusive so it was not possible to judge whether the biologists were more divergent than other groups.

It might be argued that the study of biology improved the cognitive skills of spatial ability, Field Independence and analysis, but what was more likely was that those who did not have these potential skills were "siphoned off" during their school years. However, these skills would be used, extended and refined in biology courses. Those who did not have the above skills would be likely to select subjects more suited to a different cognitive repertoire, and would not opt for the sciences.

Although the cognitive skills of spatial ability, analysis and Field Independence seemed to contribute success in the biological sciences, they probably play a similar role in the physical sciences.

C O N T E N T S

I N T R O D U C T I O N

The objective of this study was to isolate factors which might be related to ability in the biological sciences.

On the principle that those who were involved in teaching biology were specifically concerned with aptitude in their own subject, it was decided firstly, to review significant changes which had taken place in biology teaching in the last two decades to determine which abilities, skills, and aptitudes a competent biologist was expected to have or to acquire. Secondly, to consult journals in scientific and biological education to establish what investigations had been carried out in these fields and to look at some of the problem areas in the teaching of the biological sciences.

These investigations yielded a number of possible factors which appeared to be related to real or potential ability in biology. A computer search for additional relevent literature was then carried out using the E.R.I.C. (Educational Research Information Center) program.

CHAPTER 1

REVIEW OF LITERATURE

1.1 THE CHANGING PATTERN OF BIOLOGICAL EDUCATION

In the late 1950s, after the initial trials of the Biological Sciences Curriculum study, materials became available on a world wide scale (1). The emphasis in the teaching of biology was on the understanding of concepts, and of unifying themes (2).

The 1960s marked the introduction of discovery learning where importance was given to problem solving, inquiry and the processes of science, and attempts were made to bring about a closer link between methods of teaching and styles of learning (3). During the 1970s problem solving which involved judgements and values emerged (4).

School systems in different parts of the world are at different points along this pathway. The importance of these trends is that they should ensure that biology in schools provides appropriate content and the development of skills relevant to every day living.

1.2 BEHAVIOURAL OBJECTIVES

In recent years abilities and skills have been expressed in terms of behavioural objectives (5). Not only were these used in the biological sciences but in the physical sciences, in integrated science schemes (6), and in primary science (7).

In his evaluation studies of Nuffield 'A' level biology trials, Kelly (8) gave the following student objectives.

1.2.1

(a) Acquiring information, terminology and conventions related to the study of living systems.

(b) Classifying biological data and synthesising them into generalisations and principles.

(c) Making relevant observations and asking relevant questions about them.

(d) Handling quantitative information and assessing the error and degree of significance involved.

(e) Assessing critically hypothetical statements with regard to their origin and application.

(f) Evaluating the implications of biological knowledge for human society.

(g) Analysing observations and/or acquired biological knowledge and utilising them for identifying and solving problems with unfamiliar material.

(h) Making creative contributions to investigatory and problem solving studies.

(i) Recording and communicating adequately and relevantly, both verbally and in writing.

Schaefer (9) in his Teacher's Unit on Biological Equilibrium expressed his objectives in a hierarchical sequence within each category.

1.2.2 Skills A. Cognitive

(a) Ability to observe, i.e. recording without interpreting.
(b) Ability to abstract.
(c) Ability to carry out transfers.
(d) Ability to systematise, i.e. put in order, classify.
(e) Ability to draw logical conclusions.
(f) Ability to relate form and function.
(g) Ability to solve problems, i.e. to recognise a problem, to formulate a hypothesis, to test it and draw conclusions.

1.2.3 Skills B. Cognitive/Pragmatic

(a) Ability to prepare and interpret diagrams.
(b) Ability to organise knowledge and skills in the general context of everyday life.
(c) Ability to verbalise appropriately.
(d) Ability to perform manual operations.

1.2.4 Attitudes

(a) Enjoyment in decision making, i.e. courage to put forward priorities and values.
(b) Readiness for self criticism, i.e. insight into ones own shortcomings.

Meyer (4) in his "Changing Objectives in Science Education" put his objectives related to the biological sciences into broader general categories.

1.2.5 (a) Understanding and appreciating concepts.
(b) Developing skills of problem solving.
(c) Developing affective elements, i.e. scientific attitudes and skills in value clarification.
(d) Developing practical skills including observation and perception.
(e) Developing skills in effective communication.

1.3 CONCEPTS

To achieve an objective such as "understanding and appreciating concepts" it was necessary to identify appropriate concepts and consider how they could be developed. It was hoped that this approach would provide a useful framework within which teaching strategies could be planned. It made teachers examine and clarify their own concepts.

Schaefer (10) defined a concept as an idea, as information about properties, words, objects, events, processes; as a system of classifying information; as an abstract structure characteristic of a certain class, object, event, phenomenon.

According to Schaefer, a concept had a logical core with a certain name. Beyond the name and the core was an associative framework, a spectrum of associations which allowed the concept to be used in different contexts, colouring the concept "with sensory attributes, emotions and other concepts". He believed that the associative framework aided concept development and could lead to transdisciplinary thinking which would enable the learner to transfer easily from one situation to another.

Concepts are established from experiencing a number of examples from which a particular pattern or generalisation is recognised by the process of analysis (differentiation) and synthesis (integration) (11). No learner can be given a concept but he can be given appropriate experiences which will aid concept development (12). Concepts have various dimensions and in their development move from concrete to abstract and from vague to precise.

The Aberdeen studies by Arnold and Simpson (13) (14), showed that many pupils aged 15-16, had difficulties in dealing with anything abstract. It was suggested that concepts would need to be presented in a more meaningful form by the use of diagrams, models and analogies. Problems arose when the concept was not introduced at a level the pupil understood (12), when the teaching material was not arranged in a graduated sequence, when the characteristics of the concept were not emphasised, and when the practical work was not tailored to reinforce the concepts. It was also found that if two concepts or processes were similar to one another, and were taught closely together, then the learning of the one interfered with the learning of the other. Incorrect concepts are difficult to dislodge because they are meaningful to the learner (15). If something does not fit into his concept he will reject it. For example, when building up the concept of a living cell, it must be emphasised that cells are three-dimensional, otherwise the pupil will believe that it is two-dimensional because cells look flat when viewed with a microscope.

Concepts are understood when a learner can distinguish between an example and a non-example, when he can relate concepts to each other to understand a generalisation, when he can use a concept in a new situation, when he can explain observations using the concept, and when he can solve problems using the concept.

Many problem areas in biology such as photosynthesis and osmosis are those in which complex concepts are involved (13) (14) (16). If concepts of cell, gas, energy, enzyme and carbohydrate are misunderstood, then the understanding of the processes of photosynthesis and respiration will be impaired.

One method of investigating concept understanding was carried out by Osborne and Gilbert (17). In their Interview About Instances, cards were shown to students, some of which were examples and some which were not, and the students were asked to explain.

This test is similar to an exercise devised by the writer, used with biology students when discussing concept development. It consisted of 8 cards with 4 different coloured squares of different sizes mounted in different positions on a white card. The students were told whether they were looking at examples or non examples of a "tetraquad". They were then asked to keep on defining a "tetraquad" orally, as the cards were produced in sequence. Although these cards were not designed as a test, they appeared to test ability to analyse and synthesise.

1.4 SPATIAL ABILITY

Spatial ability plays an important role in the biological sciences. Many students have difficulty in seeing the relationship between transverse and longitudinal sections and the three-dimensional structure of tissues, organs and systems (18) (19) (20) (21). Success in other fields may depend on a degree of competence in spatial tasks. Smith (22) cited scientists, mathematicians and technologists as groups requiring spatial ability and the U.S. Employment Service listed, in addition, those in medical, dental and veterinary professions.

El Koussy (23) referred to spatial ability as the 'K' factor first described by Spearman (24) and defined it as "the ability to obtain and the facility to utilise the visual-spatial imagery ... and that it represents a differentiation between an ability to perceive and retain spatial patterns and an ability to switch attention from one item to another when perceived in temporal succession". He believed that spatial ability not only applied to shapes but also to letter sequences and sounds. Lord's definition (25) of his visuo-spatial aptitude was "an ability to form and control a mental image" and this included being able to manipulate the image.

Is spatial ability considered to be a single ability or is it made up of a number of separate components?

Michael et al (26) suggested three main categories.

1.4.1 (a) Spatial-Relations -Orientation

This was the ability to understand the arrangement of objects within a visual pattern using ones own body as a frame of reference so that when objects are moved into a different position they hold the same relationship to one another.

(b) Visualisation

This was the ability to manipulate objects in a sequence of movements and to be able to recognise the new position or changed appearance of the objects which had been moved.

(c) Kinaesthetic Imagery

This was the ability to discriminate between right and left in relation to ones own body.

Smith (21) proposed four components.

1.4.2 (a) A two-dimensional category.

(b) A three-dimensional category.

(c) A static category.

(d) A dynamic category.

Russell-Gebbett in her papers on three-dimensional structures in biology (19) (20), suggested that there were two distinct and separate skills within the three-dimensional field.

1.4.3 (a) Ability to abstract sectional shapes.

(b) Appreciation of the spatial relations of internal parts of the three-dimensional structure seen in different sectional planes.

Piaget (27) considered spatial ability in terms of development and achievement of specific tasks and believed that "the evolution of spatial relations proceeds at two different levels, the perceptual level and the thought or imagination level". His research showed that -

1.4.4 (a) At 6+ years a child could abstract a shape, make a mental image of it, and "internalise" it.

(b) At 7-9 years a child could distinguish between different views of the same thing.

(c) At 10-11 years he could understand geometrical sections. Initially the child was unable to differentiate between the section and the external shape of the object as a whole. This was followed by a gradual differentiation of the sectional surface still combined with other aspects of the figure. Finally the surface section was given exactly.

Doyle (28) repeated some of Piaget's tests and found that many 14 year olds were still at the concrete operational level and had difficulty with sections. He believed that this was because spatial orientated activities were neither structured nor unified. This could explain Lord's findings that students' ability to "bisect mentally" a three-dimensional figure improved with practice. Russell-Gebbett recorded a developmental factor on her tests with 11-14 year olds. She also found a high correlation between spatial ability and general scientific ability. Spatial ability does not seem to depend on cultural differences as Cohen (29) found that American Indians performed as well as other groups on spatial tasks.

Myers (30) put forward the view that "those with good spatial ability would show characteristics seemingly unrelated to that ability". He believed that those who had good spatial ability would reason in a different way, would be able to solve particular types of problems, and would have different interests.

Tests used to determine spatial ability are usually made up of one or more of the following.

1.4.5 (a) Area discrimination.
(b) Form recognition (Hidden figures).
(c) Spatial analogues.
(d) Form equations.
(e) Fitting shapes.
(f) Completion (Filling gaps).

1.5 IMAGINATION, CREATIVITY AND DIVERGENCE

Frequent references were found in the literature to imagination, creativity and divergence as hall marks of competent scientists. Abercrombie (31) stated that "inventiveness or imagination in science depends on the possibility of making new associations of schemata especially those which were not developed in close association and consequently have no conventional or traditional relationships".

Torrance (32) thought of creative thinking as a sensitivity to problems, an ability to produce a variety of ideas, ability to adapt to change, to produce unusual responses, to analyse and synthesise and "to think productively rather than reproductively".

Taylor's (33) definition of creativity is a "process of hypothesis formation, hypothesis testing and communication of results".

Maslow (34) believed that "creativity involves the process of construction and unification of synthesis .... creative individuals have a kind of cognitive flexibility".

Barron (35) maintained that "a creative person is able to tolerate conceptual ambiguity ... and is not made anxious by configural disorder but sees in it a clue to higher synthesis".

According to Roe(36), one important characteristic common to all scientists was "an imperative curiosity, a need to know".

Guilford (37) said that "the most conspicuous creative abilities are to be found in the general category of divergent thinking".

De Bono (38) claimed that "lateral thinking is a part of creative thinking".

What appeared to be common factors in these definitions of creativity was the ability to think scientifically, and that this was aided by being able to think divergently (laterally).

1.5.1 Measurements of creativity in children and adults

Torrance (32) used a Production Improvement Test where children were invited to suggest improvements to a Fire Truck, a Nurse's Kit and Scientific Toys.

In the Mother Hubbard Problem, they were asked what she could have done to avoid her predicament.

In Deviant Animal Stories such as the Flying Monkey and the Green Pig, comments were invited on how the animal should have reacted.

These were scored on the number of responses and on their quality with reference to ingenuity. Torrance used the same tests on adults but to make them more acceptable he asked the adults what a child's response might be.

Some of the criteria used to indicate creativity in adults were -

(a) Correctedness - bringing together already existing pieces of information into a new relationship.
(b) Originality - finding new and unique connections.
(c) Openness - a lack of rigidity, a "permeability of boundaries in concepts, beliefs, perceptions and hypotheses".

Examples of tests include Flanagan's Ingenuity Test (40), problem solving given clues; uses of articles such as bricks or paper clips; Hidden figures, Fables with the last line missing (41); Ask and Guess Test (39) - where a picture was given and the individual was asked what caused the event, and what was the outcome. Other methods used were creativity rating lists given to supervisors and colleagues of scientists.

Some of the tests were used in conjunction with scientific competence as measured by academic records, confidential reports, experience and publications.

Many adult studies gave inconclusive results with low or even negative correlations. As Ghiselin (43) remarked, "Discrimination of the creative from the uncreative and the more creative from the less remains hardly better than guesswork".

1.5.2 Attitudes to creativity (32) (44).

Teachers did not list creativity as being high on their list of objectives. Only 0.9% of primary school teachers and 2.3% of secondary school teachers in the U.S. selected objectives concerned with divergent thinking. School administrators and those in industry who were organisationally orientated were suspicious of creative employees. This may be because creative individuals are independent, dislike being held to a routine and require "incubation periods of seeming inactivity to hatch ideas" which may appear to others as laziness.

1.5.3 Factors which diminish creativity

1.5.3.1 In children (32)

(a) Over emphasis or misplaced emphasis on sex roles.
(b) Divergence being thought of as abnormal, is treated with suspicion. Pupils were rewarded for being convergent.
(c) The Work/Play dichotomy.
(d) Stress of change, e.g. moving schools.
(e) Authoritarian practices by teachers and parents.

1.5.3.2 In adult scientists (36)

(a) Conflict between values at work and home.
(b) Insufficient value attached to problem solving abilities.
(c) Devaluation of ideas by those in authority.
(d) Stifling of independence.
(e) Attitude that convention equals right.
(f) Restriction of curiosity.
(g) Sexual identification.

Although creativity is difficult to define there is no doubt that creative thinkers should be recognised early and that their development should be encouraged as every person has the right to realise his potential.

1.6 LEARNING PROCESSES - STRATEGIES AND STYLES

Within the cognitive domain emphasis has been placed on the processes of science (45) (46), i.e. the ability to think logically, to recognise a problem, to formulate a hypothesis, to test it in an acceptable manner and to draw relevant conclusions.

There was a growing awareness among educators that there was a need for better understanding of how learners learned and whether the learning processes could be improved by using appropriate teaching strategies.

One method of approaching this problem was by the use of Cognitive Preference Tests.

1.6.1 Cognitive Preference Tests (47) (48) (49)

A Cognitive Preference Test is one in which a number of correct statements are given on a familiar topic and learners are asked to rank or rate them in terms of personal preference. The categories from which selection is made are -

R = Recall of information.

P = Acceptance of information on principles or relationships.

Q = Critical questions in relation to completeness, validity and limitations.

A = Application dealing with usefulness and appropriateness of information.

The general conclusions from such studies were -

(1) There was no difference between ranking (ipsative) rating (normative) procedures.

(ii) High achieving students shared a strong preference for Q, a weak preference for P, and dissatisfaction for R.

(iii) Inquiry orientated courses gave higher Q scores than traditional courses which gave higher R scores.

(iv) When teachers were inquiry orientated the students gave higher Q scores.

There have been adverse criticisms of Cognitive Preference Tests. Both Jungwirth (50) and Brown (51) pointed out that these tests showed only what pupils did, not what they were capable of doing, but this is true of all tests. Doubt was expressed as to whether learners should be familiar with the context as choice might be influenced by what had been emphasised by teachers. Certain linguistic characteristics in the statements could influence selection, as could the subject matter itself. Brown maintained that there was no justification for equating differences in cognitive preferences with differences in cognitive styles.

In the search for better understanding of learning strategies and cognitive styles used by successful and unsuccessful learners, many researchers adopted the Piagetian model (52) of stages of development, believing that older pupils and students were at or beyond Piaget's formal stage. However, it was found that many students were operating at a level well below their potential ability because their learning experiences had not forced them to use a formal level (53) (54).

Children and adults varied in the extent to which they used formal operations even when these skills were well established. Entwistle (55) disagreed with the Piagetian model even as a starting point, maintaining that children's level of thinking was not constant and so strategies employed were influenced by the subject matter, the type of task, previous knowledge and interest.

1.6.2 Areas of research in this field can be divided into two major groups, a hierarchical and a non hierarchical group.

1.6.2.1 <u>Hierarchical groups</u>

(a) Kolodiy (53) referred to lower and upper formal stages.
(b) Haley and Good (56) discussed formal levels F1 to F5 At the F1 level the learner was expected to understand concepts, and at the top level of F5 he should be able to recognise functional relationships and apply them.
(c) Douglass and Kahle (57) (58) used Field Dependent and Field Independent in a hierarchical way, stating that students who were Field Dependent were not at the stage of "logical maturity", that they were non analytical and had limited ability to discriminate. Field Independent students were considered to be analytical and could extract relevant items from a distracting background.
(d) Murray (59) adopted the phrase "fully developed cognitive structure" which implied levels or stages. He also used the terms "analytical" and "intuitive". To him, analytical had a different meaning to that used by Douglass, and meant an individual who relied on the use of lower level subordinate concepts. The intuitive individual was one who used a number of interrelated higher super-ordinate concepts. To these categories he added "higher" and "lower" and this resulted in three main groups.

(i) Higher Intuitive/Higher Analytical - those who used higher level concepts but who could also reconstruct lower level concepts when required. Such individuals were at a significant advantage in terms of achievement and learning efficiency.

(ii) High Analytical/Low Intuitive - those who could utilise low level concepts but were inefficient at using inter-related higher concepts.

(iii) Low Analytical/Low Intuitive - those who had problems in using both higher and lower concepts.

(e) Jensen (60) proposed a three tier model of levels of ability. Level I was the level of rote learning, Level II of analytical ability (same meaning as Douglass), and Level III where the learner employed a wide variety of strategies.

1.6.2.2 Non Hierarchical groups

(a) Pask (61) in his investigations used computer linked systems CASTE and the portable version, INTUITION, to examine the variations in learning strategies, and to determine the effects of matching and mismatching teacher/student strategies. The essential part of the equipment was a subject matter representation in a diagrammatic form, showing the relationships among concepts which needed to be grasped before the topic as a whole could be fully understood. To aid the student's understanding, he was provided with materials and practical demonstrations. The student was allowed to explore with a good deal of freedom. Progress through the learning sequence showed up on the computer. Using this system students were forced to make their learning strategies clear. The program was geared so that the strategies were polarised into mutually exclusive groups, holist or serialist.

In this study Pask found concepts which were understood, those for which the learner had given a satisfactory explanation, were stable and were retained. Also when a student adopted one type of approach he was reluctant to give it up even if it proved unsuccessful.

Pask (64) stated that the holist had many goals and working topics under the umbrella of the main study area, and assimilated information from a wide variety of sources - he used a global approach. The serialist worked in a linear fashion only moving from one area to another when he had mastered the one in hand. Holists asked questions about broad relationships and formulated hypotheses about generalisations where as the serialist asked questions about narrow relationships and put forward specific hypotheses.

Pask believed that the differences in styles and strategies could be detected outside the laboratory situation, and that under normal classroom conditions some students would act as holists - the comprehension learners, others would act as serialists adopting an operational style, and some would be able to act in either way, adapting their style to the particular task given - the versatiles. Pask thought that the distinction between the two styles was a matter of degree because in normal learning situations both styles would need to be used. What he implied was that the style indicated the initial approach to a learning task.

(b) Witkin et al (62) (63) also used the terms Field Dependence and Field Independence but in a non hierarchical way. He said, "The FD/FI cognitive style dimension is bipolar with regard to level having no clear high or low ends, and it is neutral with regard to value, each pole having qualities adaptive in particular circumstances". He defined the FD/FI cognitive style as "tendencies to function with greater or lesser autonomy of external referents manifested in both cognitive and social domains".

1.6.3 Cognitive styles - teacher/student matches and mismatches

Pask (64) found that when teaching strategies were matched to student strategies then learning was faster and the information was retained for a longer period of time. When mismatching occurred student performance was poor and there was a failure to understand basic principles.

Jolly and Strawitz (65) found differently. Although teachers and students with matching styles had better personal relationships, mismatching did not lead to better achievement in their high school biology sample. Their FI students achieved equally well with FI and FD teachers. FD students were more successful with FI teachers and it was suggested that these teachers used teaching strategies where they structured information efficiently and this aided the FD students who had difficulty in doing this for themselves.

It was thought that content and methodology of a particular discipline could give different results. According to Brumby (66) restructuring and integration was related to subject matter as much as to cognitive style. What Witkin said was, "If you know a student's cognitive style it will suggest ways of teaching him".

1.6.4 Differences in Cognitive Style

Goodenough (67) put forward the "cue salience" hypothesis which suggested that differences in FD/FI performance was due to differences in terms of attentional processes.

FDs tended to be dominated by the most noticeable features of a stimulus, ignoring or overlooking many aspects of the stimulus complex. They made more errors in both visual and auditory fields when asked to attend to a specific stimulus in the presence of a competing one; they needed a long time to pick up information as they attended to a smaller region within the total stimulus. In relation to encoding information the FIs were more versatile. Goodenough believed that the FDs and FIs differed in their effective use of working memory particularly in high load information conditions. Herron (68) disagreed with this idea and thought that the FIs being more analytical, were able to structure the subject matter more effectively. Davis and Cochran (69) also held this view.

When FDs were helped to organise information their performance improved (70) which suggested that organisational processing contributed to the difference between them and the FIs.

In general, it may be thought that the basic difference between the two groups depends on available processes and strategies. The

The flexible types, Witkin's "mobiles" and Pask's "versatiles" are those with the greatest range of options: they have a greater willingness to try different approaches and an ability to recognise whether a particular strategy is likely to succeed or not.

1.6.5 Tests used to distinguish FDs from FIs

Most of the tests used are based on cognitive restructuring tasks (62)(63)(67)(71).

Those which rely on the visual field or on the body itself for finding the upright are -

(a) Rod and Frame Test
(b) Body Adjustment Test
(c) Rotating Room Test

Individuals were found to be relatively consistent across these tests.

(d) Embedded Figure Test - detection of hidden figures in a complex background.

Ability to detect hidden figures appears to be related to disembedding a problem solving situation. Those who were competent in these tests tended to adopt an hypothesis testing approach.

It would appear that the restructuring dimension extends beyond the visual field to the verbal domain. Tests for verbal restructuring have been produced using such techniques as hidden letters, hidden words and ambiguous sentences, but the results from these tests have been inconclusive.

1.7 PERSONALITY TRAITS

There seems to be some support for the view that scientists differ in personality from non scientists.

Head (72) (73) thought that personality played a role in determining subject choice in the physical sciences and also in success in the field chosen. Roe (74) believed that this applied to biologists as well, but that the personality traits shown by biologists were not the same as those of the physical scientists.

The main trait which appeared to be common to all scientists was in the realm of personal relationships. Barron (35) stated that they were "low in personal involvement". Roe (36) declared that they were "disinterested in other people". Witkin (63) thought that they were "concerned with ideas rather than people", that they were asocial rather than antisocial.

According to Smith (22) those with good spatial ability were independent, self-sufficient, self-confident, shared initiative and perseverance, and were vigorous.

This list of traits was similar to that of Taylor's for creative scientists - independent, self-assertive, persistent, resourceful and with a high energy level. In comparing Field Dependent with Field Independent individuals, Witkin (67) concluded that the FIs with their greater non-self polarity showed impersonal orientation which was unlikely to foster good interpersonal relationships; whereas the FDs showed personal orientation, were interested in people, and preferred interpersonal rather than solitary situations. He believed that FIs were self reliant and reflective, and the FDs impulsive.

1.8 NEUROLOGICAL DIFFERENCES

There have been attempts to explain types of imagery, spatial ability and cognitive styles in neurological terms (75) (76).

Grey-Walter (76) produced evidence to show that when thinking processes were conducted solely in terms of visual imagery, the rhythms of the cerebral cortex were non existent or low. When thinking was verbal or imageless the α rhythms were very persistent. When thinking was visual plus verbal, the α rhythms were intermediate.

In a comparison between arts and science students, a higher percentage of the science students were found to use visual imagery. Roe (74) also found a preference for visual imagery, particularly in biologists, but not in psychologists whose preferred imagery was verbal.

In another study (75) it was noticed that those with good spatial ability had a low α rhythm index or low mean resting amplitude. Spatial ability was found to be impaired if the brain was damaged in the occipital region of the right cerebral hemisphere, even when visual acuity remained normal.

The right and left cerebral hemispheres have different functions.

Witkin (63) tried to link their different ways of processing information with the FD - FI cognitive styles. The right cerebral hemisphere controls the left visual field and the left ear, suited for general processing of configurations, and as FIs showed a strong visual left field bias with the FDs showing little or no preference, Witkin suggested that the FIs showed greater right lateralised specialisation. The left cerebral hemisphere controls the right visual field and the right ear, for processing verbal conceptual functions. The FDs did not show strong left lateralised specialisation as one might have expected. With the FIs there was a higher correlation between right and left hemispheres in EEG amplitude fluctuations which seemed to indicate that there might be greater specialisation in their verbal and motor control as well. Those who did less well in spatial tests appeared to be less strongly lateralised.

The relationships of learning strategies, cognitive styles, spatial ability and neurological evidence are tabulated on the next page.

(This table is a modified and expanded version of Entwistle's (55).)

One could question the position of the categories in the cognitive repertoire row, as studies in creativity have shown that divergence and imagination play an important role. If however, one considered that these individuals had a wider than normal range of options available to them, then they would not be considered as learners type 1, but as versatile types.

The next objective was to select factors from the range of learning strategies, cognitive repertoire, cognitive styles and spatial ability which might be related to ability in the biological sciences.

It was decided to omit personality traits and neurological patterns because of difficulty in the administration of suitable tests.

TABLE 1.1

	LEARNER - Type 1	LEARNER - Type 2	LEARNER - Type (1 + 2)
Learning Strategies	Holist. Comprehension learner.	Serialist. Operational learner.	Versatile.
Cognitive Repertoire	Divergent. Imaginative.	Convergent. Analytical.	Wide repertoire. Divergent/Convergent and Analytical/Imaginative
Cognitive Style	Broad based approach (Global). Thematic. Field dependent.	Narrow based approach (Linear). Analytic. Field independent.	Uses approach suited to task. Flexible. Mobile.
Spatial Ability	Poor	Good	Intermediate
Neurological Differences	Poor lateralisation. Preference for verbal imagery. High α rhythms.	Strongly lateralised. Preference for visual imagery. Low α rhythms.	Lateralised. Uses visual and/or verbal as required. Intermediate α rhythms.
Personality Traits	Good personal relationships. Impulsive.	Impersonal. Cautious.	Satisfactory personal relationships. "Reasonable risk taker".

CHAPTER 2

FACTORS CHOSEN AND TESTS DEVISED

The study of biology involves looking for relationships among organisms at the structural, functional, and developmental levels, and between organisms and their environment. Biological sciences are less exact than the physical sciences because living organisms do not always fit into well defined categories nor do they function in a completely predictable fashion. There are numerous anomalous types, morphologically, physiologically, developmentally and ecologically.

Biologists have a preference for visual imagery (74). They have to avoid rigidity, and frequently have to delay judgement (35) - all of which are aspects of divergent thinking. Divergent thinkers prefer learning strategies which are compatible with their particular way of operating. When they tackle a learning task, their approach tends to be holistic (global) (64) rather than serialistic (linear). This does not mean that they cannot act as serialists; they do so when the occasion demands it.

The biological sciences, because of their wide and diverse content, and the vast variability of living organisms, lend themselves to this particular broad based cognitive style.

It would seem that the ideal biologist would be one whose learning strategies were versatile, whose cognitive style was flexible, who would have good spatial ability, would be divergent, and also have analytical ability.

2.1 The factors selected, for this study, those which might relate to ability in the biological sciences, were -

(a) Aspects of spatial ability
(b) Divergence
(c) Cognitive style
(d) Analytical ability

These factors were chosen firstly, because they seemed to cover areas common to all biologists, and so would not emphasise the differences in the various disciplines within the biological sciences, and secondly, because it would be possible to devise tests in these areas which could be given a biological-skill bias.

2.2 TYPES OF TESTS ENVISAGED

2.2.1 Spatial ability

Three spatial skills which are required for competence in microscopy are -

(a) Ability to visualise a two dimensional section taken from a three dimensional structure.

(b) Ability to visualise a three dimensional structure when given appropriate two dimensional sections.

(c) Ability to recognise a structure when its orientation is changed.

Many pupils experience difficulty in recognising an organism or a structure when its position is changed. The young learner has to be able to rotate mentally, the blackboard diagram or the textbook drawing before he can appreciate that it represents what he is examining, under the microscope. This orientational difficulty may arise because of previous learning experiences (77). The year old child learns that the same object has many visual patterns and that a favourite toy is still the same toy when it is presented to him in a different position. At school, when he starts to learn to read (78), he may become puzzled because he is told that lower case letters such as 'p' and 'd' are different letters, and yet the visual patterns are the same, except for a change in orientation. Other lower case letters which cause problems are 'b' and 'd', 'w' and 'm', and 'n' and 'u', letters which have been rotated vertically or horizontally. Inability to distinguish between two such letters is not confined to cultures using the Roman alphabet. Any letters which differ only in their orientation cause difficulties. Associated left-right orientation problems also occur with words: "was" can be read or written as "saw" up to the age of 8 years, and longer in left handed children. During his school years, the pupil has to learn that some things remain the same when their position is altered, but others do not. In an unfamiliar situation the learner might not know the way in which he ought to respond, and so he has problems with spatial tasks.

Tests for the three aspects of spatial ability mentioned above were constructed.

2.2.2 Divergence

Because of the great number of anomalies in all areas of biology, one skill which is useful is that of being able to review a range of similarities and differences, in order to consider the possible relationships of structures, processes, developmental patterns and ecological requirements of organisms. Those who can think in this way are at a distinct advantage in any comparative biological study.

The idea for a test for divergence resulted from the writer's misgivings of some objective tests, in particular, those of the "odd man out" variety. A child giving an unusual response was penalised for not giving the answer expected by the examiner. If the reason for the choice was asked, the child's explanation showed that his choice was perfectly reasonable.

For example, if a list of - Cat, Dog, Mouse, Tit, Bat were given and the question asked was "Which is the odd one out in this list?", then the expected response would be "Tit", as the only bird in a group of mammals. The divergent thinker might produce the following responses -

(a) Bat - the only nocturnal animal.
(b) Bat - Sports equipment - as well as an animal.
(c) Mouse - a 5 letter word, the others have 3 letters.
(d) Mouse - has 2 vowels, the others have only 1 vowel.

Even the expected answer could be given for reasons other than the fact that a tit is a bird.

(e) Tit - begins and ends with the same letter - others begin and end with different letters.
(f) Tit - is the only palindrome.

If an individual was presented with lists of items where there were many possible answers to the "odd man out", and was asked for reasons for the various choices, it was expected that the divergent thinker would give a larger number of responses.

2.2.3 Cognitive Style

Another requirement in biology is the ability to abstract appropriate information from a background which contains extraneous irrelevancies. Not only is this necessary in any study where a microscope is used but also in morphological and anatomical studies where cells, tissues, organs and systems are embedded in an organism. Inexperienced pupils have difficulty in knowing what is relevant and what is not.

According to Witkin (62), the ability to disembed a hidden figure from a distracting background is indicative of the cognitive style Field Independence.

A test was constructed with the biological skill and cognitive style included.

2.2.4 Analytical Ability

In many areas of biology, it is necessary to abstract information, to reorganise it and then use it in a different situation. This requires ability in analysis and synthesis. An exercise constructed by the writer to illustrate concept development was used as a blueprint to develop a test of analytical ability (see Chapter 1).

2.3 TESTS DEVISED

Tests were devised which were not dependent on biological knowledge, but which high-lighted the skills required in the biological sciences. This allowed the tests to be carried out on primary school children and on students and adults whose biological background was limited. (See Appendix I for complete tests.)

By using the tests on primary children it was hoped that information about when these skills emerged would be found.

2.3.1 TEST A

A test of ability to visualise a two dimensional section taken from a cut surface of a three dimensional diagram.

The sections taken were transverse and longitudinal only. It was decided to omit oblique sections on the principle that longitudinal and transverse sections have to be mastered before oblique sections can be understood.

N.F.E.R. (79) Spatial Tests 1, 2 and 3 were consulted to give guidance on a suitable format.

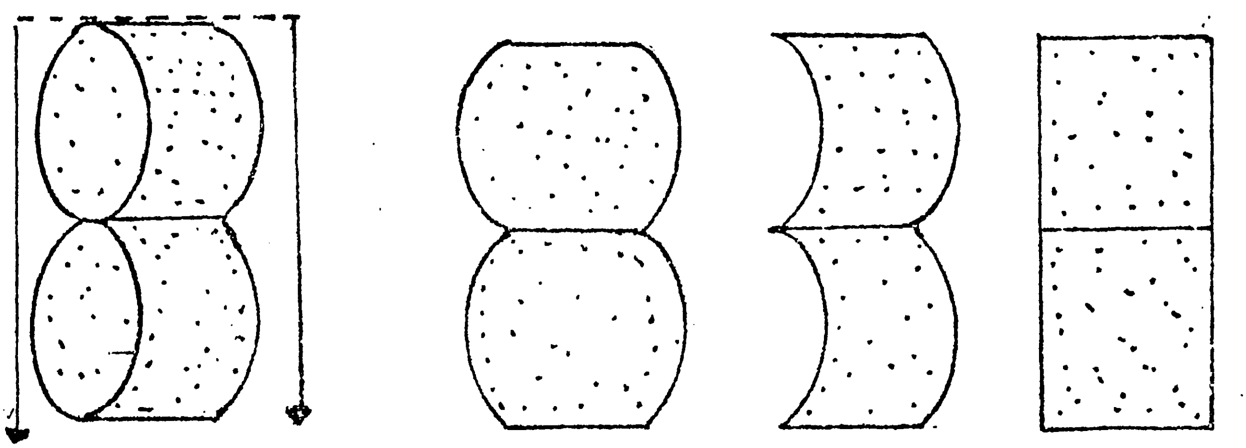
The test consisted of 10 items. In each item a diagram of a solid was given. A dotted line with arrows showed the direction of the cut. A choice of 3 possible sections was given and the subject was asked to tick the one thought to represent the correct cut surface.

Instructions and an illustrated example were given on the first sheet.

The solids were simplified and stylised examples of those found in biological tissues.

DIAGRAM 2.1

Solid



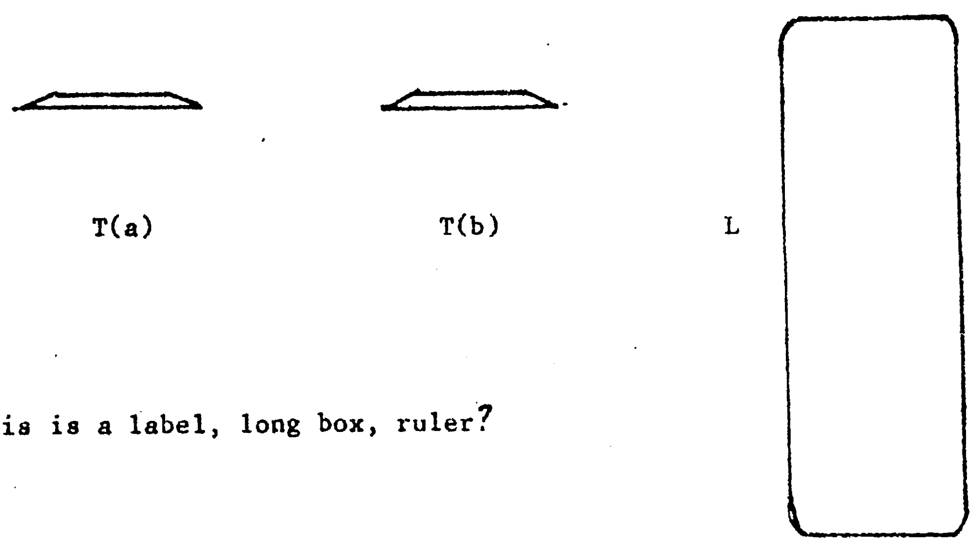
(a) (b) (c)

2.3.2 TEST B

A test of ability to visualise a three dimensional object when given appropriate two dimensional sections.

The test consisted of 11 items. Instructions and two examples were set out in the first two pages. The sections given were top transverse, middle transverse and longitudinal. All examples were taken from well known objects. A choice of three possible objects was given and the subject was asked to circle the name of the one which he believed represented the object.

DIAGRAM 2.2



This is a label, long box, ruler?

2.3.3 TEST C

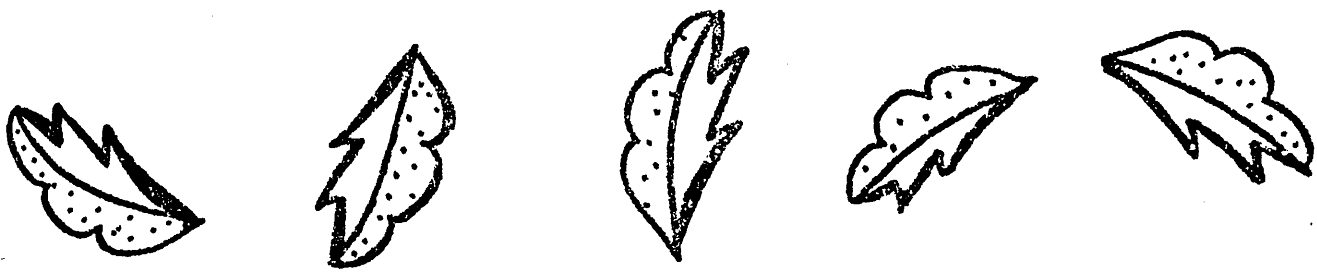
A test of ability to recognise an object when its orientation is changed.

There were 15 items in this test. Instructions and two examples were given on the first sheet.

Each test item consisted of 4 identical shapes placed in different positions - the fifth shape was a mirror image (80). The

The place of the mirror image in each item varied. Subjects were asked to circle the mirror image. The term "back to front" was used as well, for the benefit of those who were unfamiliar with the term "mirror image".

DIAGRAM 2.3



(a) (b) (c) (d) (e)

It was hoped that Tests A, B and C would give an indication of the different aspects of spatial ability required in the biological sciences.

2.3.4 TEST D

A test of ability to look for and to find a number of solutions to a problem using the technique of grouping items into like categories (Sets).

The test consisted of 12 lists. Each list had 5 items and subjects were invited to group them into sets, with 4 items per set, the fifth item being the "odd man out". Reasons were asked for their choices and it was stated in the instructions that there was likely to be more than one possible answer to each list. This was illustrated with an example.

It was hoped that this test would give some indication of divergence, i.e. the greater the degree of divergence, the greater the number of responses given.

DIAGRAM 2.4

6. ENGLISH , SPANISH , FRENCH , LATIN , CHINESE .

THE ODD ONE OUT IS ....

2.3.5 TEST E

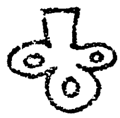
A test of ability to abstract relevant information from a distracting background.

There were 13 items in this test. Each item consisted of 4 circles in which a given shape was hidden in some or all of them. The subject was asked to identify the shapes by outlining them and then indicating how many were to be found in each circle, from the options of 0 - 1 - 2 - more. ("More" equalled 3 with one exception where 4 shapes were present.) The hidden shapes were of the same size as the one given in the example.

This test differed from a standard embedded figure test in that the hidden shapes were not always in the same position or of the same orientation as the specimen shown. This was done to make the test more realistic from the point of view of a biological skill. However, it was hoped that this test would give some indication of Field Independence.

DIAGRAM 2.5

LOOK FOR
THIS SHAPE



1

(a) 0 - 1 - 2 - more

(b) 0 - 1 - 2 - more

(c) 0 - 1 - 2 - more

(d) 0 - 1 - 2 - more

2.3.6 TEST F

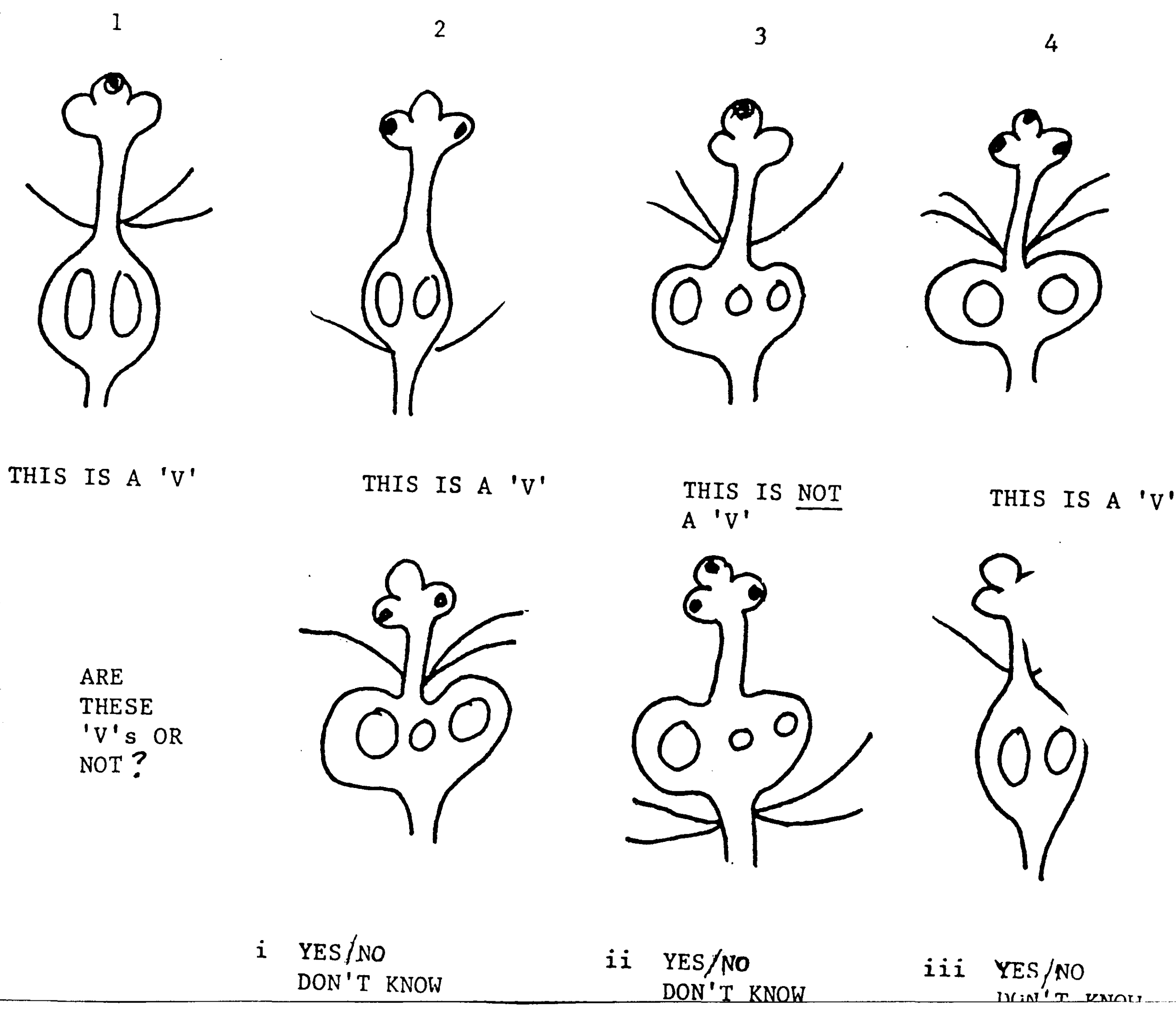
A test of ability to abstract relevant information, to group characteristics which are similar but not identical, and to

Each individual test item was made up of 4 diagrams where numbers 1, 2 and 4 were examples and number 3 a non example of a conceptual pattern. Below were 3 further diagrams, and the subject was asked to indicate which were examples of the concept and which were not, by circling the choice Yes/No/Don't know. In order to complete each test item a hypothesis had to be put forward, based on observation, and then the hypothesis had to be tested.

There were 12 items in this test. Instructions and an illustrated example were given on the first sheet.

This test should indicate the skill of ability to analyse and to synthesise.

DIAGRAM 2.6



After the construction of the tests, each underwent limited trials to eliminate problems.

CHAPTER 3

TRIAL RUN

In the trial run three groups were tested.

3.1 Primary 7 group of 90+ children aged 11 years.

3.2 Secondary 3rd year group of 60+ children aged 14 years.

3.3 Post-graduate biologists - 27 adults made up of teachers, lecturers and post-graduate students.

3.1 PRIMARY SCHOOL CHILDREN (P.7 - aged 11)

The tests were conducted in three sessions, two tests per session on separate days. The time taken for each session was approximately 40 minutes. Because of absences, not all the children did all the tests. The tests were presented to the pupils as "Puzzles for young scientists".

Before each test was given, it was necessary to ensure that the classes understood what was expected of them. This involved a short lesson on each topic, followed by a practice run. Information on how to fill in the test sheets was given orally so that the instructions did not need to be read. This was particularly important for those children whose reading skills were poor.

3.1.a TEST A

Before the test was given, the pupils were presented with a number of objects which were available in the classroom, and asked to think what a "slice" would look like, when the object was cut "across the way" (transversely) or "cut down the way" (longitudinally). Lumps of Plasticine which could be shaped and sectioned were used so that the cut surface could be seen. This was followed by asking the class to visualise cut surfaces of pencils (both circular and hexagonal in transverse section), jam jar, blackboard rubber, and other familiar articles taken from the children. Diagrams of sections were drawn on the blackboard and the children were asked which one represented the cut surface of the individual objects used. Several examples were given using the same format as the test sheets before the test was started.

3.1.b TEST B

The pupils were told that this "Puzzle" was like 'A' but "this time we are going to do it the other way round. I'll tell you where the slices were taken and you've to guess what the object is". The sections were described to the class as "a top slice across the way", a "middle slice across the way" and a "slice down the way through the middle". Sections of pencils, paintbrush, apple, pear, and banana were illustrated using the Test B format. Many children realised that it was the longitudinal section which gave the most important piece of information for identifying the object.

3.1.c TEST C

This test was introduced as the "Back to front puzzle". Names were taken from individuals and written on the blackboard in a variety of orientations plus one mirror image. The pupils were then asked "which one is back to front?" This exercise was repeated with the numbers 2 and 5 before the test was tackled.

3.1.d TEST D

The list of items from the first page example were written on the blackboard - Dog, Cat, Tortoise, Rabbit, Whale, and the children were asked to look for the "odd man out". They were told that there were many possible answers, and to try to think of as many as they could, giving a reason for each answer. This was conducted orally and all the choices and the reasons were written on the board. The number of answers given to this list varied from 6 to 10 with different classes. One of the more unusual answers given was "whale is the odd one out because you don't keep it as a pet", which is a perfectly reasonable answer for a young child. Another example was taken before the test was started.

It became obvious that this test was too long. The children became tired and were reluctant to continue. Although they missed some out, most of them tackled the last list, as a final effort. From the questions asked during the test, it was clear that some of the items were unfamiliar, e.g."pterodactyl" was known only by those classes, where dinosaurs had been studied.

3.1.e TEST E

This test was introduced by its own title of "Hunt the Shape". Several examples were put on the board, and individual children were asked to circle the hidden shapes using coloured chalk, then underline the number of shapes seen in each circle. The children were told that "the shapes you are looking for are the same size as the one at the top of the page. Some shapes are the same way up, some may be upside down, and some may be turned to one side. Be careful, because in some of the circles, there are no hidden shapes at all". Another example was taken before the test began.

3.1.f TEST F

As with the other tests, several examples were put on the blackboard using the same format as the test itself. Individual children were asked to explain orally, to the rest of the class, how they decided on whether it was a "yes" (an example of the concept) or a "no" (a non example). When a child gave the response "don't know" another child was invited to explain. Several examples were given before the test started. Of all the tests this was the one that these primary school children found most difficult.

3.2 SECONDARY SCHOOL PUPILS (S.3 - aged 14)

These classes were tested in the first term of the academic year. The pupils had been studying 'O' grade Biology for approximately 3 months.

The tests were conducted in two sessions, three tests per session on different days and the time taken for each session was approximately 45 minutes. As with the primary school children not all the pupils did all the tests, as some were absent for one of the sessions.

Instructions for all the tests were given orally and one or two practice examples were taken to ensure that the pupils understood what they were expected to do. The procedure was similar to that used with the primary school children but the language was modified to suit the older age range.

Test D appeared to be too long even for 14 year olds, and some of the items were unfamiliar. Many did not know that "maple" was a tree.

3.3 POST-GRADUATE BIOLOGISTS

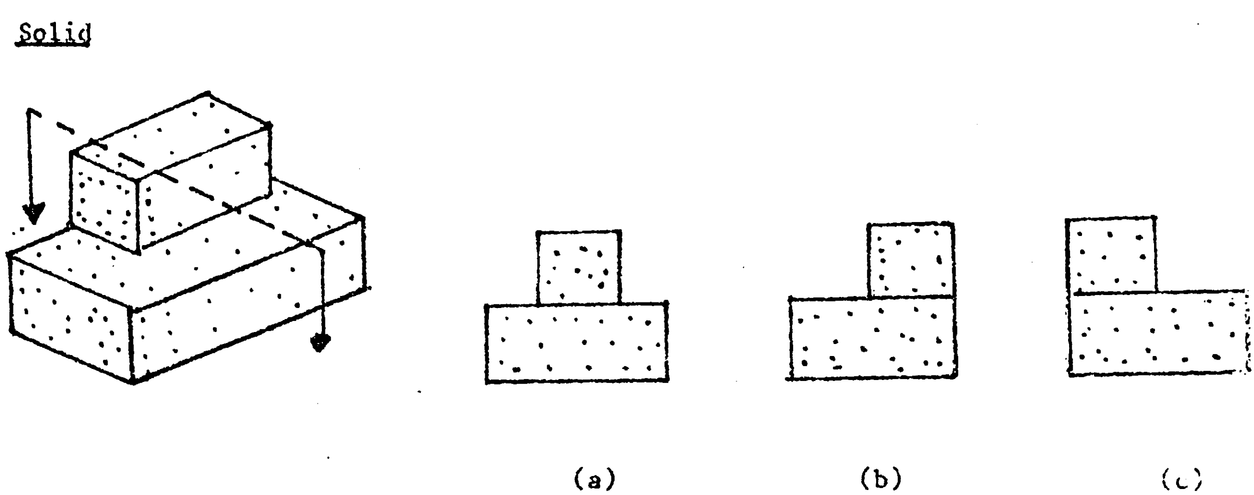
The tests with an additional written instruction sheet were given to the post-graduates, and they were asked to complete the six tests in not more than $1\frac{1}{4}$ hours. Test D was put in last, so that a limited time would be spent on it. These tests were unsupervised as the post-graduates came from a variety of establishments, so it would have been difficult to get them together to administer the tests.

3.4. CHANGES MADE - REDRAFTING THE TESTS

3.4.a TEST A

As many of the primary and some of the secondary pupils had difficulty in distinguishing between the diagram of some of the solids, and the cutting lines, it was decided to shade in the solids and the sections using small dots.

DIAGRAM 3.1

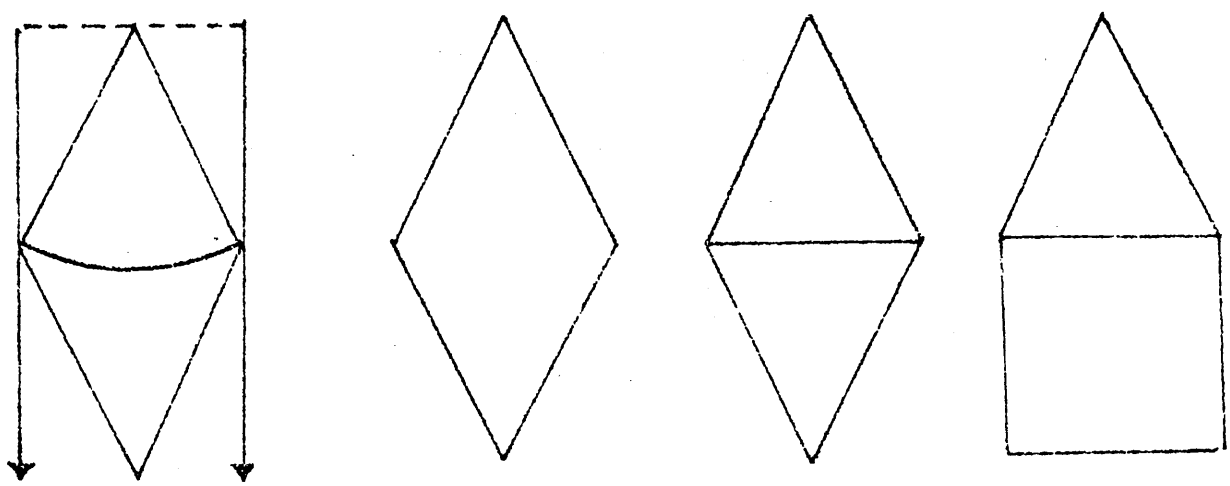


There was some ambiguity regarding No. 3, the double cone. If one thought of it as two distinct cones, then the section with the horizontal line would be taken as the correct answer, but if the two cones were considered to be in one piece, the section without the horizontal line would be chosen. This was changed to avoid ambiguity.

DIAGRAM 3.2

3.

Solid



(a) (b) (c)

Some of the diagrams were of poor quality and this resulted in there being two possible correct answers. All diagrams were checked and altered when the test was redrafted.

3.4.b TEST B

In No. 5, one of the choices was "cake of soap" but many of the primary children had never seen a round cake of soap, so this response was not chosen as a possible answer. In the redraft "saucer" replaced "cake of soap" as a possible choice.

3.4.c TEST C

As many of the primary children had difficulty with No. 1, it was decided to start the test with a more familiar example, No. 5, the name "David". In the redraft No. 1 and No. 5 were interchanged.

The quality of some of the diagrams had to be improved and better spacing was also required.

3.4.d TEST D

Some of the post-graduate biologists had not read the instructions properly and so only gave one response per list. To draw attention to the instructions it was decided to enclose them in a thick lined rectangle.

Fatigue affected both primary and secondary pupils so the test was cut from 16 to 12 questions. In addition to "pterodactyl" and "maple", other unfamiliar items were the names, "Nan" and "Miriam", and the terms "linen","silk", "tangerine", "slacks", "knickerbockers", "natural gas", "peat", "clog" and "radish". These were either deleted when the test was shortened or replaced by more familiar terms, e.g. "Amanda" replaced "Nan".

3.4.e TEST E

To the instructions were added "Outline the ones you see" and "The shapes are approximately the same size as the one shown". Both these instructions had been given orally to the school children, but it was decided they should be included in the instructions. This was to ensure that all groups tested later did not look for different sized shapes, and also the outlining of the shapes would give a double check on those who had not indicated the number found.

5 b. was altered as one of the shapes was appreciably larger than the one shown. The large one was deleted.

3.4.f TEST F

No alterations were required.

3.5 COMMENTS ON THE TRIAL RUN

Because some of the tests were found to have errors or ambiguities, the comments had to be of a very general nature.

(a) Primary 7 (aged 11) had originally been thought of as the youngest group to be tested, but as many of these children had high scores on some of the tests, it was decided to include a younger age group. A sample of Primary 4/5 - aged 8-9 was taken. Tests D and F were omitted for this age range, Test D because reading and writing skills were not well developed at this stage, and Test F, because the mean score for the 11 year olds was 25% and so this was probably the lowest age limit for this particular test.

(b) It was thought from the results that there might be a maturational/developmental factor as the younger children did less well than the older ones on all the tests. For the main run, using the redrafted tests samples were taken at age group intervals of approximately two years from the 8 year olds to 17 year olds.

(c) Despite the shortcomings of Tests A and B, in the trial run, certain tentative trends emerged.

In Test A, transverse sections were recognised more accurately than longitudinal sections. This may be because it is easier to visualise a transverse section from the solid by altering slightly ones viewpoint, whereas the longitudinal section is virtually invisible.

The scoring on Test B was much higher than the Test A scores. One possible explanation is that pupils find it easier to go from two dimensional sections to a three dimensional solid because this process is a synthesis, whereas it is the more difficult process of analysis which is involved in going from three dimension to two dimensions.

(d) In Tests C and E many individuals in both school groups had difficulty in rotating shapes mentally, but solved this problem effectively, by rotating the paper.

(e) In Test E a number of individuals "saw" shapes which were not present. This included the post-graduate biologists, but they did not "imagine" as many as the secondary or primary school children.

(f) Many children found the need to verbalise when attempting Test F. They virtually muttered aloud as they attempted the items.

The tests were amended and the main trial on a large sample was carried out.

CHAPTER 4

MAIN RUN OF THE TESTS

After the trial run, the tests were amended and the following groups were tested.

4.1 SAMPLING TECHNIQUE

4.1.a Primary 4/5

This was a group of primary school children aged 8-9 years old. Some of the classes were made up of the younger pupils, some older, and some were composite classes with a mixture of the two age groups.

The sample size was 106, 50 girls and 56 boys. The tests used were A, B, C and E. Tests D and F were omitted, D because of the younger children's limited skill in reading and writing, and F, because it was thought that this was the one where the lowest limit was at Primary 7, the 11 year old stage. (See Chapter 3)

The procedure adopted was similar to that of the trial run; an introductory lesson on each topic, followed by practice of a number of examples. Instructions on how to complete the tests were given orally, to ensure that the children knew what was expected of them.

The tests were given in two sessions of two tests per session. The time taken for each session was approximately 50 minutes. Because of absences, not all of the pupils completed all of the tests. This applied to all groups where testing was done in more than one session.

4.1.b Primary 7

This was a sample of primary school children aged 10-11 years old, made up of 95 pupils, 49 girls and 46 boys. The tests were given in three sessions, two tests per session. The time taken was approximately 40 minutes per session. The procedure adopted for the introduction of the tests, was the same as the one used with the younger children.

Test D which had been shortened to 12 items, and amended, was found to be more appropriate and was tackled without difficulty.

4.1.c Secondary 2

This was a group of secondary school pupils aged 13-14 years old; the sample was 68, 36 girls and 32 boys. This sample was taken at the end of the academic year and most of the pupils tested intended to continue with two or more of the sciences. The two schools from which the sample was taken, had a strong science tradition, pupils being able to take all three sciences, biology, chemistry and physics, if they wished. (In many schools biology and physics are mutually exclusive.)

The tests were conducted in two sessions of three tests per session: the time for each session was approximately 50 minutes. The procedure adopted was similar to that used with the primary school children, but the language used was geared to the older age range.

4.1.d Secondary 4

This sample was a group of secondary school pupils aged 15-16 years old - 83 in total, 52 girls and 31 boys. These pupils had been studying 'O' grade biology for just over four terms. In this sample, a number of pupils were taking biology as the sole science subject, their other main subject being art or geography. Approximately two thirds of the pupils were studying biology with chemistry or more rarely, with physics. The tests were conducted in two sessions of three tests per session, and the time per session was approximately 45 minutes.

The same procedure was used as that of the S.2 group.

4.1.e Secondary 6

This was a group of secondary school children aged 17-18 years old. The sample size was 74, 40 girls and 34 boys. Some pupils were following the Certificate of Sixth Year Studies course in biology; others the 'H' (Higher) grade biology course. Most of those taking the 'H' grade biology had already completed successfully, 'H' or 'O' grade courses in chemistry and/or physics, and were using their 6th year to add to their science qualifications.

The writer tested just over 60 of these pupils, but the rest were carried out by their class teachers who had been given instructions on how to conduct the tests. The time allocated for the tests was approximately $1\frac{1}{2}$ hours, and all tests were tackled in one session.

4.1.f Biology Students

The sample was made up of 85 undergraduate students, 49 women and 36 men, taken from a first year university biology class. The majority of the students were aged 18-19 years of age, but there were a few who were taking the Biology I course in their second or third year. Instructions had been given to the group by one of the lecturers, but the writer was available during the tests to give advice if required. Unfortunately, the tests were conducted late in the afternoon, at the end of a practical class, and as a result some of the students did not complete all 6 tests. The time taken for the tests was approximately $1\frac{1}{4}$ hours.

4.1.g Post-graduate Biologists

This sample of 65, made up of 30 women and 35 men included teachers, lecturers and research students. As in the trial run, written instructions were given and the post-graduates were asked to complete the tests in $1\frac{1}{4}$ hours.

4.1.h Non science students

This sample consisted of 30 students, 21 were first year university students in the Arts Faculty, aged 18-19, and were tested by the writer; the remainder were Divinity students who were briefed by the writer, but completed the tests on their own without supervision. The time suggested for completion of the tests was approximately $1\frac{1}{4}$ hours.

4.1.i Non science post-graduates

This sample of 35 adults, consisted of teachers, lecturers, graduate divinity students, social workers and civil servants. Written instructions were given and the members of the group were asked to complete the 6 tests in approximately $1\frac{1}{4}$ hours, in their own time.

4.2 INFORMATION COLLECTED

The following information was collected from the groups.

4.2.a Primary school children (P.4/5, P.7)

Age. Sex.
Favourite school subject
Best school subject
Class teacher's estimate of general ability on an A to E scale.

4.2.b Secondary school pupils

(i) S.2. S.4
Age. Sex
Preferred science subject - biology, chemistry, physics.
Class teacher's estimate of scientific ability in S.2, and ability in biology in S.4, on an A to E scale.

(ii) S.6
Age. Sex
Science subjects taken. Results of 'O' and 'H' grade examinations in the sciences, if known.
Class teacher's estimate of ability in biology on an A to E scale.

4.2.c Biology students (undergraduates)

Age. Sex
Qualifications on entry to university (sciences only)

4.2.d Post-Graduate Biologists

Sex
Type of biologist, e.g. botanist, zoologist, ecologist, geneticist, microbiologist, etc.
Occupation - teacher, lecturer, researcher.

4.2.e Non science students (undergraduates)

Sex

Course of study

4.2.f Non science post-graduates

Sex

Occupation

4.3 OBSERVATIONS

4.3.a TEST A

It was noticed that a number of children in the 8-9 year old group (P.4/5) had difficulty with this test and required reassurance before they would continue. It would appear that the 8-9 year old age range is the limit for this test.

4.3.b TEST C

Some pupils, even the 17 year old, found difficulty in rotating the diagrams mentally, and as in the trial run, solved the problem by turning the test paper. One 8-year old got out of his seat and rotated himself round the paper.

4.3.c TEST D

Despite drawing attention to the instructions by surrounding them with a thick outline, some of the post-graduate biologists, post-graduate non scientists and non science students, had not read the instructions properly and gave only one answer per list. As a result, this test must be regarded with caution as far as these groups are concerned.

4.3.d TEST E

One non science post-graduate did not complete this test and added a note explaining that she had had difficulty as "the shapes kept moving". This phenomenon can be caused by after images particularly if two complimentary colours are used. This seemed an unlikely explanation as the black diagrams were on a deep yellow background. This person admitted that she suffered from astigmatism but did not say if she wore spectacles with correcting lenses when she attempted the test.

The only other person known to have problems with this test was a slightly dyslexic sixth former.

4.3.e TEST F

The need to verbalise audibly was widespread even with the biology students.

After the sampling had been completed the following questions had to be considered.

(i) Are the tests reliable?

(ii) Are the tests valid?

CHAPTER 5

RELIABILITY AND VALIDITY

If the reliability and validity of a test are not considered, then the data from these tests and conclusions drawn, must be suspect. Data of all educational measurements contain errors, and the question which has to be asked is what is the magnitude of the errors? (81)(82)(83)(84)(85).

5.1 RELIABILITY

Reliability deals with consistency, stability and accuracy. If a test is given to a group on a number of occasions will the results be consistent? How much is the error of measurement? Errors of measurement are random errors and are the result of a number of causes; fluctuations in the conditions under which the test is administered, fatigue, and changes in mood of those sitting the test. Such factors are temporary, but are not constant as they change from time to time. Since reliability is associated with random error, then reliability can be thought of as the relative absence of errors of measurement.

Absolute reliability would mean that the same person would give exactly the same answers to the same items on every occasion. Reliability of tests can mean that the same group would generate the same all over score on different occasions, but not necessarily on a person by person basis. It is this latter form of reliability which is being considered.

5.1.1 Factors affecting reliability

(a) Test length - the longer the test the higher the reliability provided that the test is not so long that fatigue or boredom starts to affect performance.

(b) Range of ability - the greater the spread of individual differences, the higher the reliability.

(c) Item content - the more similar the test items are in content, the greater the inter-correlations of the items, and so the higher the reliability.

(d) Item difficulty - the selection of items of moderate difficulty increases test dispersion. When a test is constructed so that 50% of those taking the test answer correctly each time, the item variance is high. If the items are too easy or very difficult item variance is much reduced and so the reliability drops.

5.1.2 Increasing reliability

Unreliability can be reduced by -

(a) Minimising guessing in the test. Multiple choice items are more reliable than true/false items.
(b) Having clear, precise, test instructions.
(c) Adopting a consistent test procedure.
(d) Reducing scoring errors by using a simple unambiguous marking scheme.

5.1.3 Methods of determining test reliability

To estimate the reliability of tests the following methods can be used -

(a) Test-Retest (Test/Post test).
(b) Alternate or parallel forms.
(c) Split half method.
(d) Rational equivalence.

5.1.3.a Test-Retest

With this method, the same test is given on two separate occasions. The time interval between the two tests has to be considered carefully. If the time gap between the tests is too short, those taking the test may recall some of the answers given in the previous test, enabling them to spend more time on difficult items. When the content is familiar, the individuals may be more confident. There may also be a practice effect. All these factors will tend to inflate the retest scores. If the time interval between the tests is too long, particularly if the tests are given to children, a maturation factor may start to operate, thus affecting the retest scores.

5.1.3.b Alternate or parallel forms

As with the previous method, the time gap has to be long enough to eliminate practice and memory effects, but not too long otherwise the developmental aspect affects the scores. The reliability coefficient will not be unduly different, provided that the increase in the second test score is fairly constant, as the paired scores will have the same relative positions in the two distributions. The main difficulty with this method is in matching the test items in the second test. The two tests must not be identical nor too dissimilar in content and difficulty, otherwise the correlations will be either too high or too low.

5.1.3.c Split-half method

When this method is used, the test is split into two equivalent halves. If the test is relatively homogeneous, the method normally employed is to take the odd-even numbers split. If the test is not homogeneous, the items can be ranked in order of difficulty and then split into two comparable halves. The main advantage of using this method is that the test is completed on one occasion, so variations which occur in the different test situations are eliminated. The reliability of the half test is calculated and then the reliability of the whole test is estimated using the Spearman-Brown formula.

5.1.3.d Rational equivalence

This method gives an estimate of reliability free from the objections of the previous methods. The assumption in this procedure is that the items within one form of a test have as much in common with one another as do the items in a parallel or equivalent form (82). There are two forms of this Kudar-Richardson procedure, K20 and a simplified version K21.

The one which was used to test the reliability of Tests A, B, C, D, E and F in this project was a modified version of K21. According to Garrett (83), this formula gives a satisfactory approximation of test reliability even when the test items cover a wide range of difficulty.

$$\text{RELIABILITY COEFFICIENT} = \frac{nSDt - M(n-M)}{SDt\ (n-1)}$$

n = Number of test items

M = Mean of test score

SDt = Standard deviation of test score.

This formula under-estimates by approximately 0.02 the reliability coefficient found by the split half technique. An index of reliability can also be calculated.

$$\text{INDEX OF RELIABILITY} = \sqrt{\text{RELIABILITY COEFFICIENT}}$$

The index of reliability is the maximum correlation which the test is capable of yielding.

With Test D, "n" - the number of items, was taken as 67 which was the maximum number of responses made.

The reliability coefficients and indices of reliability are tabulated below.

TABLE 5.1

Test	Number in Sample	Number of items in test	Reliability Coefficient	Index of Reliability
A	642	10	0.80	0.89
B	642	11	0.69	0.83
C	632	15	0.90	0.95
D	533	67	0.85	0.92
E	626	82	0.91	0.95
F	631	12	0.87	0.93

(An example of the calculation is in Appendix II)

From these results it would seem that the tests are reasonably reliable as group tests.

5.2 VALIDITY

Validity is the degree to which a test measures what it is intended to measure, and the purpose for which it is meant. As there are many uses to which a test can be put, there are several ways a test can be validated. Methods of validation can be grouped into four main categories - content, predictive, concurrent and construct validity.

5.2.1 Content validity

Content validity is how representative the test is, and how well the content is sampled. Theoretically, a test high in content validity would be one which sampled exhaustively every possible aspect of the area to be investigated. A more realistic and practical method by which content validity can be established is by careful analysis of the content to be covered, and then making an informed judgement on how well the items are representative, and how relevant they are to what is being measured.

The following procedure was carried out to safeguard content validity of Tests A, B, C, D, E and F.

(a) Ensuring that the objectives were clearly defined before each test was constructed.

(b) Taking care with the test construction.

(c) Running a trial of the tests to eliminate unsuitable items and ambiguities.

(d) Taking reasonably large samples on the main run of the tests.

5.2.2 Predictive and Concurrent validity

These two forms of validation can be considered together as they differ only in the time dimension, concurrent relating to present performance only. A test predicts a certain outcome, or some present or future performance, so that interest is not so much on what is behind the performance as for what it may predict. The main difficulty of predictive validation is in criterion selection, i.e. the degree to which the test correlates with some known measure (criterion) of success. It may be that there is no relatively objective record of performance; records which are available may be inaccurate, incomplete or biased. Results of examinations and class teachers' estimates of children's ability are often the only criteria which are obtainable.

5.2.3 Construct validity

Construct validity is evaluated by investigating the qualities a test measures; by showing that certain constructs account, to some extent, for performance on the test or tests. Construct validity is also related to the use of tests to confirm predictions; predictions about group differences, predictions about correlations. It can therefore be said that construct validation involves the testing of hypotheses.

5.3 HYPOTHESES AND PREDICTIONS

5.3.1 In this study, the over all hypothesis is that spatial ability, divergence, field independence and analytical ability are required for competence in the biological sciences. Those groups showing some degree of success in biology should perform better on the tests than those groups without a background in biology.

It may be that the biological sciences are chosen because they appeal to those who have these abilities, or, the biological sciences are not selected because these skills and aptitudes have not been developed.

5.3.2 PREDICTION

The following predictions were made before a detailed analysis of the test results was carried out.

(a) Developmental/maturational factor

A developmental/maturational trend should show in all tests: the younger children should do less well than the older pupils; and the undergraduates should have lower scores than the post-graduates; the mean for each test should rise with increase in age.

(b) Biological experience

Because of added experience in basic biological techniques, the groups of those taking or having taken courses in the biological sciences, should have higher test scores than the corresponding non science groups, i.e. the undergraduate biology students should have higher test scores than the undergraduate arts and divity students, and the post-graduate biologists should score more highly than the non science post-graduates.

(c) Distribution curves

(i) The pattern of distribution of test results should be similar in the unselected groups - Primary 4/5 (aged 8-9), Primary 7 (aged 10-11) and Secondary 2 (aged 13-14) but there should be a shift to the right as the pupils mature and the mean scores rise.

(ii) The distribution curves should start to skew to the right, markedly, with the selected biology groups and Secondary 4 (aged 15-16), Secondary 6 (aged 17+), biology undergraduate students (aged 18+) and the post-graduate biologists. The skew should be progressive, with the greatest skew shown by the post-graduate biologists.

(iii) The non science undergraduates and post-graduates should show a distribution similar to the unselected groups, but the curves should be further to the right because of maturity.

(d) Correlations

Tests which measure related factors should show significant positive correlations with one another, whereas tests of non related factors should give low or negative correlations.

(i) There should be positive inter-correlations of Tests A, B and C, as they all measure different aspects of spatial ability. Also there may be a positive correlation with Test E because ability to find a hidden figure, i.e. form recognition, is regarded by some to be an aspect of spatial ability. (21)(26)(27).

(ii) There should be a positive correlation between Test C and Test E as difficulties in recognising shapes when their orientation is changed would lead to inability to distinguish hidden shapes in the different positions in Test E.

An analysis of the results of Tests A, B, C, D, E and F across the various groups was then carried out.

CHAPTER 6

ANALYSIS OF RESULTS - INDIVIDUAL TESTS

In the discussion of the results, each test will be considered without differentiating between males and females, as it was found that sex differences, for the most part, were insignificant.

A table of frequency distributions across the groups will be given for each test within the text. Frequency distribution histograms for each group in each test are in Appendix II.

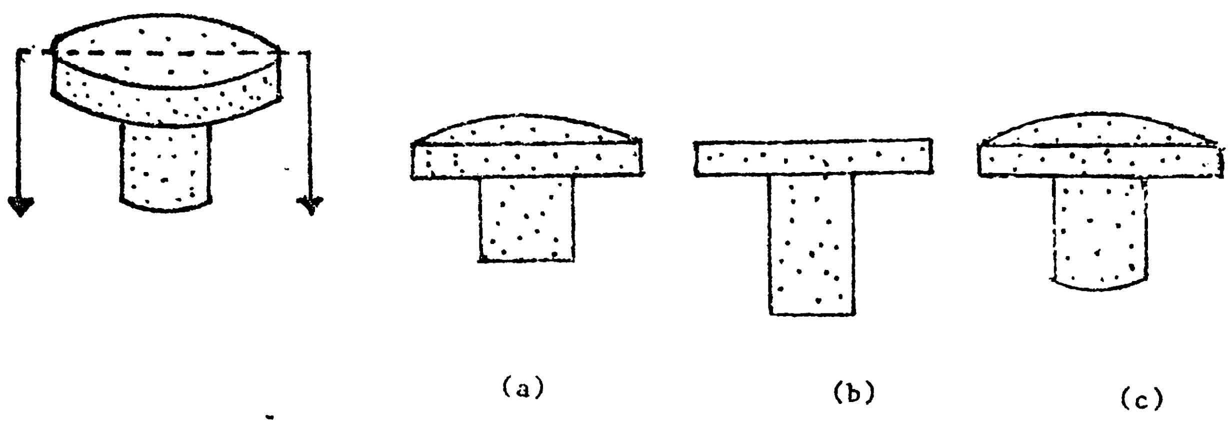
Tests A, B, C, D, E and F are in Appendix I.

6.1.1 TEST A

Test A was a test of ability to visualise a two dimensional section taken from a cut surface of a three dimensional diagram.

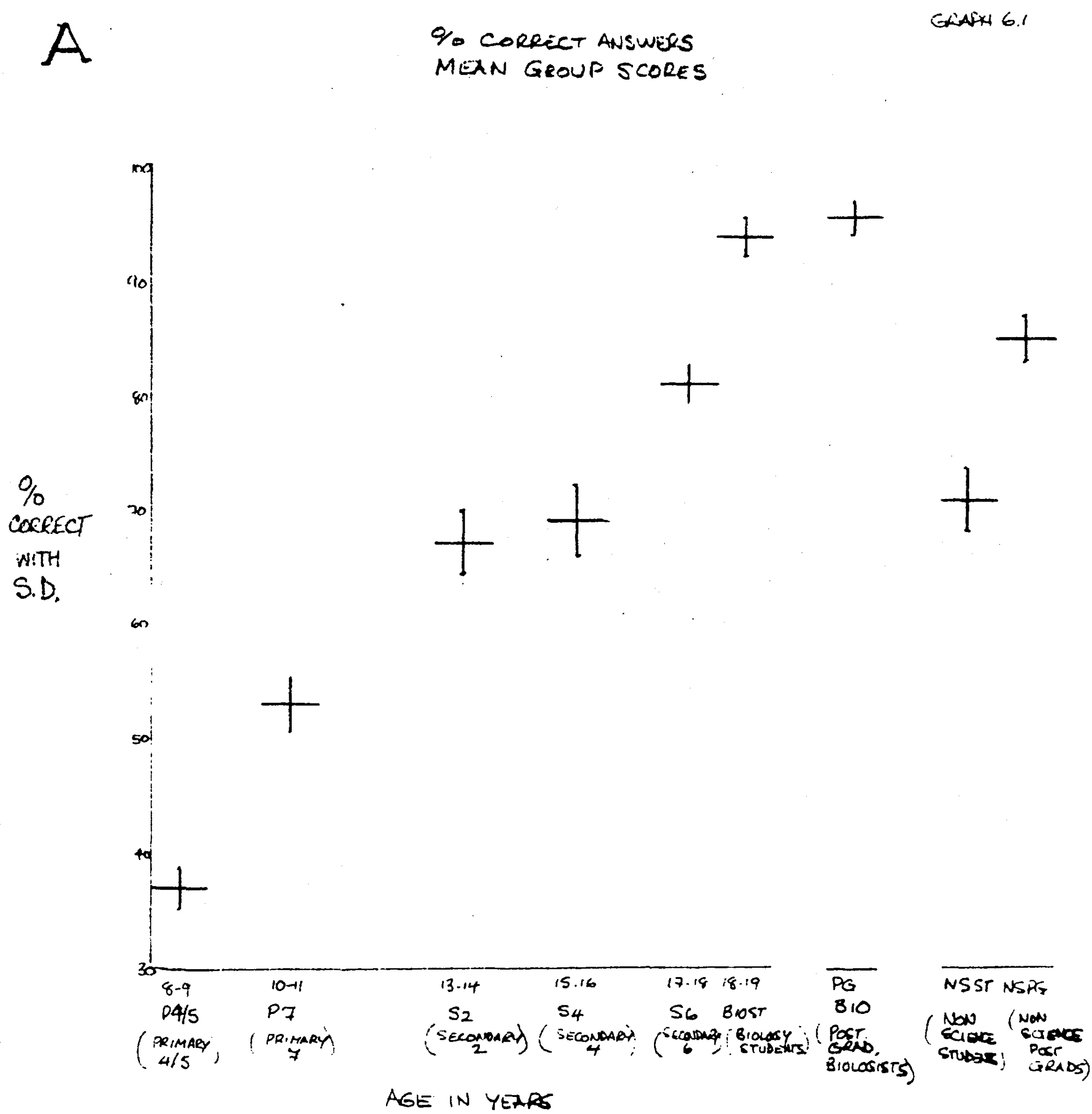
DIAGRAM 6.1

Solid



In order to compare the different group scores, a graph was constructed taking the percentage mean group score with the standard deviation, and plotting it against age.

GRAPH 6.1



As was predicted, there was a developmental/maturational pattern, the younger primary school children doing less well than the secondary school pupils, and the post graduates scoring higher than the corresponding under graduate groups. It would also appear that those with more extensive experience in the biological sciences were more competent than the other groups, i.e. Secondary 6, aged 17+, biology students and post graduate biologists.

TABLE 6.1.

TEST A — FREQUENCY DISTRIBUTION TABLE

GROUP	N	0	1	2	3	4	5	6	7	8	9	10	MEAN	S.D
NSPG	36				1	2	0	3	3	3	7	17	8.52	2.0
NS ST.	30		1	0	0	2	3	3	4	5	6	6	7.16	2.3
PG Bio	65							3	0	1	10	51	9.63	1.1
Bio ST	85					1	0	1	1	9	21	52	9.38	1.1
S6	74		1	3	2	4	1	6	4	10	10	33	8.1	2.5
S4	83			2	4	11	15	4	7	8	16	16	6.9	2.6
S2	68			1	7	7	8	10	8	4	11	12	6.7	2.5
P7	95	1	2	3	11	18	22	9	9	11	9	0	5.3	2.1
P4/5	106	1	0	12	38	29	16	8	1	1	0	0	3.7	1.5
		NO CORRECT												
TOTAL	624	2	4	21	63	74	65	47	37	52	90	187	7.01	2.7

6.1.3 With the P.4/5 children (aged 8-9) the distribution of scores approached a normal curve, but slightly less so with the P.7 (aged 10-11); both these groups of primary school children would have had limited experience in spatial tasks, and probably none in the 3-dimensional to 2-dimensional field. The S.2 pupils (aged 13-14) had completed two years in the secondary school and so would have had more experience than the primary school children, and this was reflected in the skew to the right shown by this group. Skewing to the right became progressive, as age increased, with the greatest skew shown by the post graduate biologists.

The non science students' mean score was similar to that of the S.4 (15-16 year olds), but the non science post graduates mean was higher than the S.6 (17-18 year olds). This could be explained by the wide variety of backgrounds of the non science post graduates, many of whom were teachers and who would have had some experience of spatial tasks. This would also account for the more pronounced skew in the distribution compared with the smaller skew shown by the non science students.

With P.7 (aged 10-11), S.2 (aged 13-14) and S.4 (aged 15-16) there was a bimodal distribution, most pronounced in the S.4 group. This was not caused by sex differences; the bimodal distribution was evident when the distribution was separated into scores for boys and girls. The bimodal distribution might be explained by the fact that not all the pupils were maturing at the same rate; maturation rates tend to speed up during adolescence. The pupils who were less mature could form a population giving a normal distribution of scores, while the more mature group would produce a distribution further to the right. When the two groups were put together the results would give a bimodal distribution. With the S.4 (aged 15-16) the bimodal distribution was more marked. In addition to maturation factors operating, the S.4 group contained approximately one-third of pupils taking biology as a sole science subject, and this group might not have been so competent in spatial tasks as those pupils taking other sciences combined with biology. This could account for the S.4 distribution being more markedly bimodal than the other groups.

6.1.4 It could be concluded that every day experience added to maturation, would lead to improvement in spatial tasks of the type shown in Test A, i.e. from 3-dimensions to 2-dimensions, but specialised experience would lead to a greater improvement and this would account for the different mean scores and different degrees of skewing across the groups.

The test items were then taken on an item by item basis, and scored as % of wrong answers, to highlight those items found to be difficult.

TABLE 6.2

TEST A

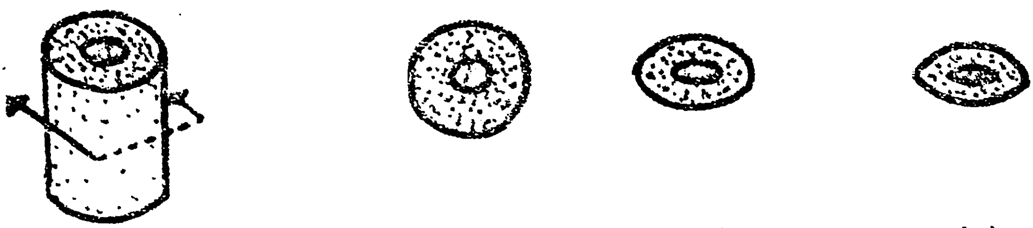
% WRONG ANSWERS

Group Q.	P.4/5	P.7	S.2	S.4	S.6	BIO.ST.	PG.BIO.	NSST	NS.PG.
1	90.5	67.3	50.0	34.9	12.1	2.3	3.0	33.3	25.0
2	23.5	23.1	25.0	28.9	25.6	3.5	1.5	23.3	8.3
3	76.4	58.9	38.2	40.4	25.6	8.2	7.6	26.6	22.2
4	10.3	8.4	2.9	4.8	6.7	2.3	0	6.6	5.5
5	94.3	74.4	55.8	49.3	28.3	15.2	7.6	36.6	13.8
6	25.4	10.5	1.4	7.2	6.7	3.5	3.0	10.0	11.1
7	56.6	30.5	4.4	4.8	6.7	1.1	0	0	8.3
8	79.2	47.3	47.0	34.9	20.2	4.7	1.5	30.0	11.1
9	92.4	85.2	57.3	59.0	39.1	14.1	6.1	56.6	30.5
10	79.2	64.2	47.0	33.7	20.2	5.8	3.0	30.0	11.1

6.1.5 From this table of results, it appeared that transverse sections were recognised more easily than longitudinal sections, possibly because a transverse section can be visualised from a 3-dimensional diagram by altering slightly, the perspective of the top surface. The questions which were answered most accurately were Numbers 4, 6 and 2, in that order. How much alteration of perspective was required to visualise the transverse section seemed difficult for some individuals to assess, when given a choice of different degrees of alteration as in No. 2. Many of the young children and a few of the adults did not appreciate that a cylinder was circular in transverse section, and gave an ellipse as the chosen answer. This suggested that although some individuals could "manipulate" the perspective, they could not do so, accurately.

DIAGRAM 6.2

2. Solid



(a) (b) (c)

With the longitudinal sections, not all were recognised with equal ease. As was stated in Chapter 3, a longitudinal section may be more difficult to recognise as the individual has to be able to visualise what the section would look like in the absence of obvious clues, because the section is virtually hidden. Questions No. 5 and No. 7 were those where the solid was made up of a figure which when sectioned would give transverse and longitudinal sections with straight lines. Questions No. 1, No. 3, No. 8, No. 9 and No. 10 were those which contained diagrams of solids which had curves, and which would give circular or elliptical transverse sections, but longitudinal sections made up of straight lines. Initially it was thought that the diagrams of solids with straight edges were easier to recognise (i.e. No. 5 and No. 7) than the curved solids, but the results showed that No. 5, the hexagonal solid, was found to be the second most difficult item. It might be thought that primary school children would be relatively unfamiliar with this shape and this would account for their low scores on this question, but it did not explain why those with biological knowledge also made mistakes with No. 5, particularly as this shape is a common one; many cells are hexagonal in transverse section and these structures are introduced early on in biology courses.

The original hypothesis on longitudinal sections had to be revised -

> A longitudinal section taken from a solid diagram which has a base or any side which is not made up of straight lines, or where the base or any side has more than 4 sides, are more difficult to recognise than a longitudinal section taken from a solid diagram which has a straight lined base or sides, the sides of which are 4 or less in number.

6.1.6 In order to test the hypothesis that transverse sections are recognised before longitudinal sections, and that simple longitudinal sections are identified before complex ones, a revised Test A was produced and tested on a group of 55, P.7 (aged 10-11) children. (The Revised Test A is in Appendix I.)

In questions No. 5, No. 8 and No. 9, the diagrams used were the same shapes as those in the original Test A, but the solid diagrams were rotated 90° and the longitudinal sections taken through these changed shapes.

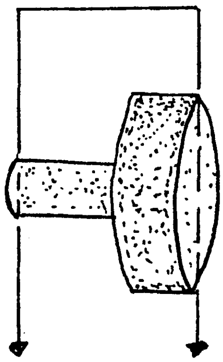
No. 10 was completely revised with a cylinder embedded in two rectangular blocks instead of one block.

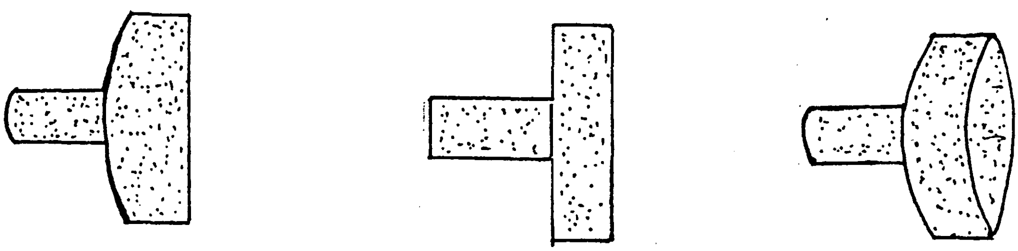
All other items in the test remained the same as those of the original Test A.

DIAGRAM 6.3

8.

Solid.





(a) (b) (c)

The results of the Revised Test A with this group, as a % of wrong answers per item, is tabulated in Table 6.3.

TABLE 6.3

REVISED TEST A

GROUP P.7 (aged 10-11) N = 55

QUESTION	% WRONG ANSWERS
1	70.0
2	22.2
3	62.9
4	9.2
5	87.0
6	22.2
7	24.0
8	68.5
9	77.7
10	77.7

6.1.7 It can be seen with the Revised Test A that transverse sections were recognised more easily than longitudinal sections, and that the complex longitudinal sections, those with sides or bases which were circular or elliptical or had more than 4 sides were more difficult to visualise than the simple longitudinal section of 4 sides.

6.1.8 Tentative conclusions from the results of both Test A and Revised Test A were -

(a) P.4/5 (aged 8-9) - pupils can recognise with reasonable accuracy a transverse section taken from a diagram of a 3-dimensional object.

(b) P.7 (aged 10-11) - pupils can recognise a transverse section and a simple longitudinal section taken from a diagram of a 3-dimensional object.

(c) Secondary school pupils can recognise a transverse section, a simple longitudinal section, and some of the more complex longitudinal sections.

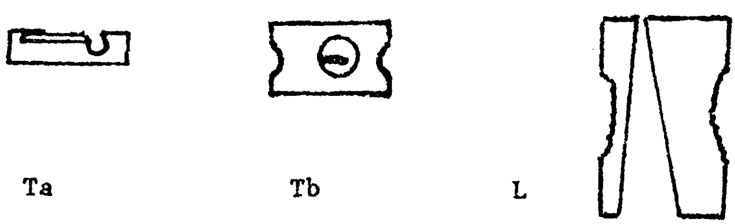
(d) Those with wider experience in the biological sciences have a greater understanding of intricate, complex solid shapes and can distinguish transverse and longitudinal sections more easily than non biologists.

6.1.9 To confirm that the process of recognising a 2-dimensional section taken from a 3-dimensional drawing of a solid took place in the stages suggested, it would be necessary to construct a much longer test which included more items from each category, as these results only give an indication that the aspect of spatial ability, from 3-dimensional to 2-dimensional develops in three stages.

6.2.1 TEST B

Test B was a test of ability to visualise a three dimensional object when given appropriate two dimensional sections.

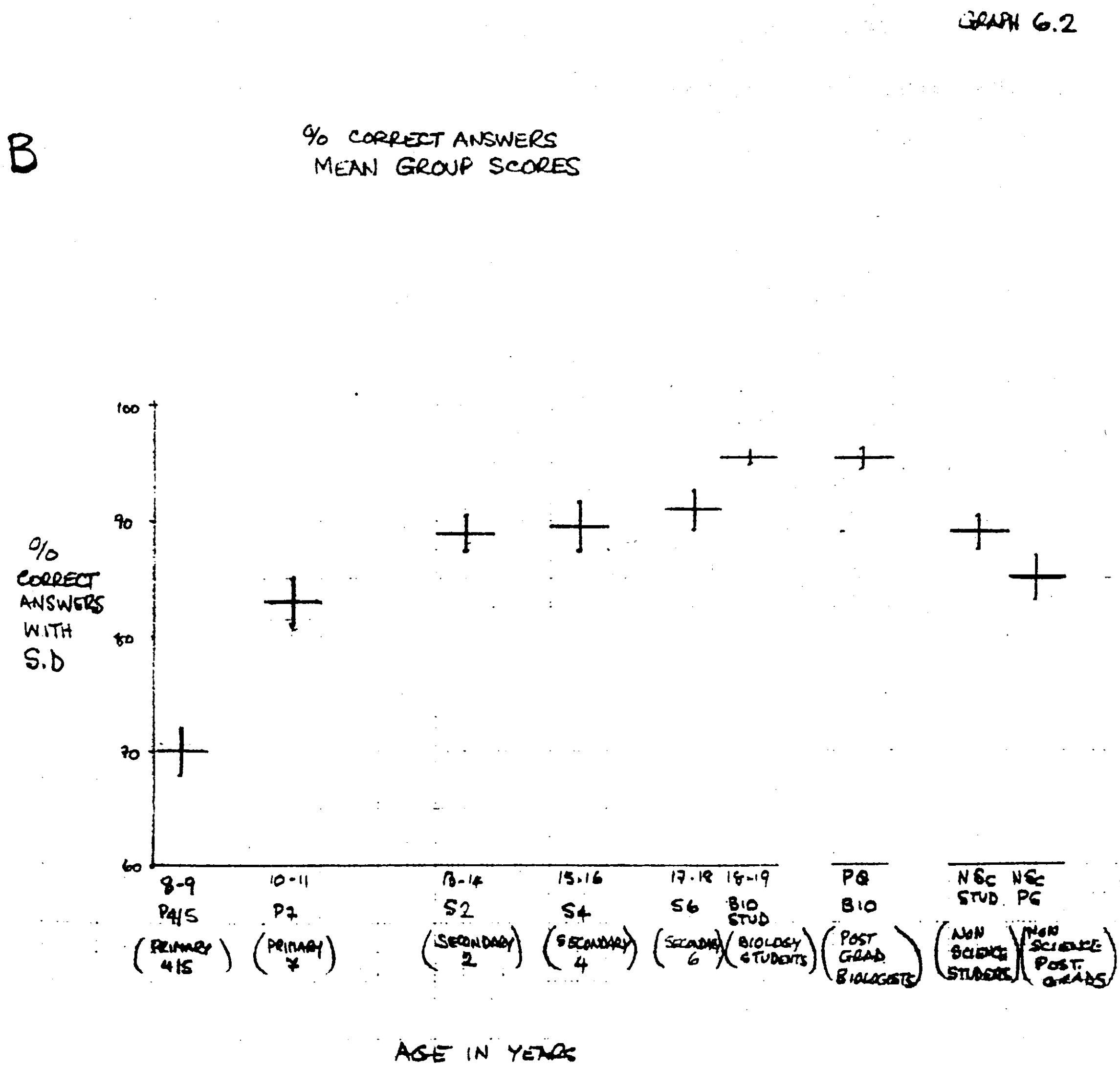
DIAGRAM 6.4



This is a clothes peg, pencil sharpener, camera?

To compare the performance of the different groups, a graph was constructed giving % mean group scores with their standard deviations, plotted against age.

GRAPH 6.2



6.2.2 This test showed a general developmental/maturational pattern but it was not so marked as the one shown by Test A. There was a higher starting point with Test B; the P.4/5 (8-9 years) had a mean score of 70% compared with 37% in Test A. The younger children did less well than the older children, and there was a gradual levelling out at the secondary school level, then rising with the biology students and post graduate biologists whose scores were similar at the 95^{+}% correct scores.

The non science students performed better than the non science post graduates, but both of these groups had scores similar to the secondary school pupils. This suggested that experience in the biological sciences tended to increase the scores.

Table 6.4 shows the group frequency distributions.

TABLE 6.4

TEST B — FREQUENCY DISTRIBUTION TABLE

GROUP	N.	0	1	2	3	4	5	6	7	8	9	10	11	MEAN	S.D
NSPG	36						2	2	3	1	8	7	13	9.3	1.8
NSST	30								2	2	8	9	9	9.7	1.4
PG BIO	65								1	1	3	16	44	10.6	0.96
BIO ST	85									2	6	23	54	10.5	0.9
S6	74				1	1	1	1	1	1	7	18	43	10.1	1.6
S4	83			1	0	0	1	1	2	4	14	29	31	9.8	2.0
S2	68							2	3	6	13	25	19	9.7	1.4
P7	95			1	1	1	2	7	8	6	14	25	30	9.2	2.0
P4/5	106		1	2	1	4	12	7	10	24	20	19	6	7.8	2.2
		NO. CORRECT													
TOTAL	642	0	1	4	3	6	18	20	30	47	93	121	248	9.5	1.8

6.2.3 The table showed that even with the P.4/5 (aged 8-9) group there was a skew to the right, more marked with the P.7 (aged 10-11). As the scores increased so did the skew, reaching a maximum with the biology students and post graduate biologists where the mean group scores were 96%.

The table below gives % wrong answers on an item by item basis.

TABLE 6.5

TEST B

% WRONG ANSWERS

Group Q.	P.4/5	P.7	S.2	S.4	S.6	Bio. St.	P.G. Bio.	N. Sc. St.	N. Sc. P.G.
1	32.0	8.4	17.6	7.2	8.1	2.3	1.5	6.6	5.5
2	8.4	8.4	7.3	4.8	5.4	2.3	3.0	10.0	11.1
3	16.9	15.7	8.8	9.6	2.7	1.1	0	10.0	2.7
4	21.6	11.5	4.4	8.4	5.4	2.3	6.1	16.6	13.8
5	38.6	17.8	11.7	7.2	8.1	2.3	3.0	6.6	2.7
6	30.1	20.0	17.6	20.4	18.9	14.1	4.6	16.6	30.5
7	21.6	15.7	7.3	7.2	9.4	3.5	1.5	6.6	16.6
8	45.2	36.8	32.3	28.9	14.8	9.4	13.8	16.6	25.0
9	38.6	13.6	8.8	8.4	4.0	2.3	0	3.3	11.1
10	26.4	12.6	4.4	6.0	6.7	8.2	13.8	20.0	30.5
11	38.6	15.7	14.7	8.4	4.0	2.3	0	3.3	13.8

6.2.4 The items which were the most difficult to identify were question No. 8 - the "polo mint"; No. 6 - the ruler, and No. 10 - the drawing pin. Question No. 11, the pyramid and No. 5, the coin were more difficult than No. 9, the cone and No. 6, the screwdriver. The easiest objects to identify were found to be No. 3, the filter funnel, No. 4. the pencil sharpener and No. 2, the 4 legged stool.

It would appear that objects with a distinctive and irregular longitudinal section were easily recognised, e.g. the pencil sharpener, whereas those with a less well defined and regular longitudinal section were found to be more difficult to identify, e.g. ruler, and coin.

6.2.5 A Revised Test B was carried out with a sample of 55, P.7 (10-11 years) pupils. Items No. 5, No. 7, No. 8 and No. 10 were altered by modifying the longitudinal section to match a different object from the same list.

(Revised Test B in Appendix I.)

No. 5 became a saucer, No. 7 a lollipop, No. 8 a doughnut and No. 10 a door handle.

TABLE 6.6

REVISED TEST B

GROUP P.7 (aged 10-11) N = 55

QUESTION	% WRONG ANSWERS
1	20.3
2	5.5
3	14.8
4	11.1
5	12.9
6	20.3
7	38.8
8	40.7
9	16.6
10	18.5
11	20.3

As with the original Test B, No. 8 - the "polomint" and the doughnut, proved to be the most difficult. The order of difficulty was very similar to that shown by the corresponding P.7 group on the original Test B.

These results also indicated that those items with a distinctive and irregular longitudinal section were recognised more easily than those with a regular and less distinctive longitudinal section.

The scoring in this test was high as compared with Test A. There could be several possible explanations:-

6.2.6 (a) Test B was much easier than Test A because the items from which the test was constructed were familiar, and the choice given was a name and not a diagram.

(b) It is much easier to build up a 3-dimensional image from 2-dimensional sections as this involves a synthesis rather than an analysis. As was noticed in the trial run, the primary school children soon realised that it was the longitudinal section which gave the best clue to the identification of the object, showing that they did not find it difficult to build up a 3-dimensional image.

(c) Experience of seeing and using 2-dimensional representations of 3-dimensional objects is common, e.g. diagrams of road maps, plans of buildings. Most primary school children can draw a 2-dimensional plan of a journey from home to school.

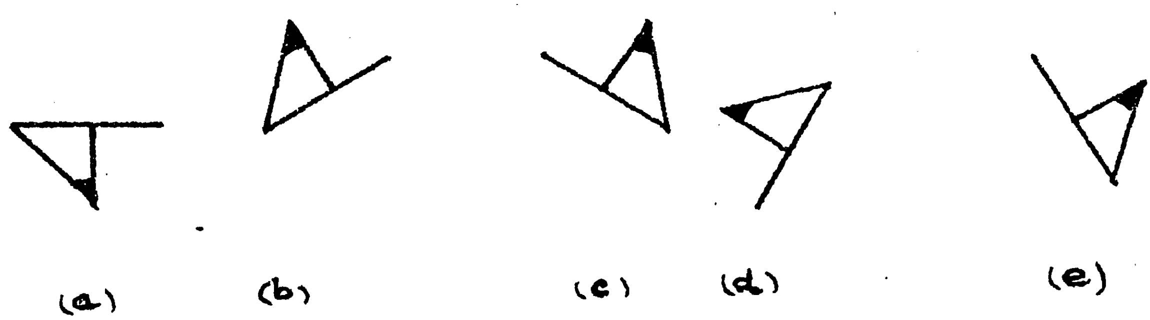
6.2.7 If the high scoring in this test implies that going from 2-dimensions to 3-dimensions is an easier process than from 3-dimensions to 2-dimensions, then this raises questions about the teaching of spatial tasks.

It would seem that the order of teaching should be from 2-dimensions to 3-dimensions first, and not from 3-dimensions to 2-dimensions as has been the custom in the biological sciences.

6.3.1 TEST C

Test C was the test of ability to recognise an object when its orientation is changed.

DIAGRAM 6.5

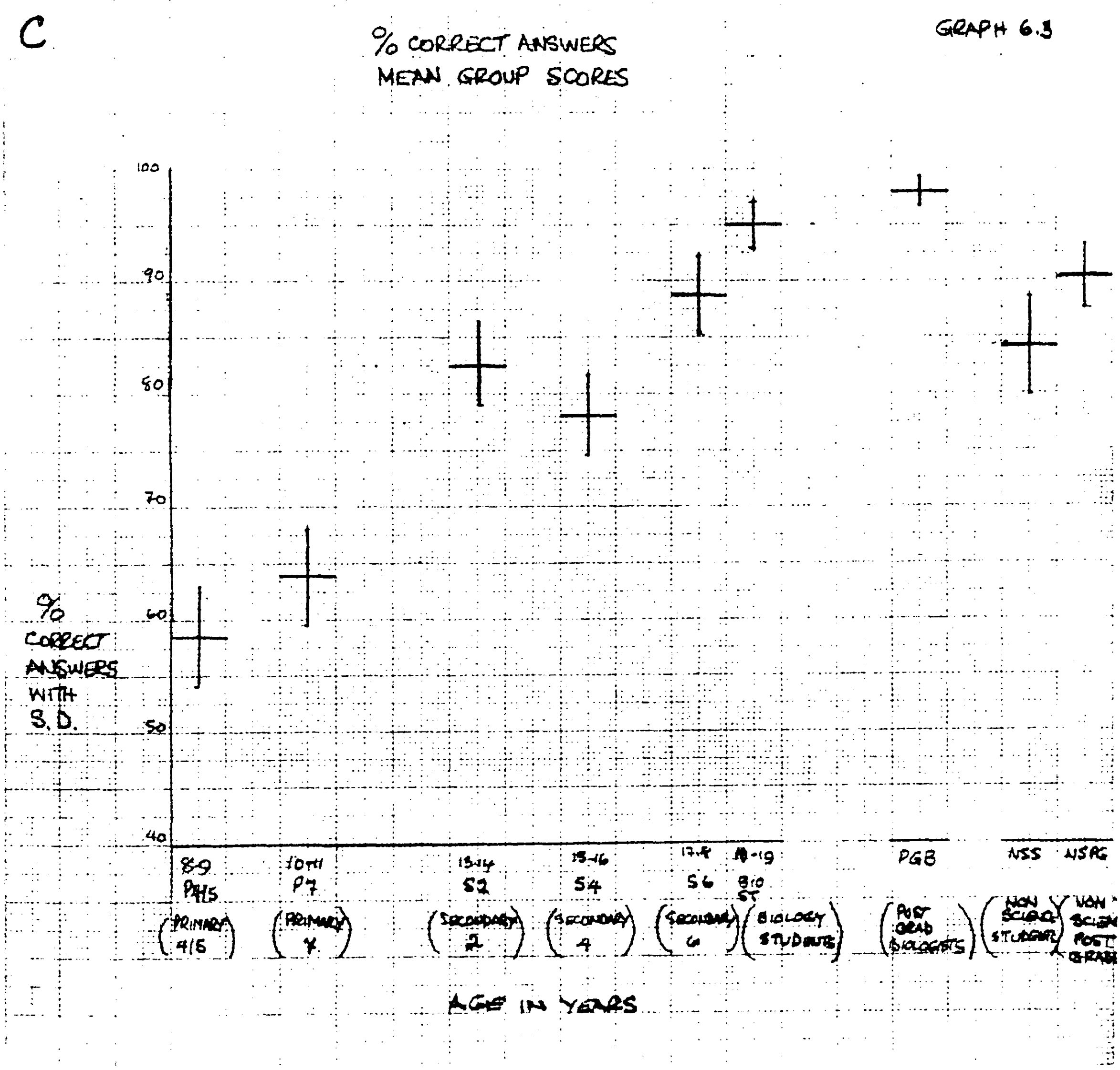


Graph 6.3 represents the % mean group scores with standard deviations plotted against age.

6.3.2 As with Tests A and B, a developmental/maturational pattern emerged; the primary school children did less well than the secondary pupils; the post graduates performed better than the corresponding undergraduate groups. Experience in the biological sciences appeared to increase the scores in S.6 (aged 17-18), the biology students and post graduate biologists, all of whom would have acquired some expertise in the use of a microscope. The S.2 (13-14 years) group had a higher score than the S.4 (15-16 years) group. As has already been mentioned, the S.2 group were made up of pupils who had shown a preference for the sciences whereas the S.4 group contained approximately one-third of pupils studying biology as the sole science combined with non science subjects. This could account for the differences in the scores.

The non science post graduates scored higher than might have been expected, but as many of them were experienced teachers they would have learned to deal with "upside-down" situations in the

GRAPH 6.3



classroom, and this would account for their high scoring.

Table 6.7 shows the frequency distributions of the groups.

TABLE 6.7

TEST C

FREQUENCY DISTRIBUTION

GROUP	N																	MEAN	S.D.
N.S. P.Grad.	36					1	0	0	0	1	0	1	1	3	4	2	23	13.72	2.3
N.S. St.	30		1	1	0	0	1	0	0	2	0	0	1	2	3	4	15	12.62	3.9
P.G. Bio.	65												1	1	3	6	54	14.7	1.0
Bio. St.	85						1	0	0	1	1	1	1	2	4	14	60	14.27	1.8
S.6	74			2	0	2	1	2	0	1	1	1	1	2	4	10	47	13.35	3.3
S.4	83				6	1	3	2	0	6	2	3	7	7	8	7	31	11.72	3.8
S.2	68				2	1	2	2	2	1	1	3	6	4	7	8	29	12.43	3.4
P.7	88				4	4	11	3	6	7	7	6	8	4	8	12	8	9.65	3.6
P.4/5	103		2	1	6	5	12	14	8	3	10	7	8	8	8	5	6	8.48	3.8
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15		
		NO. CORRECT																	
Totals	632		3	4	18	14	31	23	16	22	22	22	34	33	49	68	273	11.98	3.8

6.3.3 The frequency distribution of P.4/5 (aged 8-9) and P.7 (aged 10-11) scores showed a wide scatter which suggested that some of the pupils resorted to guessing the answer. The difference in the mean scores of these two primary school groups probably indicated that this skill involving orientation was at an early stage of development. As competence improved during the secondary school stage, the distribution began to skew, noticeable even at the S.2 (13-14 years) level. The skew was progressive peaking with the post graduate biologists where over 80% of the group had a perfect score of 15. There was a fairly stable standard deviation of approximately 3 with all the groups except the biology students and post graduate biologists where the standard deviation was 1.6 and 1.0 respectively, which was to be expected with the highly selected group of biologists who had had experience of orientation tasks. Apart from these two groups there were a number of individuals in every other group who had problems with orientation. Excluding the primary school children, 15% of the sample, scored less than 8 out of 15.

Table 6.8 shows the % wrong answers.

6.3.4 The most difficult items were No. 8, No. 14, No. 6 and No. 5. There did not appear to be a common factor linking these items either in design or in the position of the mirror image in the sequence. By far the easiest was No. 1, the name "David" possibly because a mirror image of a name was easier to recognise than a mirrored shape.

6.3.5 Because a number of pupils had difficulty with orientation, it is important that in the introductory teaching in the use of a microscope that the object being viewed should be presented in the same orientation as the blackboard or text book diagram otherwise it may not be recognised.

TABLE 6.8

TEST C

% WRONG ANSWERS

Group / Q.	P.4/5	P.7	S.2	S.4	S.6	Bio. St.	P.G. Bio.	N.S. St.	N.S. P.Grad.
1	0.9	1.1	0	3.6	0	0	0	6.6	0
2	49.5	31.0	16.1	22.8	10.8	7.0	7.6	26.6	11.1
3	50.4	24.1	13.2	18.0	12.1	4.7	0	10.0	11.1
4	16.5	18.3	10.2	15.6	5.4	4.7	1.5	23.3	11.1
5	52.4	47.1	20.5	21.6	16.2	8.2	3.0	23.3	8.3
6	60.1	48.2	20.0	37.3	13.5	3.5	3.0	16.6	5.5
7	46.6	40.2	11.7	22.8	10.8	0	0	10.0	2.7
8	68.9	64.3	27.9	31.3	13.5	4.7	3.0	16.6	13.8
9	29.1	19.5	11.7	18.0	12.1	4.7	4.6	10.0	2.7
10	42.7	41.3	23.5	28.9	9.4	3.5	1.5	13.3	8.3
11	27.1	35.6	14.7	19.2	9.4	7.0	1.5	16.6	5.5
12	51.4	39.0	16.1	15.6	8.1	3.5	0	10.0	11.1
13	48.5	37.9	20.0	20.4	5.4	4.7	1.5	13.3	11.1
14	66.0	60.9	32.3	30.1	14.8	9.4	1.5	16.6	11.1
15	33.0	33.3	16.1	20.4	17.5	4.7	0	16.6	11.1

6.4.1 TEST D

Test D was a test of ability to look for and to find a number of solutions to a problem using the technique of grouping items into like categories. A typical list was: COAL, WOOD, NORTHSEA GAS, COKE, PETROL, and individuals were asked to group the items into as many sets as they could. It was hoped that this test would give some measure of divergence; the greater the number of responses, the greater the divergence.

As was previously stated, the results of this test must be viewed with some caution, as several of the adults had not read the instructions properly and consequently gave only one response per list. The scores of the undergraduates and post graduates should probably have been slightly higher than those shown in the results.

Graph 6.4 shows the % mean group scores of acceptable responses with their standard deviations, plotted against age.

6.4.2 A slight developmental/maturational trend showed, with the primary school children doing less well than the secondary groups, and the post graduates performing better than the corresponding undergraduate groups. The non science students and the non science post graduates mean scores were marginally less than the biology students and the post graduate biologists.

Table 6.9 gives the frequency distribution of the number of responses, in bands.

6.4.3 There was a wide spread of results with a high standard deviation in every group. Apart from a few individuals in each group who had high scores, the general pattern was almost that of a normal distribution curve, the curve moving to the right with increase in age. The post graduate scores were higher than the corresponding undergraduate groups. This might suggest that the post graduates were more divergent than the undergraduates, but it could also be argued that the post graduates were likely to have a better command of language than the undergraduates. If language expertise had been the sole factor which influenced scores, then the non science post graduates and the non science students should

GRAPH 6.4

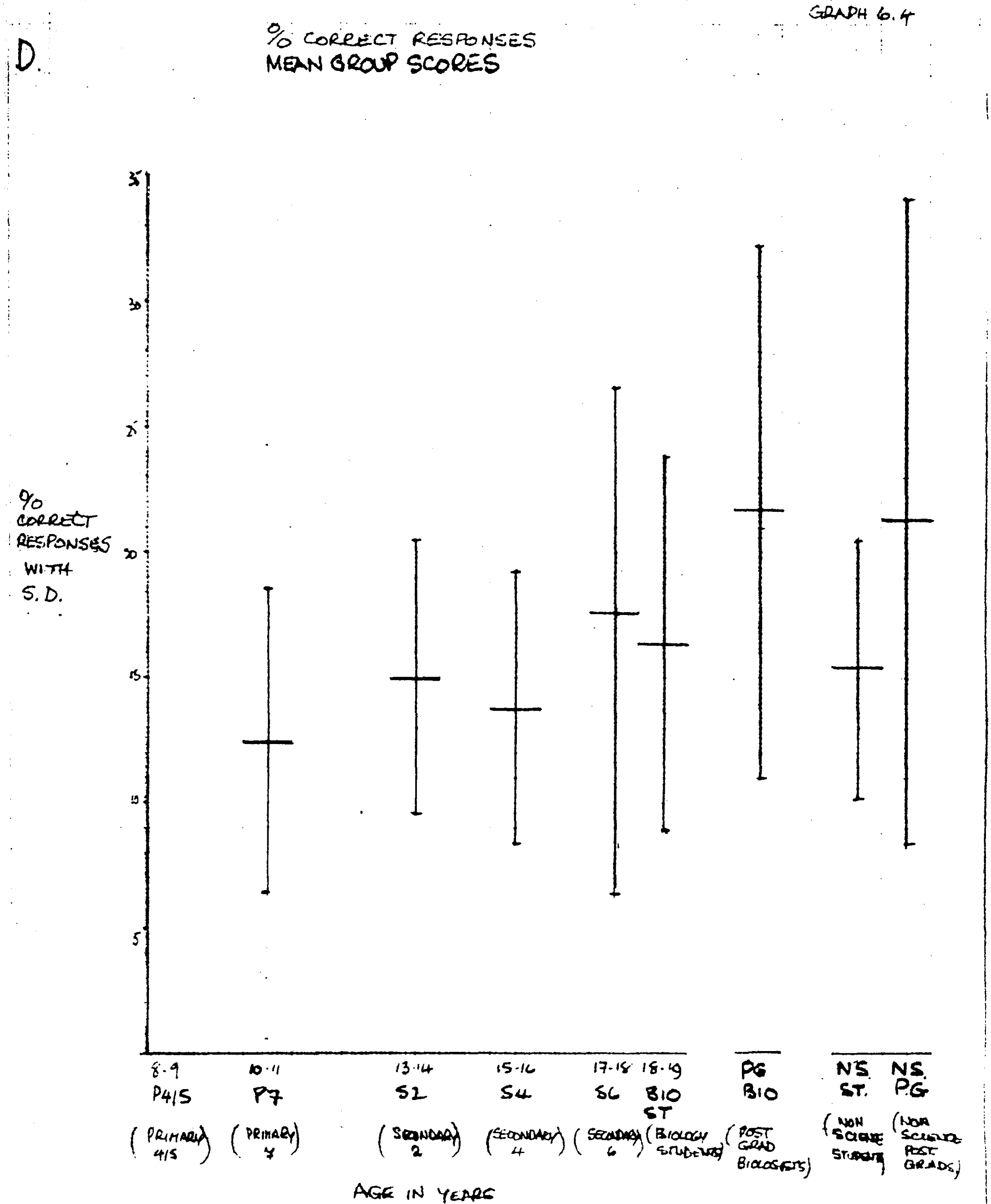

GRAPH 6.4
D.
% CORRECT RESPONSES
MEAN GROUP SCORES
% CORRECT RESPONSES WITH S.D.
35
30
25
20
15
10
5
8-9
P4/5
(PRIMARY 4/5)
10-11
P7
(PRIMARY 7)
13-14
S2
(SECONDARY 2)
15-16
S4
(SECONDARY 4)
17-18
S6
(SECONDARY 6)
18-19
BIO ST
(BIOLOGY STUDENTS)
PG
BIO
(POST GRAD BIOLOGISTS)
N.S.
ST.
(NON SCIENCE STUDENTS)
N.S.
P.G.
(NON SCIENCE POST GRADS)
AGE IN YEARS

TABLE 6.9

TEST D

FREQUENCY DISTRIBUTION

GROUP	N.	0-3	4-7	8-11	12-15	16-19	20-23	24-27	28-31	32-35	36-39	40-43	44-47	45-51	52-55	56-59	60-63	64-67	MEAN	S.D.
NS.PG.	36	1	1	3	7	10	5	3	2	0	0	0	2	0	0	1	0	1	21.2	13.0
NS.ST.	30	1	0	4	9	10	5	1											15.6	5.1
PG.BI.	65	1	2	5	9	10	17	9	5	2	1	1	0	1	1	0	0	1	21.89	10.8
BI.ST.	85	2	1	13	26	21	14	3	0	1	2	0	2						16.63	7.7
S.6	74	3	0	9	18	18	11	5	8	0	0	0	0	0	2				17.77	9.1
S.4	83	1	7	24	28	14	5	2	1	0	1								13.44	5.4
S.2	68		2	17	26	11	6	3	2	1									15.0	5.5
P.7	92	5	9	31	23	16	3	1	2	2									12.57	6.0
Total	533	14	22	106	146	110	66	27	20	6	4	1	4	1	3	1	0	2	16.16	8.5

NO. OF RESPONSES

have had higher scores than the post graduate biologists and biology students, because the non scientists would have been more experienced in the field of language than the scientists.

6.4.4 Originally it was thought that the responses given by the groups would divide into two categories; sets formed which were linguistic in origin, and those which depended on other characteristics. Linguistic responses were those in which the grouping was done using such criteria as double letters in a word, palindromes, number of syllables, words beginning and ending with the same letter, and derivations of words. These linguistic responses when they occurred, did so across all groups. Differences were only noticeable with the post graduate groups, where the non-science post graduates gave a greater number of linguistic responses than the post graduate biologists, although the total number of responses was similar.

6.4.5 The quality of the responses was not assessed, but the primary school children gave the most novel answers. In No. 1, several of the young children gave "bat" as the odd one out, stating that it was not an animal but was "something used to hit a ball"; and in No. 3 gave "squash" as a fruit drink and not a game. One child gave No. 4 - "square" was not a shape but "a kind of dance". To P.7 (aged 10-11) "coke" was a well known soft drink, but to S.6 (age 17-18) and the biology students "coke" was also given as a short name for "cocaine".

6.4.6 If this test gives any indication of divergence then it would appear that the biologists were no more or no less divergent than corresponding groups of non-scientists. It may be that since divergent responses are not normally encouraged in formal science that individuals are reluctant to respond divergently even when invited to do so. The primary school children seemed to be less inhibited, but were hampered by their lack of skill in expressing themselves in a written form. It might have been more appropriate to conduct this test orally and on an individual basis with the primary school children. With the older students and adults it might have been profitable to word the instructions "What answers might a young child give", to make the test more acceptable to the older age range. Torrance (32) used this idea when giving creativity tests to adults.

6.5.1 TEST E

Test E was a test of ability to recognise and abstract relevant information from a distracting background.

DIAGRAM 6.6

LOOK FOR THIS SHAPE

(a) 0 - 1 - 2 more

(b) 0 - 1 - 2 more

(c) 0 - 1 - 2 more

(d) 0 - 1 - 2 - more

Although this is a specific skill required by biologists it can also be used to test for the cognitive style Field Independence (62), as one way for testing for this style is by using an Embedded Figure Test. In addition form recognition is also thought to be one aspect of spatial ability where embedded figures can be used to detect this spatial skill (22).

Graph 6.5 gives the % mean group scores of figures correctly identified with standard deviations plotted against age.

6.5.2 As with the other tests, a developmental/maturational pattern emerged, the younger children doing less well than the older ones, and the post graduates performing better than the corresponding under graduate groups. The biology students did not score as highly as the S.6 (aged 17-18) group. This could be explained by the fact that the biology students completed the battery of tests at the end of an afternoon practical class, and probably by the time they tackled Test E, some of them were becoming tired.

The test was marked on the number of hidden figures correctly identified. Some of the embedded figures had a different orientation to the one shown in the diagram. As with Test C many pupils rotated the paper when looking for the hidden figures. Those who had difficulty with orientation probably missed more figures than those who had not.

Individuals in every group "found" figures which were not present, even the post graduate biologists. The number of figures "imagined" by the graduate groups was smaller than those of the other groups. The largest number of "imagined" figures was given by P.7 (10-11) and not P.4/5 (aged 8-9) as might have been expected.

Table 6.10 is a table of frequency distributions of group scores.

GRAPH 6.5

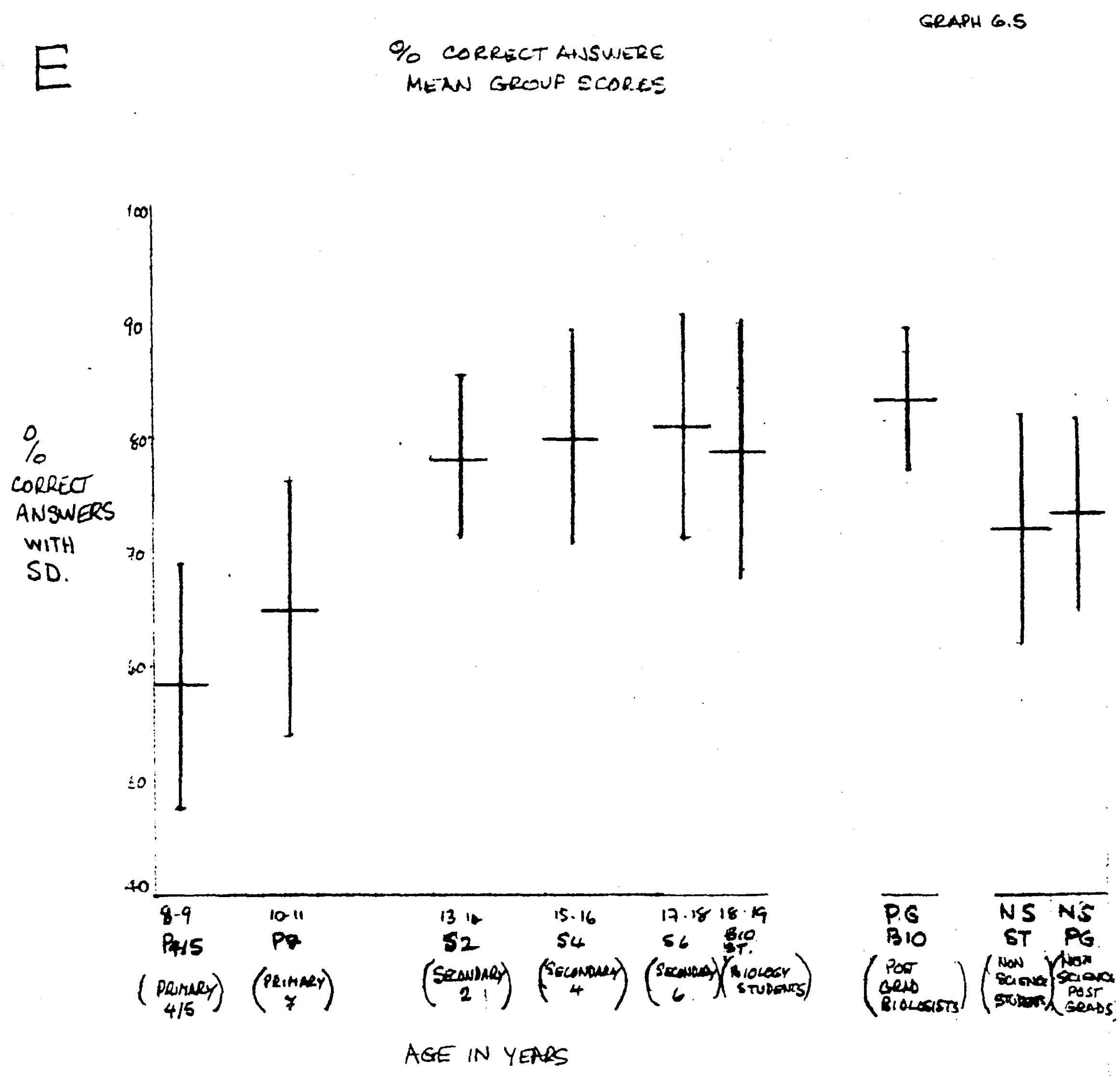

GRAPH 6.5
E
% CORRECT ANSWERS
MEAN GROUP SCORES
% CORRECT ANSWERS WITH SD.
100
90
80
70
60
50
40
8-9
P4/5
(PRIMARY 4/5)
10-11
P7
(PRIMARY 7)
13 14
S2
(SECONDARY 2)
15-16
S4
(SECONDARY 4)
17-18
S6
(SECONDARY 6)
18-19
BIO ST.
(BIOLOGY STUDENTS)
P.G
BIO
(POST GRAD BIOLOGISTS)
N S
ST
(NON SCIENCE STUDENTS)
N S
PG
(NON SCIENCE POST GRADS)
AGE IN YEARS

TABLE 6.10

TEST E

FREQUENCY DISTRIBUTION

GROUP	N	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-82	MEAN	S.D.	% MISSED FIGURES
N.S. P.G.	34								4	2	4	6	10	5	3		60.0	8.7	23.1
N.S. ST.	30				1	0	0	1	2	3	3	6	9	3	2		61.1	10.9	25.4
P.G. BIC.	65								1	1	4	15	16	16	12		68.2	6.6	16.8
BIO. ST.	79				1	0	2	5	3	6	7	8	19	15	10	3	63.4	12.0	17.7
S.6	74						1	2	2	1	6	7	20	15	16	4	67.9	9.6	14.8
S.4	88						2	0	1	9	9	14	9	25	13	1	65.9	9.6	17.8
S.2	70						2	1	4	3	7	14	19	13	7		63.6	9.0	20.7
P.7	88		1	1	1	2	5	10	11	17	7	12	15	5	1		53.7	12.1	30.2
P.4/5	103	1	1	2	3	11	10	15	16	13	12	12	4	1	2		46.8	12.7	40.4
		10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-82			
		NO. CORRECTLY IDENTIFIED																	
Totals	626	1	2	3	6	13	22	34	44	55	59	94	121	98	66	8	60.6	12.5	27.3

TABLE 6.11

TEST E

FREQUENCY DISTRIBUTION

PRIMARY 4 (Aged 8) AND PRIMARY 5 (Aged 9)

GROUP	N	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-82	MEAN	S.D.	% MISSED FIGURES
P. 5	49				1	1	3	3	8	8	10	8	4	1	2		53.8	10.4	34.3
P. 4	54	1	1	2	2	10	7	12	8	6	2	3					40.2	10.7	50.7

NO. CORRECTLY IDENTIFIED

6.5.3 This was the only test where there was a decided difference between the P.4 pupils (aged 8) and the P.5 pupils (aged 9).

Table 6.11 shows that the distribution was almost a normal distribution for both groups but the P.4 (8 year old) children missed approximately 50% of the missing figures while the 9 year olds failed to find approximately 35%.

The P.7 (aged 10-11) distribution was bimodal and this suggested that there could be an age factor operating and that the younger children in this group were less skilled than the older ones, giving two slightly different distributions similar to the one seen with the 8 year olds and 9 year olds.

With S.2 (13-14 years) the distribution showed a slight skew to the right. With S.4 (15-16 years) there was a further skew but here the curve was bimodal probably because of the subject mix in this particular group rather than an age difference. With S.6 (aged 17-18) and the biology students skewing was increased, but there was a substantial tail of biology students whose scores were low. This might have been the result of fatigue. With the post graduate biologists there was a decided skew to the right which suggested that the post graduate biologists had developed a successful disembedding technique. The distribution of scores of the non science students and non-science post graduates was similar to that of the S.2 (13-14 years) group, but the spread of scores was wider with the non-science students, with a tail similar to that shown by the biology students.

Table 6.12 gives the % of missed figures taken question by question, for each of the groups.

TABLE 6.12

TEST E

% MISSED FIGURES

GROUP QUESTION	P.4/5	P.7	S.2	S.4	S.6	BIO.ST.	PG.BIO.	NS.ST.	NS.PG.
2	10.8	7.4	4.0	3.6	5.6	3.6	4.5	8.8	9.8
3	18.8	8.0	4.5	4.5	6.2	4.5	4.9	6.6	8.8
4	56.1	36.7	32.2	28.0	25.4	28.0	27.0	37.6	35.2
5	62.8	37.2	27.1	24.7	20.8	24.9	20.4	34.7	33.1
6	38.1	17.2	13.5	13.2	7.2	13.2	5.8	15.0	7.3
7	12.0	10.3	5.4	5.0	9.7	5.0	15.0	12.0	10.0
8	19.5	14.6	5.7	4.4	3.1	4.4	5.7	12.9	11.1
9	59.7	68.7	36.6	26.9	30.1	26.9	54.1	54.9	70.5
10	43.8	39.9	32.2	29.7	22.0	29.7	17.8	30.9	28.5
11	60.2	49.6	35.0	28.0	19.1	28.0	14.5	30.3	18.9
12	55.7	37.2	28.3	22.0	20.8	22.0	16.0	20.9	26.0
13	23.6	14.5	7.8	11.2	2.0	11.2	1.5	7.7	4.9
No. 'Imagined' per Person	1.6	4.4	1.4	1.6	1.8	1.6	0.5	1.5	0.7

6.5.4 The most difficult question was No. 9, the one containing the figures of the "star", followed by No. 4 - the "teddy bear", No. 11 - the "part cylinder" and No. 5 - the "mushroom". The order of difficulty was slightly different for the different groups. The ones which proved to be the easiest were No. 2 - the "three grapes", No. 8 - the "skittle" and No. 3 - the "ellipse".

The items causing difficulty belonged to one of the following categories -

(a) Shapes embedded in another shape, e.g. "telescoped" part cylinders in No. 11, the two entwined "hearts" in the third circle of No. 10.

(b) Shapes which were surrounded by similar shapes, e.g. the "teddy bears" in No. 4, and number 2 in No. 12.

(c) Shapes constructed of straight lines rather than curves, e.g. No. 9 - the "star".

(d) Shapes which were incorporated into part of the boundary circle, e.g. the "mushroom".

6.5.5 To find out if these types of shapes were more difficult to distinguish than others a Revised Test E was constructed and tested with a group of 55, P.7 (10-11 years) children. (Revised Test E is in Appendix I.)

The following questions were altered -

No. 4 - a "mouse head" replaced the "teddy bear"
No. 5 - a "club head" replaced the "mushroom"
No. 9 - a "trapezium" replaced the "star"
No.11 - a "wavy flag" replaced the "part cylinder" and was telescoped into other flags as the cylinders had been.
No.12 - the number "2" was replaced by number "5".

In all of the new items the same number of shapes was incorporated into the distracting background, and placed in the same positions within the four circles, in order to avoid the introduction of additional variables. (Revised Test E in Appendix I.)

Table 6.13 shows the results of this Revised Test E.

TABLE 6.13

REVISED TEST E
WITH P.7 (aged 10-11)

QUESTION	% MISSED
2	5.7
3	7.2
4	35.0
5	71.1
6	32.7
7	5.4
8	13.3
9	77.2
10	41.5
11	72.7
12	63.3
13	14.8
TOTAL % MISSED	39.3
NO. IMAGINED PER PERSON	3.6

6.5.6 The order of difficulty for the Revised Test E with P.7, gave almost the same results as the original Test E with the same age range. In the original Test E the order was No. 9, No. 11, No. 5, No. 12 and No. 4, whereas with the Revised test it was No. 9, No. 11, No. 5, No. 12, but the next was No. 10, which was then followed by No. 4. It was interesting to note that the hidden animals, the "teddy bear" and "mouse" in No. 4 was found to be relatively more difficult to find by the adults, and was rated as the second most difficult item by them.

The number of shapes missed in the Revised Test E was 39% compared with 30% on the original test but the number "imagined" was slightly lower at 3.6 per person, compared with 4.4 per person in the original test. It would seem that if shapes are well hidden, by similarity of background, overlap, straight lined structures, and those impinging on the boundary, then these are the most difficult to distinguish.

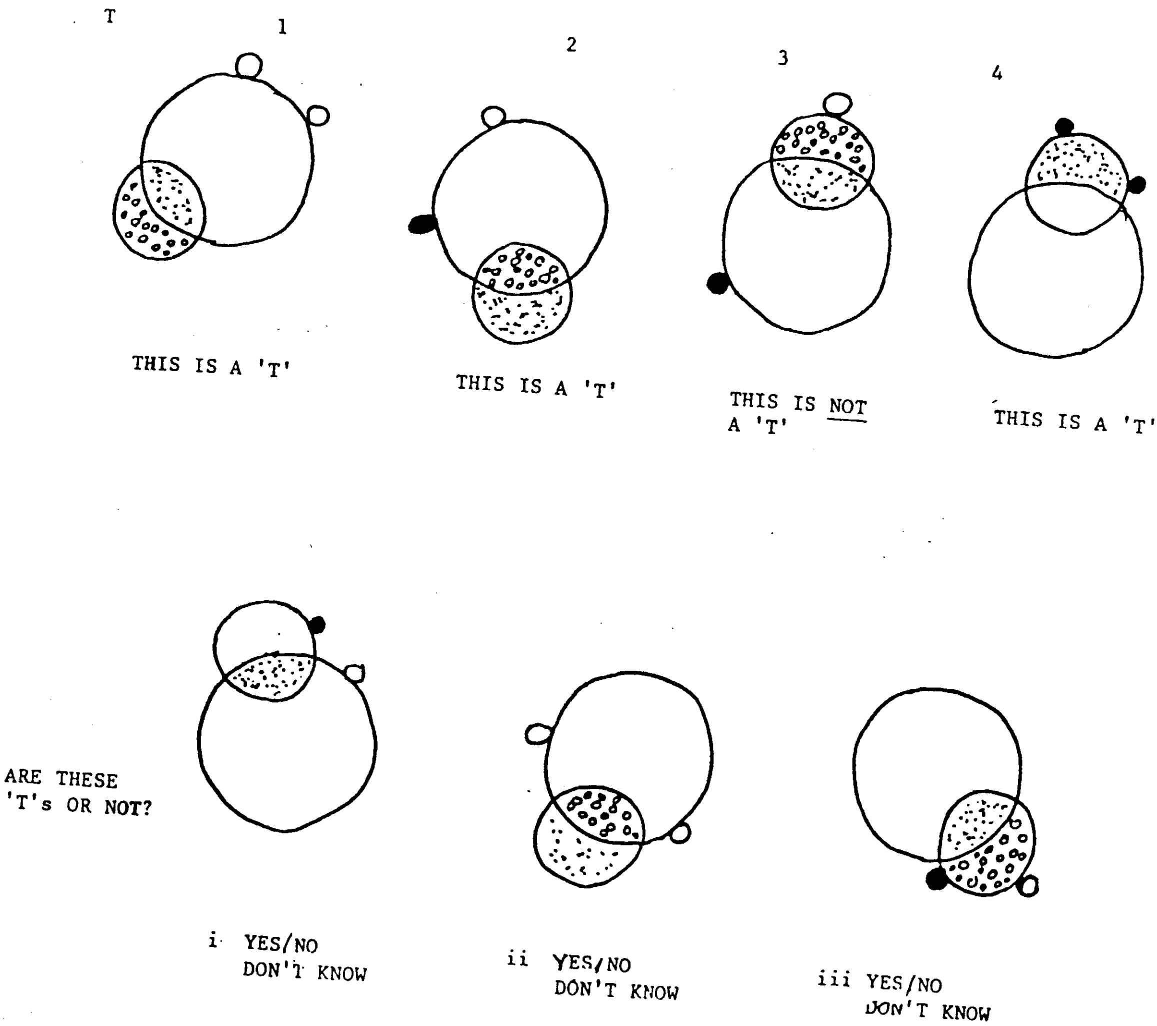
6.5.7 If Test E gives an indication of the cognitive style Field Independence, then it would appear that those with a good background in the biological sciences contain a higher proportion of Field Independent individuals than the non science groups. It would also seem that a cognitive style is a developing style and is not easily detectable below the age of 13-14. It could be argued that those who have a strong Field Dependent cognitive style are not likely to be attracted to the sciences, particularly the biological sciences, and so these individuals are progressively "filtered out" during their school years, and in the early stages of their tertiary education.

The relationship of Test E to spatial ability will be considered in a later section when the inter relationships of the six tests are discussed.

6.6.1 <u>TEST F</u>

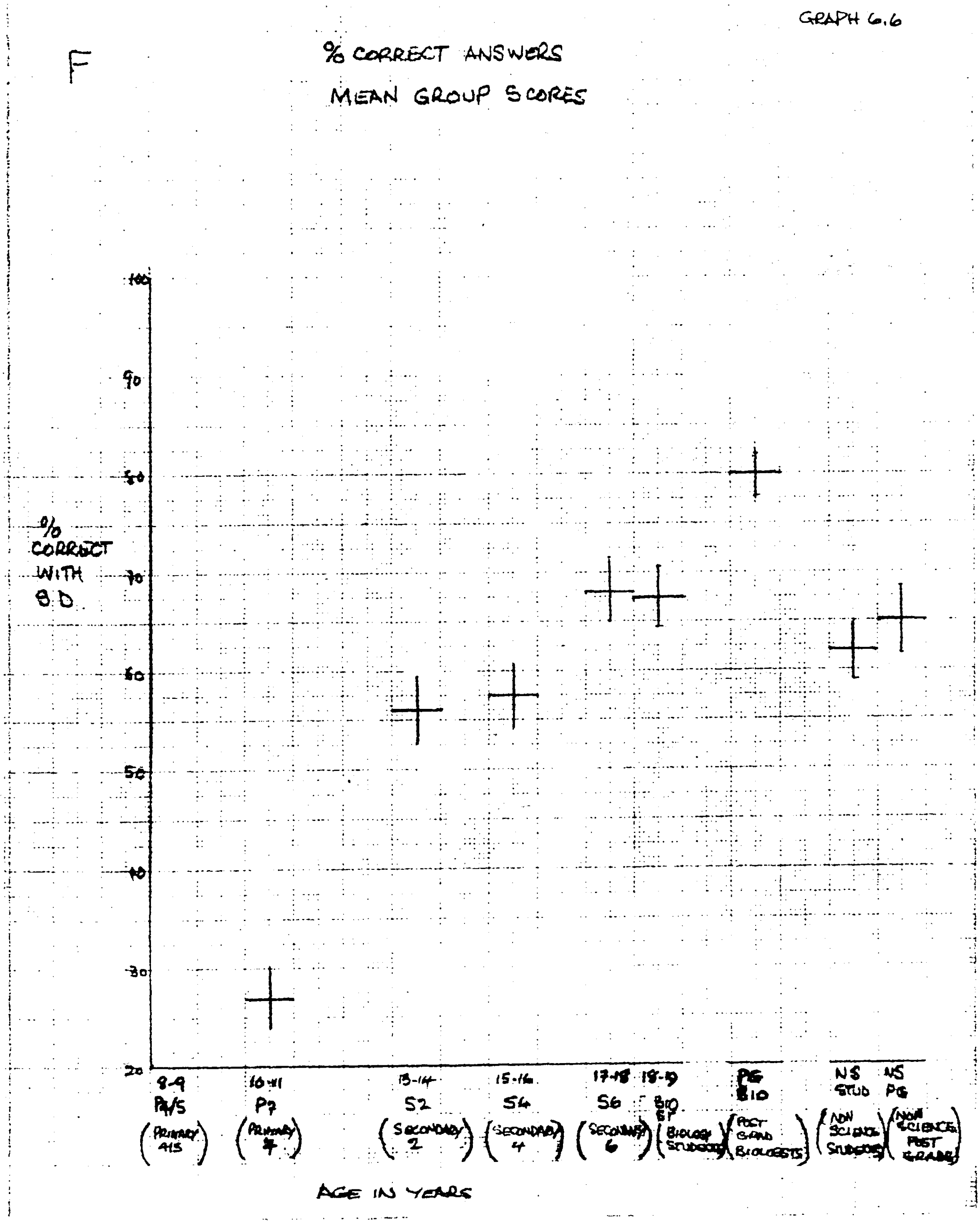
Test F was a test of ability to abstract relevant information, to group characteristics which are similar but not identical, and to use them in a new situation.

DIAGRAM 6.7



This test demands good analytical ability. Graph 6.6 gives the % mean group scores of correct answers plotted against age.

GRAPH 6.6


GRAPH 6.6
F
% CORRECT ANSWERS
MEAN GROUP SCORES
% CORRECT WITH S.D.
100
90
80
70
60
50
40
30
20
8-9
P4/5
(PRIMARY 4/5)
10-11
P7
(PRIMARY 7)
13-14
S2
(SECONDARY 2)
15-16
S4
(SECONDARY 4)
17-18
S6
(SECONDARY 6)
18-19
BIO
(BIOLOGY STUDENTS)
PG
BIO
(POST GRAD BIOLOGISTS)
NS
STUD
(NON SCIENCE STUDENTS)
NS
PG
(NON SCIENCE POST GRADS)
AGE IN YEARS

6.6.2 As with the other tests, Test F showed a developmental/ maturational pattern, the P.7 children (aged 10-11) did appreciably less well than the secondary pupils; the post graduates showed more competence than the corresponding undergraduate groups. This developmental trend differed from the previous tests in two ways; the large difference between P.7 (aged 10-11) and S.2 (aged 13-14), and the small differences between the ages of 13 and 16, and between 17 and 19. It would appear that analytical ability is not well developed at the primary school level but develops rapidly thereafter. If it is thought that experience in the biological sciences increases analytical ability or that those without good ability in this field do not opt for the biological sciences, then this would account for the decided improvement at S.6 (17-18 years) and to the peak shown by the post graduate biologists, and also for the smaller increase in scores and the levelling out shown by the two non science groups, the non science students and the non science post graduates.

Table 6.14 shows group frequency distributions.

6.6.3 With the P.7 (aged 10-11) there was a decided skew to the left which suggested that analytical ability was not well developed in this age group. If a score of 8, i.e. 75% correct was taken as an index of competence, then approximately 10% of the primary pupils showed ability in analysis.

With the S.2 (aged 13-14), although the scatter of results was wide there was a slight skew to the right. The pattern of distribution was similar with S.4 (15-16 years). In both groups the level of analytical competence rose to approximately 50%. With the S.6 (17-18 years) pupils there were more individuals in the top score bands, the competence level rising to approximately 70%. The results were similar with the biology students. Both groups, S.6 and the biology students showed a tail which probably represented those who were less competent in analysis, perhaps having little aptitude for the biological sciences.

With the post graduate biologists the skew was more marked, the competence level rising to above 90%. Even with the post graduate biologists, there was a short tail.

TABLE 6.14

TEST F

FREQUENCY DISTRIBUTION

GROUP	N														MEAN	S.D.
N.S. P.G.	36	3	1	0	3	1	1	2	3	1	5	4	4	5	7.83	3.8
N.S. ST.	30	0	0	2	4	0	3	2	3	3	3	4	3	3	7.46	3.2
P.G. BIOL.	92	0	0	3	1	3	1	1	1	8	13	27	18	16	9.56	2.3
BIOL. ST.	70	1	7	4	2	0	1	3	2	6	8	16	11	9	8.1	3.7
S.6	74	2	2	3	3	3	2	2	5	10	10	11	11	10	8.22	3.3
S.4	83	4	3	5	5	5	7	5	3	9	15	11	10	1	6.9	3.4
S.2	70	1	2	6	4	5	4	6	5	7	8	14	16	2	6.71	3.3
P.7	176	33	21	36	19	20	12	8	9	7	2	8	1	0	3.21	2.8
		0	1	2	3	4	5	6	7	8	9	10	11	12		
		NO. CORRECT														
TOTALS	631	44	36	59	41	37	31	29	31	51	64	95	67	46	6.6	3.8

TABLE 6.15

TEST F

% WRONG ANSWERS

QUESTION GROUP	P.7	S.2	S.4	S.6	Bio. St.	P.G. Bio.	N.S. St.	N.S. P.G.
2	75.0	25.7	38.5	21.6	20.0	9.2	20.0	19.4
3	60.8	38.5	44.5	36.4	42.8	35.3	56.6	55.5
4	58.6	30.0	28.9	29.7	21.4	15.3	30.0	33.3
5	79.3	51.4	49.3	48.6	42.8	36.9	50.0	36.1
6	79.3	71.4	65.0	50.0	54.2	43.0	56.6	58.3
7	73.9	25.7	30.1	18.7	21.4	12.3	30.0	36.1
8	57.6	27.1	21.5	22.9	30.0	9.2	16.6	19.4
9	54.3	27.1	21.5	18.9	21.4	9.2	20.0	19.4
10	73.9	32.8	28.9	22.9	27.1	12.3	20.0	36.1
11	77.1	48.5	45.7	27.0	27.1	15.3	43.3	44.4
12	78.2	51.4	50.6	36.4	38.5	29.2	50.0	38.8
13	88.0	61.4	67.4	36.4	31.4	27.6	56.6	41.6

With the non-science students, the competence level was approximately 50% similar to that of the S.2 and S.4 groups. The non-science post graduates had a higher level of approximately 60%. Both these groups showed a wide scatter. It was unlikely that the scatter was the result of guessing because of the number of possible combinations of responses in a set of three.

The test was scored on the basis that all three diagrams had to be correctly identified as belonging to or not belonging to the set. A "don't know" response for any of the three answers was marked as wrong because it showed that the individual had not fathomed which characteristics were common to the diagrams and which were not.

Table 6.15 shows the percentage wrong answers.

6.6.4 Of the test items, No. 6 was found to be the most difficult and No. 9 the easiest. Other easy items were No. 8 and No. 2; difficult items No. 5, No. 12 and No. 13.

In the construction of items for this test, it was difficult to assess which items were likely to be easier than others. The writer believed that the easiest was No. 2 but this was not borne out by the results.

6.6.5 As was mentioned before, language seemed to play an important role in aiding the individual to answer the test items. This was the only test where many pupils talked to themselves; probably the adults did too, but not aloud. The need to verbalise even when confronted with a non verbal situation might account for the low scores given by the primary school children whose language skills were less well developed than the older pupils and adults. According to Maccoby (86), language is used in all problem solving situations, even in spatial ability tests.

Having reviewed the tests individually, the next stage was to consider the inter-relationships of the six tests.

CHAPTER 7

ANALYSIS OF RESULTS - INTER-RELATIONSHIPS OF THE TESTS

7.1 Tests A, B and C all measured different aspects of spatial ability; Test A - 3-D to 2-D skills, Test B - 2-D to 3-D skills, and Test C, orientation skills. It would be expected that there would be positive correlations between the test results across the groups. Test E could also be considered to indicate the spatial ability of form recognition, and so Test E should also give positive correlations with Tests A, B and C. As many of the hidden figures in Test E were of different orientations, this test should give a positive correlation with Test C, the orientation skills test.

Another possible positive correlation may be between Test E and Test F; Test E was a test for Field Independence, and Test F, analytical ability. According to several researchers, (68) (69) those with good analytical skills were more Field Independent than those whose analytical ability was poor.

Test D, the test for divergence, was unlikely to relate closely to other tests for two reasons; there was some considerable doubt as to whether this test measured divergence adequately, and also, the test results of the undergraduates and post graduates were suspect because the instructions had not been understood properly, and so the number of responses given was probably less than would have been given, had the test been administered under more controlled conditions.

7.2 It was noticed that not all aspects of spatial ability developed at the same rate, and so the level of competence in each test, although increasing with age, did not develop in step with the other spatial tests. Competence in one field of spatial ability could not be directly equated with competence in a different sphere.

To compare the developmental patterns of spatial ability, Piaget's measure was taken as a guide (27). Piaget judged

TABLE 7.1

SPATIAL COMPETENCE - AS A GROUP %

TEST		TEST A	TEST B	TEST C	TEST E
SPATIAL TASK		3-D to 2-D	2-D to 3-D	ORIENTATION	FORM RECOGNITION
COMPETENCE LEVEL		OVER 70% CORRECT	OVER 72% CORRECT	OVER 73% CORRECT	OVER 73% CORRECT
GROUP	AGE				
P.4/5	8-9 yrs.	1.8	65.1	33.9	18.4
P.7	10-11	42.1	78.9	45.5	37.5
S.2	13-14	51.4	92.6	79.4	75.7
S.4	15-16	56.5	93.9	72.3	74.7
S.6	17-18	77.0	93.2	84.2	83.8
BIO. STUDENTS	18-19	97.6	100	95.3	70.0
POST GRAD. BIOLOGISTS	-	95.4	98.5	100	90.7
NON SCIENCE STUDENTS	-	70.0	93.3	83.3	66.6
NON SCIENCE POST GRADS.	-	83.3	80.6	91.7	70.5

individuals to be competent in spatial tasks when they had a score of 75% correct. Because of the different number of items in Tests A, B, C and E it was not possible to take 75% exactly, and so the figures of 70% to 73% correct, were taken as an indication of competence in spatial tasks.

To compare the different developmental phases a table of results across the groups was constructed (Table 7.1).

7.3 From the table, it would appear that -

(a) Of all the spatial tasks, the one which took longest to develop was the 3-D to 2-D aspect, this skill lagging behind the 2-D to 3-D skill.

(b) There was a close relationship between the development of orientational skills and form recognition.
(The low score of the biology students in Test E was probably due to fatigue, as they did the tests after an afternoon practical class.)

(c) The order of development of spatial skills seemed to be, 2-D to 3-D, followed almost equally by orientation and form recognition, then 3-D to 2-D.

(d) Those who were highly competent in spatial tasks were the biology students and post graduate biologists which suggested that experience in the biological sciences contributed to increased competence in spatial tasks, or those who were poor at spatial tasks did not opt for biological sciences.

(e) The non science undergraduates and post graduates showed a different pattern of competence. In most spatial tasks they were similar to the S.6 group (aged 17-18) except in Test E, form recognition, where the scores were similar to those of the S.2 group (13-14 years). Since Test E was also used to indicate Field Independence, it could be argued that this factor was also operating. If the non science groups contained a higher proportion of Field Dependent individuals, and the other groups had

TABLE 7.2

CORRELATION COEFFICIENTS AT 5% AND 1% OF SIGNIFICANCE

GROUP	P.4/5	P.7	S.2	S.4	S.6	BIOLOGY STUDENTS	POST GRAD. BIOLOGISTS	NON SCIENCE STUDENTS	NON SCIENCE POST GRADS.
NUMBER	N = 97	N = 83	N = 65	N = 83	N = 74	N = 68	N = 65	N = 30	N = 34
TESTS IN PAIRS									
A/B	1%	5%	1%	5%	1%	1%	1%	N.S.	1%
A/C	1%	1%	1%	1%	1%	1%	1%	1%	1%
A/D	-	1%	1%	N.S.	5%	5%	N.S.	5%	N.S.
A/E	5%	1%	1%	1%	1%	1%	N.S.	1%	N.S.
A/F	-	N.S.	N.S.	1%	5%	1%	N.S.	N.S.	1%
B/C	5%	1%	1%	1%	1%	N.S.	1%	N.S.	N.S.
B/D	-	N.S.	1%	N.S.	1%	N.S.	N.S.	N.S.	N.S.
B/E	1%	5%	1%	5%	1%	N.S.	1%	N.S.	N.S.
B/F	-	N.S.	5%	N.S.	1%	N.S.	N.S.	N.S.	5%
C/D	-	N.S.	1%	5%	5%	N.S.	N.S.	N.S.	N.S.
C/E	1%	1%	1%	1%	1%	1%	1%	5%	1%
C/F	-	1%	1%	1%	1%	5%	N.S.	5%	5%
D/E	-	N.S.	1%	N.S.	1%	N.S.	1%	N.S.	5%
D/F	-	1%	1%	1%	5%	N.S.	N.S.	N.S.	5%
E/F	-	N.S.	1%	1%	1%	1%	1%	N.S.	1%

a higher number of Field Independent individuals, then this could account for the lower scores in Test E for the non scientists. As was mentioned in Chapter 6, the non science post graduate group contained many teachers who had experience of orientational skills, and so this could account for their higher scores in Test C.

7.4 A developmental factor was also shown with Test F, analytical ability and, as was previously stated in Chapter 6, this skill was poorly developed below the age of 13-14 years.

7.5 Correlations (83)(87)(88)

Correlation coefficients were calculated using the Pearson product moment method because this took into account the magnitude of the scores, as well as their relative positions.

Correlation coefficients were calculated and checked using two computer programs (89) (90).

The Table 7.2 gives the correlation coefficients at the 5% and 1% level of significance, indicating significance only. The numerical values for the tests are in Appendix II.

7.6 (a) The results indicated that, in general, spatial aspects of 2-D to 3-D, 3-D to 2-D, orientation and form recognition inter-correlate positively and significantly. Discrepancies in some of the groups probably result from different levels of expertise in different spatial tasks, because of the effect of developmental processes, or because of different backgrounds of experience.

(b) With most groups there was also a positive significant correlation between Tests E and F which suggested a link between Field Independence and analytical ability. Those who were more Field Independent were likely to have good analytical ability whereas those who were more Field Dependent were less likely to show proficiency in analysis.

(c) As was stated before, the results of Test D for divergence, were suspect, and so it would be unwise to draw any conclusions from the results of this test. However, there appeared to be some link between Test D and the other tests, particularly with the secondary school groups of S.2 (aged 13-14) and S.6 (aged 17-18). One possible explanation was that these groups contained a high proportion of pupils who were flexible, versatile learners with a wide cognitive repertoire; they were divergent, had good spatial ability, were Field Independent and analytical.

The third phase of results was the consideration of differences within and across the groups, including possible sex differences.

CHAPTER 8

DIFFERENCES WITHIN AND ACROSS THE GROUPS

8.1 The following areas were considered -

(a) Sex differences.

Was there a relationship between gender and performance?

(b) Subject choice.

Were the primary school children who preferred mathematics to English better at spatial tests? Were the primary school pupils who liked academic subjects better at the test than those who preferred non academic subjects? Did the secondary school pupils who showed a preference for the biological sciences perform better than those who preferred the physical sciences?

(c) Qualifications on entry to university.

Was there any relationship between qualifications on entry to university and test performance by the biology students?

(d) Teachers' Estimates.

Was there any relationship between teachers' estimates of pupils' ability and their test scores?

(e) Comparisons of groups.

Was there any significant difference between the biology students and the non science students, or between the post graduate biologists and the non science post graduates?

8.2 Use of Chi-Squared Test.

As most of the groups were not made up of populations which would give a normal distribution of ability, it was decided to use the non parametric X^2 test, to test agreement between observed results and those expected on a given hypothesis. Because only one degree of freedom would be involved, the Yates correction was applied to reduce error (91). This was done by subtracting 0.5 from the absolute difference between observed and expected scores. Also it was decided that a null hypothesis could be disregarded when the probability was 0.05, i.e. 5% or less.

Below is an example of a X^2 calculation. The hypothesis was that S.6 (17-18 year olds) males were better than females on Test A (3-D to 2-D test).

Scores of over 8	fo	23		fo	20		43
	fe	19.75	(i)	fe	23.24	(ii)	
Scores of 8 and under	fo	11		fo	20		31
	fe	14.24	(iii)	fe	16.75	(iv)	
		34			40		74

Correction for continuity -

(i) $fo \sim fe = (23-19.75) - 0.5 = 2.75 \quad \frac{(fo-fe)^2}{fe} = \frac{2.75^2}{19.75} = 0.383$

(ii) $fo \sim fe = (20-23.4) - 0.5 = 2.74 \quad \frac{(fo-fe)^2}{fe} = \frac{2.75^2}{23.24} = 0.323$

(iii) $fo \sim fe = (14.24-11) - 0.5 = 2.74 \quad \frac{(fo-fe)^2}{fe} = \frac{2.74^2}{14.24} = 0.527$

(iv) $fo \sim fe = (20-16.75) - 0.5 = 2.75 \quad \frac{(fo-fe)^2}{fe} = \frac{2.75^2}{16.75} = 0.451$

$X^2 = 1.685$ Total 1.685

$df = (r - 1)(c - 1) = 1$

Probability = 0.20 i.e. 20%

Conclusion - The hypothesis was rejected as there was no significant difference between males and females in Test A for S.6 pupils.

8.3 Sex Differences

Maccoby (86) believed that there were probably fewer differences between males and females in their performance on tests than is often thought, the two sexes tending to perform in a similar fashion. She noted that if there were no sex differences, then no reference was made to this fact, but if differences were found, then they were recorded. In her review of over 2000 studies on verbal ability, 65% of the studies showed no difference between the sexes; 28% of the studies showed that females performed better than males, but 7% indicated that males were more successful than females. With spatial ability 59% of studies showed no difference between the sexes, 36% indicated that males were better than females, and 5% of the studies showed that females performed better than males. Evidence was also produced to show that there were even fewer distinctions between males and females in Field Independence, divergence and analytical ability.

Maccoby pointed out that if there were any sex differences, they did not emerge until adolescence. When differences were found, females tended to be more competent in verbal skills whereas males had better spatial ability. Factors such as intelligence, appropriate experience, and motivation were more likely to influence performance rather than gender differences.

The results of sex differences across the groups are tabulated in Table 8.1.

8.3.1 From this table it would appear that there were few sex differences, but when they did occur, the males were better at spatial tasks and the females with tasks which involved language.

The S.4 (15-16 year old) girls were better on Test D which although testing divergence, also demanded competent language skills. The P.7 (10-11 year old) boys were better than the girls at Test E which measured Field Independence and the spatial ability of form

TABLE 8.1

SEX DIFFERENCES - SIGNIFICANT % ONLY

GROUP	Primary 4/5	Primary 7	Secondary 2	Secondary 4	Secondary 6	Biology Students	Post Grad. Biologists	Non Science Students	Non Science Post Grads.
AGE	Aged 8 - 9	Aged 10-11	Aged 13-14	Aged 15-16	Aged 17-18	Aged 18-19	-	-	-
TEST									
A								MALE 0.1%	MALE 5%
B									
C									
D	-			FEMALE 5%					
E		MALE 5%							
F	-								

recognition. In Test A (3-D to 2-D) the non science males in both undergraduate and graduate groups performed significantly better than the females; this was not so with the corresponding biology groups. It could be put forward that the biological sciences or even the physical sciences did not appeal to females whose spatial ability was poor, and that there was a "self selection" process which directed them into disciplines which did not require spatial ability.

8.4 Subject Choice

8.4.1 It was thought that primary school children of P.7 (aged 10-11) might perform better on spatial tasks if they were competent in, or had a liking for, mathematics, whereas those with a bias towards English might do less well. Those with good language skills, on the other hand, might have higher scores on Test D, the test for divergence, because it depended, particularly at this age, on competence in language. It was also thought that those who had a preference for academic subjects such as English and Mathematics might do better, all round, than those who had abilities in non academic subjects such as Drama, Art, Physical Education and Music.

No significant differences were found so subject choice did not seem to affect test performance at the 10-11 year old level.

8.4.2 The secondary school children were asked which of the three sciences they preferred. Approximately one-third of the pupils stated that they had no distinct "favourite" science.

The only significant difference found was between those pupils who preferred the physical sciences to biology in S.4 (15-16 year olds) on Test C, the orientation test, with a 5% significance level in favour of the physical science pupils. As was mentioned in a previous chapter, many of the S.4 group contained pupils who were taking biology with non science subjects, and this could explain why those who preferred the physical sciences were better at Test C.

8.5 Qualifications of biology students on entry to university.

Two separate criteria were used -

(a) Students who had taken an Advanced level course in Biology, or the Scottish Certificate of Sixth Year Studies in Biology were compared with those who had a lesser qualification such as a Scottish Higher Grade in Biology.

(b) Students who had an 'A' grade pass in Advanced Level Biology, Scottish C.S.Y.S. Biology or Higher Biology were compared with those who had lower grades.

No significant differences were found between the test results and the university entrance qualifications.

Jackson (92) found that results in Matriculation Biology were not a good predictor of success in a first year university course in General Biology I in South Africa. The best predictor was a general Matriculation Rating which was the sum of points allocated to subjects across the curriculum.

8.6 Teachers' Estimates

8.6.1 With the primary school children P.4/5 (8-9 years) and P.7 10-11 years) class teachers gave an estimate of general ability of their pupils on a 5-point scale. Pupils who were placed in the two top bands were compared with those who had been placed lower down the scale.

The results are tabulated in Table 8.2.

From these results it would appear that the more able younger children (P.4/5) were better at the spatial tasks of 3-D to 2-D, 2-D to 3-D and form recognition, whereas the more able older P.7 children were better at Test D which involved language competence in addition to divergence.

It was possible that the teachers who estimated the pupils' abilities were using different criteria. If the teachers of the P.4/5 children estimated ability in terms of mathematical skills and those of P.7 used language skills as their criteria then this could account for the different results.

8.6.2 The teachers of the secondary school pupils were also asked to estimate pupils' ability on a 5-point scale. With S.2 (13-14 years) this was an estimate of ability in the sciences in general, as most of this group had been following an integrated science course. With S.4 (15-16 years) and S.6 (17-18 years) it was an

TABLE 8.2

TEACHERS' ESTIMATES OF ABILITY

(TOP ABILITY BANDS COMPARED WITH LOWER ABILITY BANDS)

GROUP	P. 4/5	P. 7
AGE	AGE 8 - 9	AGE 10 - 11
TEST	SIGNIFICANT %	
A	0.1% top bands	N.S.
B	1% top bands	N.S.
C	N.S.	N.S.
D	-	0.1% top bands
E	0.1% top bands	N.S.
F	-	N.S.

estimate of ability in the biological sciences.

The estimates were based on the performance of pupils in examinations and in their course work. As with the primary school children the top two ability bands were compared with those who had been given lower grades.

TABLE 8.3

TEACHERS' ESTIMATES OF ABILITY

(TOP ABILITY BANDS COMPARED WITH LOWER ABILITY BANDS)

GROUP	S.2	S.4	S.6
AGE	AGED 13-14	AGED 15-16	AGED 17-18
TEST		SIGNIFICANT %	
A	5% top bands	0.1% top bands	0.5 % top bands
B	1% top bands	N.S.	N.S.
C	1% top bands	1% top bands	1% top bands
D	N.S.	1% top bands	5% top bands
E	N.S.	N.S.	0.1% top bands
F	N.S.	5% top bands	0.1% top bands

TABLE 8.4

COMPARISON OF GROUPS

TEST	BIOLOGY STUDENTS with NON SCIENCE STUDENTS	POST GRAD BIOLOGISTS with NON SCIENCE POST GRADS
	SIGNIFICANT %	
A	0.1% Bio. St.	0.5% P.G. Bio.
B	0.1% Bio. St.	0.1% P.G. Bio.
C	5% Bio. St.	1% P.G. Bio.
D	N.S.	N.S.
E	N.S.	5% P.B. Bio.
F	N.S.	1% P.G. Bio.

From Table 8.3 it would appear that if teachers' estimates are a reasonably reliable guide to ability, that those with good general scientific ability at the S.2 (13-14 years) stage are better at spatial tasks of 3-D to 2-D, 2-D to 3-D and orientation than the less able pupils. The biology pupils of S.4 (15-16) of good ability were better at spatial tasks, analytical tasks and were possibly more divergent. The able pupils of S.6 (16-18 years) showed proficiency at spatial tasks were more analytical, and Field Independent and were probably more divergent. Test B (2-D to 3-D) was not significant at the S.4 and S.6 stage because scoring was high for all pupils and therefore indiscriminating.

8.7 Comparison of groups

The undergraduate biology students were compared with the non science undergraduates and the post graduate biologists with the non science post graduates.

The results are tabulated in Table 8.4.

From the table it would seem that the biology students were more proficient at spatial tasks than the non science students, and that the post graduate biologists had better spatial ability, analytical ability and were more Field Independent than the non science post graduates. There was no difference in divergence across the groups.

The next stage was to summarise the conclusions reached from the information in the previous chapters.

CHAPTER 9

CONCLUSIONS AND COMMENTS

9.1 From the results of the inter-test correlations, there appeared to be a link among the tests of spatial ability in Test A (3D to 2D), Test B (2D to 3D) and Test C (Orientation), and a less well defined cross-link with these tests and Test E, which tested, in part, for form recognition. Those who had good spatial ability tended to show it, in its various aspects. The other two tests which inter-correlated were Test E (Field Independence) and Test F (Analytical ability) which suggested that those with good analytical ability were likely to be Field Independent. The relationship of Test D (Divergence) was more doubtful, firstly because of the mis-understanding of the test instructions by the unsupervised adult groups, and secondly, because it was by no means certain that this test was testing solely for divergence.

DIAGRAM 9.1

INTER-RELATIONSHIPS OF TESTS

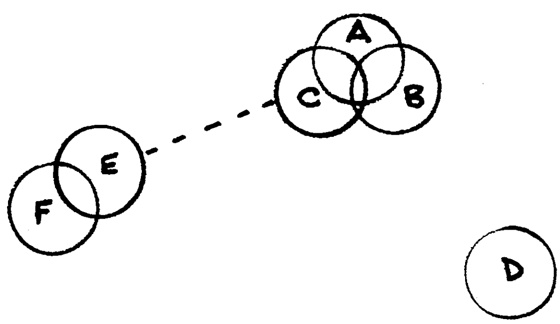


TABLE 9.1

PROFILES

GROUP SCORES - MEAN %

GROUP	TEST AGE (YRS)	A	B	C	E	F	MEAN SCORE D
POST GRAD. BIOLOGISTS	-	96.4	95.9	98.0	83.1	79.7	21.9
BIOL. STUDENTS	18-19	93.8	95.5	95.2	77.3	67.5	16.6
S.6	17-18	80.8	91.8	89.0	82.8	68.4	17.8
S.4	15-16	69.3	89.1	78.1	80.3	57.4	13.4
S.2	13-14	67.0	87.9	82.9	77.6	55.9	15.0
P.7	10-11	53.1	83.2	64.3	65.5	27.8	12.6
P.4/5	8-9	37.4	70.6	56.5	46.8	-	-
NON SCIENCE STUDENTS	-	71.6	84.8	84.1	74.5	62.1	15.6
NON SCIENCE POST GRADS.	-	85.2	88.2	91.5	76.9	65.3	21.2

9.2 In an attempt to highlight other links which might be present, a table was constructed, using the mean group scores, to try to get a broad picture of each group, a profile, which would show general achievement on a group basis. As was stated in Chapter 8, when overall scoring on a test was high within a group, it was not possible to discriminate between those with high ability in a particular skill, and those who were scoring only marginally lower. Such links would not show up as significant positive correlations.

Another reason for looking at a group profile was to get an idea of what achievement was likely to be at each age level, and also to show the developmental pattern of a specific skill. The profiles should show the stage at which a particular skill was required to be taught, plus some indication of the sequence of teaching it.

9.3 At the beginning of this study, the hypothesis was put forward that a competent biologist would have good spatial ability, high analytical skills, would tend to be Field Independent and would be divergent.

The post graduate biologists were considered to be a group who had shown success in the biological sciences and so this group could be used as a "yardstick" against which other groups could be "measured".

From the Table 9.1, it can be seen that the post graduate biologists had high scores in all the tests, which indicated competence in spatial tasks (Tests A, B, C), were the most Field Independent group, (Test E) and had good analytical ability (Test F). Even with Test D (Divergence) they had a higher score than any other group, marginally higher than the non science post graduates. However, the difference between the two post graduate groups was not statistically significant, in Test D and also there were doubts as to the validity of this test.

Competence levels across the tests were also high with the biology students and the S6 (17-18 yr) groups. It was concluded that those with longer experience in the biological sciences were competent at spatial tasks, showed analytical ability and tended to be Field Independent. These skills are required in the biological sciences but they are also improved by practice and reinforcement during a biological education. As previously stated, individuals whose skills in these areas were poor, would be unlikely to select the biological sciences, or if they did opt for biology, their lack of success would probably deter them from continuing beyond a certain level. Many biology teachers would agree that this "self-filtering mechanism" operated in such a way that, by age 17 (S.6), only those pupils who had shown some previous aptitude were likely to make a success of their studies in biology.

9.4.a Spatial ability

From the results shown in Chapter 6, and also from Table 9.1, it was apparent that not all spatial skills developed at the same rate. The one which took longest to develop was 3-D to 2-D skill shown in Test A. Even at S.4 (15-16 yrs), the mean group score was 69% which was below Piaget's 75% index of competence, showing that pupils who had a reasonable knowledge of cell structure and who had some experience of using a microscope, still required assistance with 3-D to 2-D skills. In Chapter 6 it was indicated that the spatial ability skill 3-D to 2-D appeared to develop in three stages: transverse sections were recognised before longitudinal sections, simple longitudinal sections were mastered before complex ones. This order of difficulty would have to be taken into account in teaching 3-D to 2-D skills.

The 2-D to 3-D skills (Test B) developed before the 3-D to 2-D, and this suggested that these should be introduced before the 3-D to 2-D skills were taught. The introduction of appropriate transverse and longitudinal sections helps pupils to visualise a 3-D image. The 8-9 year olds of P.4/5 had a mean score of 70%; showing that they were reasonably competent in the 2-D to 3-D field. From the teaching point of view, the technique of building up the 3-D image should be mastered first. Within the 2-D to 3-D skill, there was also a developmental sequence. Shapes which had regular sections, particularly the longitudinal section, were more easily recognised than those which had more uniform shaped sections, e.g. it was easier to recognise sections taken from a pencil sharpener, than those taken from a coin. Cubes and spheres would present difficulties as the transverse and longitudinal sections are identical, and yet these two solids are frequently used as illustrations in spatial exercises, because of their being familiar.

The two spatial skills of orientation (Test C) and form recognition (Test E) are related to one another, and could be thought of as forming a sequence for teaching purposes. Pupils have to be able to recognise a shape first, before they can appreciate one whose orientation has been altered. Ability to rotate a shape mentally, caused difficulties even with older secondary school pupils.

A teaching programme which included specific experiences in spatial skills would lead to a better understanding of some aspects of biology, and so would improve performance, not only in the biological sciences, but in other areas of the curriculum where spatial skills were required.

Spatial skills of form recognition, orientation, and 2-D to 3-D, could be taught at primary school level and then these skills could be reinforced in the early stages of the secondary school when the 3-D to 2-D skill could be introduced.

9.4.b Analytical Skills and Field Independence

From Table 9.1 it was evident that analytical ability was poorly developed at the 10-11 year old level (P.7), but improved between that age range and the 13-16 year old stage, with a further increase at the 17-19 year old level. Science education in the early stages of the secondary school would incorporate some analytical tasks, and so experience plus maturity would account for the improvement at the 13-16 year old age range. It would be unwise to conclude that the next "spurt" could be attributed solely to an increase in biological knowledge and experience. What was more likely to have happened was that an elimination process had already taken place, and those whose analytical skills were poor had dropped out of the sciences. Also those who were nearer the Field Dependent end of the spectrum were likely to have taken up subjects more suited to their particular cognitive style.

What could be done to improve analytical skills and make pupils more Field Independent? The view could be put forward that these skills cannot be taught. However, children could be given experiences which would improve their observational skills, and if these were linked with practice in written and oral reporting, plus exercises in making informed judgements, then this would go some way towards giving pupils a wider range of cognitive options.

9.4.c Divergence

The results of Test D were suspect and so no definite conclusions could be drawn from the results of this test. Divergency cannot be ignored as it is an essential ingredient in the cognitive repertoire. In school science classes, pupils are encouraged to be convergent, because teachers are influenced by external examinations where the emphasis is on one correct answer. In factual examinations, particularly those which contain multiple choice items, pupils who are divergent are penalised for giving an unexpected answer, even although the response given may be as good as the one the examiner has decided is the correct one, if the reason for the choice was known.

9.5 To help pupils to realise their potential, a programme which includes a more systematic approach to spatial tasks, analysis and divergency should be incorporated into the curriculum at both primary and secondary stages of education.

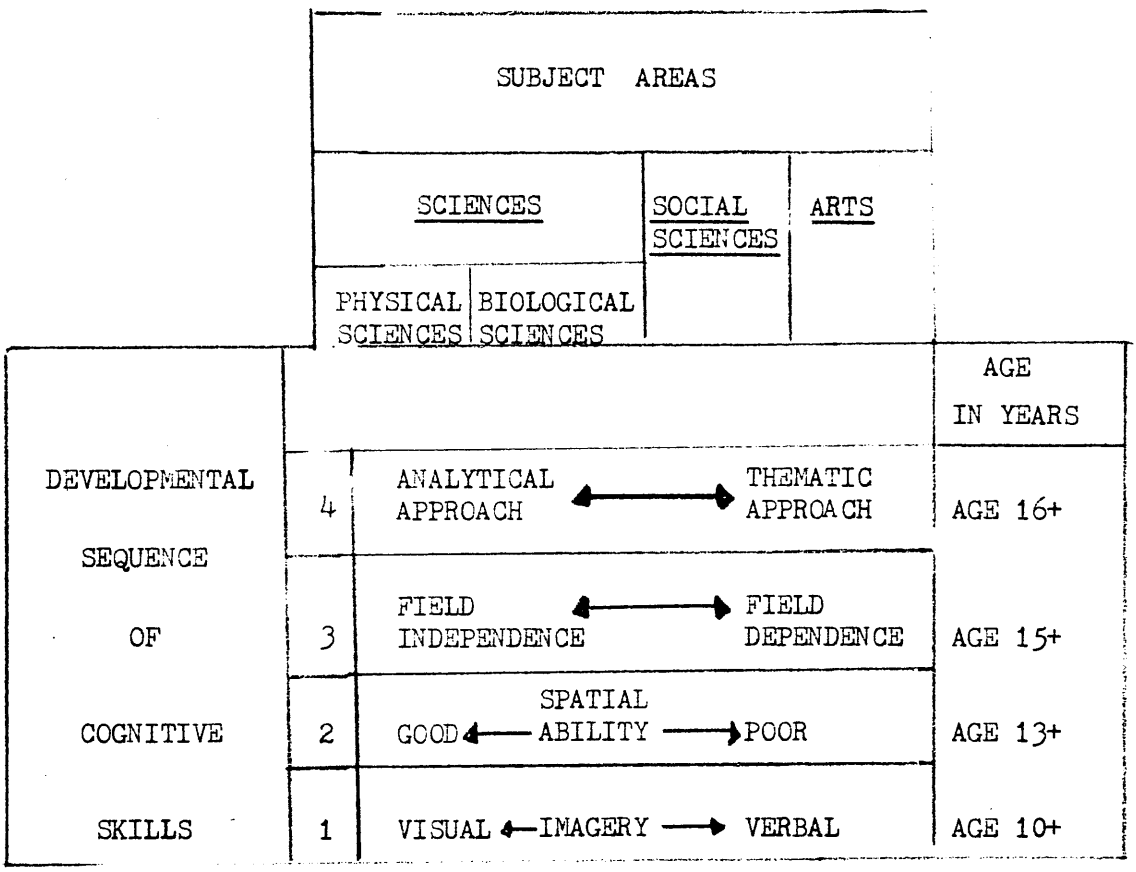
9.6 All the tests showed an age related pattern; the younger children scoring less than the older ones, the post graduates performing better than the undergraduates, so maturation played a role in the development of cognitive skills. It was also noticed that cognitive skills did not all develop at the same rate; there appeared to be a sequence, with analytical skills taking the longest to develop. How this cognitive sequence might be related to developmental stages or levels will be discussed in the next chapter.

9.7 As was mentioned in Chapter 1, there have been attempts to account for imagery, spatial ability and cognitive styles in terms of neurological differences. (63)(75)(76). Science students, particularly biologists, were found to have a preference for visual imagery whereas arts students preferred verbal imagery (74).

If it was assumed that an individual's imagery preference was fairly well established as either visual or verbal, by the time he was 10+ years, then this could provide the first step in a theoretical staircase model of cognitive development. The type of imagery used, influences spatial ability,(25) in that ability to visualise is required for competence in spatial tasks, and the imagery preference may also play a part in the development of other cognitive skills.(63)

DIAGRAM 9.2

THE "COGNITIVE STAIRCASE"



The model would give an indication of where broad subject preferences were likely to lie, and might also "explain" how the "self selection" process operated. The greater the movement to the left, the greater the bias towards the sciences; the greater the movement to the right, the stronger the preference for the arts. The model might also suggest that subject choice could be determined by the type of cognitive skill an individual possessed, and this in turn, would influence career choice.

Divergence was not included in the cognitive staircase because the results of Test D were inconclusive.

The final chapter is a review of the research which is still required to be done, in the area of cognitive skills, and also how the results of this project might be explained in terms of known theories of cognitive organisation and development.

C H A P T E R 10

FURTHER RESEARCH

10.1 In relation to further research on this project, three areas would need to be considered -

(a) Modification of the individual tests;

(b) Sampling;

(c) Teaching of specific skills.

10.2 Modification of the tests

10.2.1 TEST A

From the results it was clear that the 3-D to 2-D spatial skill developed in several stages. Transverse sections were recognised before longitudinal sections because all that was required to visualise a transverse section, was a slight alteration of perspective of the top surface of the solid. However, it was noticed that although individuals knew how to "manipulate" visually, the perspective, some of them did not do so with accuracy, resulting in the selection of an ellipse rather than a circle for the transverse section of a cylinder, in Question No. 2. More examples of this type with a choice of varying transverse perspectives would need to be included to find out if this was a problem with solids other than cylinders.

With the complex longitudinal sections more examples of the type in Question No. 5 would need to be added, i.e. straight lined figures of more than four sides, as there was only one of this kind in the test, and it was found to be the second most difficult item.

Oblique sections were not included in Test A, but it would be worth while finding out when oblique sections could be recognised. It is likely that this skill would not develop until the complex longitudinal sections had been mastered, and perhaps should only be given to older pupils at S.6 (17-18 year olds), undergraduate biology students, and post graduate biologists.

10.2.2 TEST E

Test E had a dual purpose, testing for the spatial ability of form recognition, and for Field Independence. The hidden shapes in this test included those of different orientations to the example given, and so it was not possible to decide how much individuals were able to recognise a shape when its orientation was unaltered. (In the Witkin E.F.T., the hidden shapes were of the same orientation as those of the examples.) A short test of form recognition alone, should be added to the battery of spatial ability tests.

10.2.3 TEST D

This was the test which caused most problems and there was some doubt as to its validity with regard to giving a clear indication of divergence. It was obvious that language played a part in individuals being able to produce a large number of responses. With the adult groups the test instructions were not carried out properly and many considered that the test was too elementary for them. To make the test more acceptable to adults, perhaps the instructions should have been worded, "What answers do you think a child would give?" This technique was used by Torrance, (32) who had similar problems with adults on simple creativity tests.

One alternative would be to revise the test completely making it non verbal; this would reduce the effect that language had on the results and would allow the test to be used more effectively with primary school children who were hampered by their lack of skill in writing down their responses. With younger primary school children the test could be administered orally and on an individual basis.

10.2.4 TEST F

In Test F, the test for analytical skills, there was a need for a wider range of difficulty of test items, particularly those of a simpler kind, to try to get more detailed information on how analytical skills developed.

10.3 Sampling

There were considerable differences in performance between P.7 (10-11 years) and S.2 (13-14 years) in some of the tests. What was required was a sample of S.1 (12-13 yrs) to bridge this gap. It would also have been useful to have other intermediate age ranges such as S.3 and S.5 pupils who were studying biology.

The samples of the non-science groups were too small. In addition to increasing the sample sizes of the non-science students and non-science post graduates, non-science school groups at the S.4 (15-16 yrs.) and S.6 (17-18 yrs) would have given more data for comparisons between non-scientists and biologists.

Perhaps the greatest omission was in not having samples of physical scientists. Factors which contribute to competence in the biological sciences probably also play a role in success in the other sciences.

10.4 Teaching of Specific Skills

In this project, no attempt was made to teach some of the skills, and then to retest to find out if any improvement had taken place.

It had been shown that spatial skills could be improved by teaching, (25) and not only should they be taught, but the teaching should be systematic. As far as the biological sciences are concerned, if teaching of spatial skills is done at all, it is usually tackled in a fragmentary and haphazard fashion.

Both De Bono (38) and Torrance (32) believed that divergence could be improved by providing appropriate and stimulating experiences, but what appeared to be more important was to give encouragement and show approval to individuals who gave divergent responses.

The ability to abstract relevant information, to evaluate it and to use it, affects the skills of Field Independence and analysis. Should pupils be given experiences in learning to discriminate between what is relevant and what is not? How far discrimination skills could be taught, and the skill transferred to new situations would depend on how far it was considered that the skill was dependent on cerebral hemisphere lateralisation, (75) and therefore strongly hereditary, or whether the view was taken that improvement could take place if appropriate experiences were given.

Observational skills can be improved with practice, and if pupils were given first hand experiences in learning to discriminate, in making judgements, and were given practice in written and oral reporting, this might aid analytical skills.

10.5 Cognitive Organisation and Development

Are there any relationships between the results of this project and known theories of cognitive organisation and development?

Is development a continuous process; is there a distinct difference between one stage and the next? Piaget, (52)(93) considered that each stage was characterised by a different set of cognitive processes. Jensen,(60) thought in terms of levels where there was no such clear cut distinction.

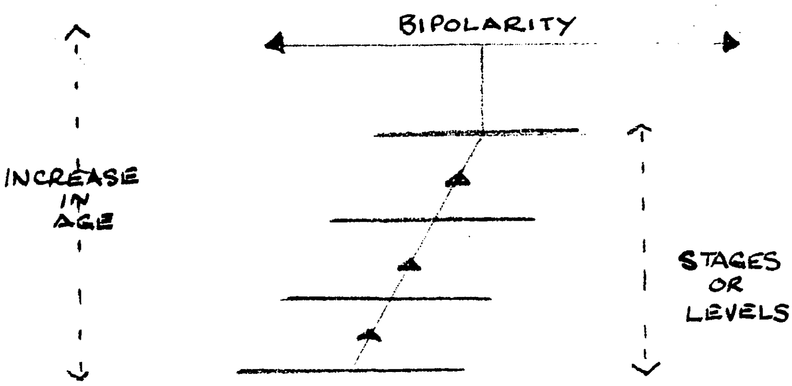
With Piaget's model, the stages which might be relevant to this project are Stages 2 and 3 since the age ranges tested were from 8+ years through to adulthood. Piaget's Stage 2, the concrete operational stage, from ages 7 to 11, was one when operational thought emerged, when a basic stock of concepts had been acquired and organised into coherent systems. At this stage children were thought to be able to classify objects into groups, and to understand relationships provided that these were related to practical problems and concrete situations.(7) Piaget believed that cognitive restructuring took place before Stage 3 was reached. Stage 3, was the formal operational stage (11+ to 15+ years) where pupils were believed to be able to think abstractly; this stage being characterised by an ability to hypotheses, to understand probability, and to think in terms of what was possible.

Ausubel,(12)(94) also believed in the existence of a cognitive structure which was hierarchically organised. Others such as Witkin,(67) Pask,(64) and Marton,(95) considered certain cognitive abilities to be bipolar.

It might seem that the hierarchical and non hierarchical stances were mutually exclusive but when it is realised that the "non hierarchical" researchers were dealing with an older age range of 17+ years, and the "hierarchical" group were dealing with ranges of children as they progressed towards adulthood, then both views could be reconciled. Stages or levels would precede bipolarity; bipolarity being shown only with cognitive styles and strategies and after certain cognitive abilities had been reasonably well established.

DIAGRAM 10.1

COGNITIVE DEVELOPMENT



"Cognitive growth requires proper experiences, but experiences will lead to growth only if they can be assimilated". (96)

The assimilation process probably depends partly on genetic factors, and so cognitive development results from the interaction of environment on heredity.

10.6 How do the factors of spatial ability, Field Independence and analytical skills investigated in this study fit in with theories of learning? Although these three factors are all of a cognitive nature they will be considered separately, as they appear to be independent cognitive skills with no obvious links among them. Divergence will not be included because the results of Test D were inconclusive.

10.6.1 Spatial Ability. (Tests A, B, C and partly E)

Piaget's work on spatial ability (27) showed that by the age of 6+ a child could abstract a shape; by 7-9 years he could distinguish between different views of the same thing, but it was not until 10+ years that he could identify a geometric section. The Piaget sequence was therefore, form recognition, orientation followed by an ability to visualise a 2-D section taken from a 3-D object.

Tests A, B, C and partly E appeared to show a sequence of development similar to those of Piaget with the 3-D to 2-D skill being the last one to emerge. The ages at which these skills appeared were slightly older than those given by Piaget, but this was probably because the mean group scores were taken rather than scores from individual children. However, it can be seen from the frequency distributions (Appendix II) that there was a range of ability within each group.

Piaget's investigations on spatial ability did not explain why the writer found that the 2-D to 3-D skill was one which emerged early on, well before the 3-D to 2-D skill. However, Piaget's stages of development theory could provide a possible explanation. The process of going from 2-D to 3-D involves a syntheses, the building up of a 3-D image from appropriate visible sections, i.e. understanding relationships of a concrete nature, and so a child at Piaget's Stage 2, the concrete operational stage, should be able to visualise a 3-D image when given appropriate 2-D sections. The process of going from 3-D to 2-D, involves an analysis, requiring the ability to visualise a 2-D section in the absence of concrete visible clues, i.e. the situation is more abstract. It may be that a child has to be at Piaget's Stage 3, the formal operational stage, before he becomes proficient in 3-D to 2-D tasks.

If the results of the spatial ability tests are interpreted from Ausubel's (12)(94) point of view, then this would involve the building up of concepts. Ausubel's theory of subsumption was based on the belief that a person's organisation, stability and clarity of knowledge was the main factor which influenced the learning and retention of meaningful new material. Concepts are established from experiencing a number of examples from which a particular generalisation is recognised, by the process of differentiation followed by integration.

With the spatial skill of form recognition, it would not be necessary to build up a complex concept system, as matching shapes is a relatively simple operation. With orientation skills, form recognition plus the ability to rotate, mentally, a shape, was all that was required. Children who had difficulty in rotating the shape, solved the problem by rotating the paper, and so all that they were required to do, was to hold the original image in mind, and then check to see if it matched the diagram.

The ability to build up a 3-D image from 2-D sections, and the ability to go from 3-D to 2-D, would require first hand experience of a number of examples so that a pattern could be recognised, i.e. a concept network would need to be built up. The only way that the results of Tests A (3-D to 2-D) and B (2-D to 3-D) could be explained using the Ausubel model, was that pupils were more successful with Test B (2-D to 3-D) than with Test A (3-D to 2-D) because they had been given more experiences in 2-D to 3-D tasks, than in 3-D to 2-D. This would fit in with what is taught in primary schools, where children are introduced to 2-D maps, and to 2-D instructions on how to construct models, whereas they have little experience in the 3-D to 2-D field.

10.6.2 Field Independence/Field Dependence. (Test E)

It would be more difficult to explain the results of Test E for Field Independence in terms of Piaget's stages or Ausubel's theory, except that the ability to abstract information could be thought of as a Piaget Stage 3 skill, the formal operational stage, or that the ability to abstract was required to build up concepts.

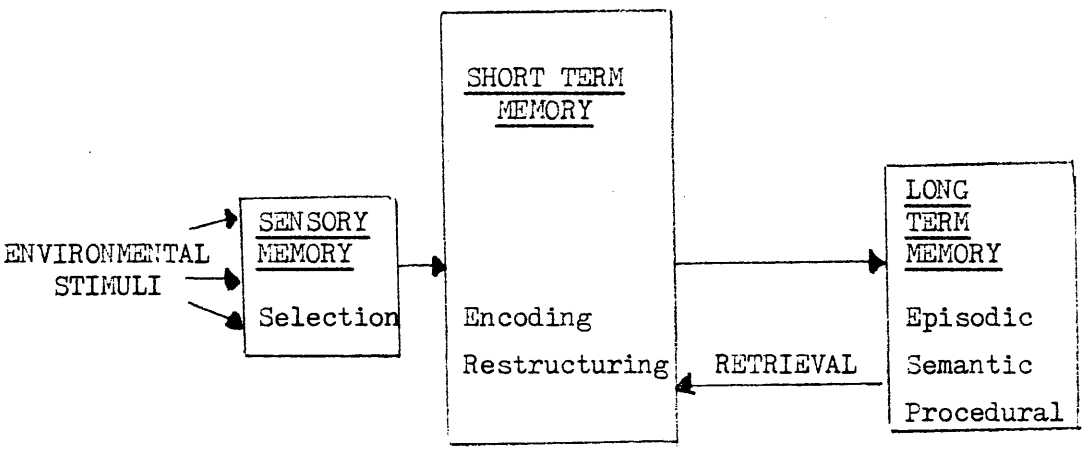
Goodenough and Witkin (62)(63) attributed differences between Field Dependent and Field Independent individuals to the way that they processed information.

Information processing involves, firstly, the sensory memory which accepts sensory information which registers perceptually. The attentional process also operates. Goodenough believed that Field Dependent individuals were likely to attend only to the most salient features of a stimulus complex, ignoring others. He also suggested that they attended to a smaller region of the total visual field.

This implied that less information was being passed to the short term memory. The amount of information which can be held by the short term memory is limited but if information can be restructured and "chunked" (97) into larger meaningful pieces, then more information can be held. Field Dependent individuals might be poorer at dis-embedding (abstracting relevant information) because insufficient information was fed into the short term memory, or because their restructuring skills were more limited.

DIAGRAM 10.2

INFORMATION PROCESSING



In Test E, it is unlikely that the long term memory was involved except for the procedural memory where skills of how to tackle an exercise of this kind might have been stored.

According to Witkin, restructuring information in a perceptual cognitive way, required the breakdown of a stimulus into its component parts, and this suggested that if the number of parts was large, then a potential overload situation was present. Field Independent individuals were found to be better than Field Dependent ones in high load conditions, which again suggested that their restructuring skills were more efficient than those of the Field Dependent individuals.

Another view taken, (68)(69) was that Field Independent individuals were better at restructuring because they were more analytical.

Successful biologists appeared to be at the upper end of the FD - FI spectrum, and their ability to abstract relevant information from a distracting background as in Test E, probably came about in two ways. Firstly, those who did not have this disembedding skill, were "filtered out" during their school years and in the early stages of their tertiary education. Secondly, during a biological education, the skill of disembedding was practised and reinforced, by anatomical studies, where cells, tissues and organs were embedded in organisms, and in areas of comparative biology where information has to be abstracted in order to compare different physiological processes, developmental patterns and ecological factors.

There was a significant positive correlation between Field Independence and analytical ability but the writer did not have evidence that the Field Independent biologists had good restructuring skills.

10.6.3 Analytical Ability. (Test F)

As was stated in Chapter 2, Test F, the test for analytical ability was derived from an exercise constructed by the writer to illustrate to students how concepts developed and was based on Ausubel's theory of concept development. In this test, three examples of a "concept" were given plus one non example. Individuals had to be able to abstract what the examples had in common; a generalisation had to be made and this information used to decide if the diagrams below were examples of the "concept" or not.

Examples → Analysis ⟶ Synthesis ⟶ Generalisation → Use in new situation.
(differentiation) (integration)

Those who were unable to follow the above sequence, could not build up the "concept".

Test F could also be considered in terms of Piaget's stages of development, with Test F being a Stage 3 operation where only those at the formal operational level could tackle this test successfully. They had to be able to formulate several hypotheses from the information given, then test them, discarding those which were invalid, before arriving at an acceptable solution.

In conclusion, it could be said that the tests used in this project have some relationship with theoretical models of cognitive organisation and development, but no single theory can account for the results.

In this study a number of factors were investigated - spatial ability, field independence and analytical ability, but there are probably other factors which contribute to success in the biological sciences, such as type of imagery, and information processing skills. All these factors and their bearing on competence in the physical sciences would be worthy of investigation.

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APPENDICES

APPENDIX I (in back pocket)

Contents: Tests A, B, C, D, E and F

Revised Tests A, B and E.

APPENDIX II

RELIABILITY COEFFICIENT

TEST. F.

n = NO OF ITEMS = 12

SDt = STANDARD DEVIATION OF TEST. = 3.82

M = MEAN OF TEST. = 6.6

$$\frac{n\,SDt^2 - M(n-M)}{(n-1)\,SDt^2}$$

$$= \frac{12 \times 3.82^2 - 6.6(12-6.6)}{11 \times 3.82^2}$$

$$= \frac{175.05 \times 35.64}{160.1}$$

$$= 0.87.$$

RELIABILITY COEFFICIENT OF TEST F. IS 0.87.

INDEX OF RELIABILITY

$$\text{INDEX OF RELIABILITY} = \sqrt{\text{RELIABILITY COEFF}}$$

$$= \sqrt{0.87} = 0.93$$

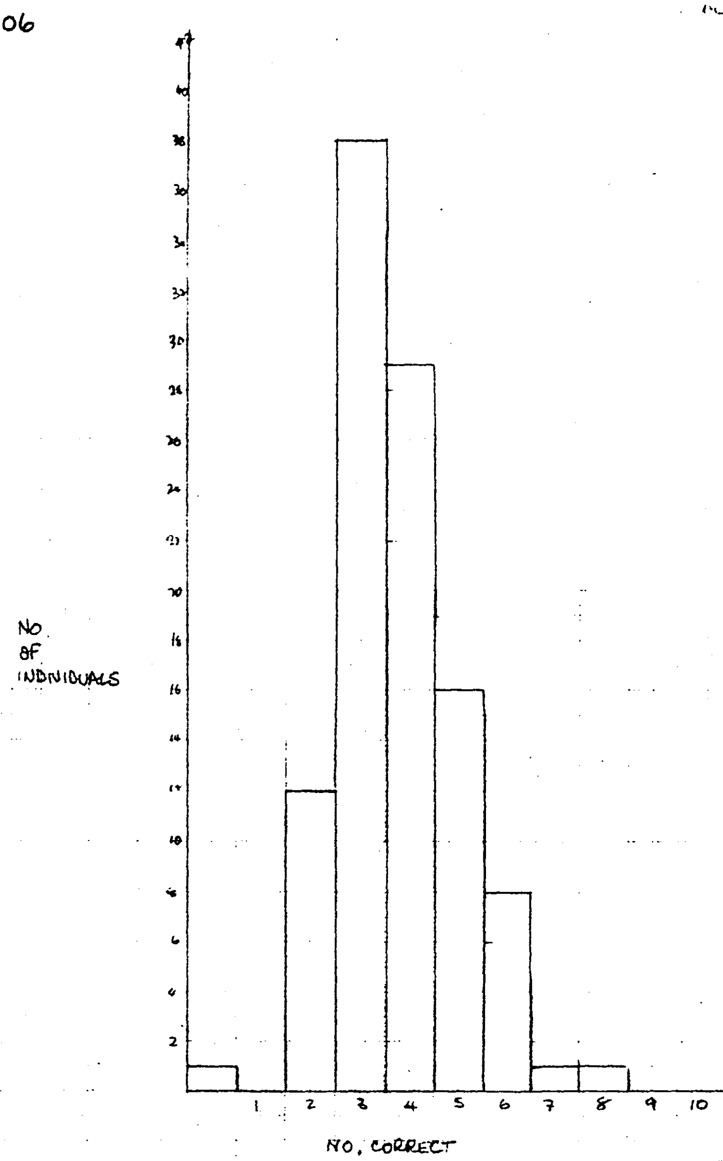
INDEX OF RELIABILITY OF TEST F IS 0.93

CORRELATION COEFFICIENTS

GROUP	P4/5	P7.	S2	S4	S6	BIOLOGY STUDENTS	POST.GRAD BIOL.	NON-SCIENCE STUDENTS	NON-SCIENCE POST.GRADS
NUMBER	N=97	N=83	N=65	N=83	N=74	N=68	N=65	N=30	N=34
AGE (yrs)	8-9	10-11	13-14	15-16	17-18	18-19	—	—	—
TESTS									
A/B	+0.33	+0.26	+0.52	+0.27	+0.50	+0.31	+0.46	+0.25	+0.51
A/C	+0.31	+0.40	+0.32	+0.30	+0.51	+0.59	+0.49	+0.48	+0.57
A/D	—	+0.34	+0.37	+0.20	+0.24	+0.31	+0.06	+0.41	+0.27
A/E	+0.24	+0.52	+0.48	+0.37	+0.53	+0.57	+0.18	+0.65	+0.31
A/F	—	+0.14	+0.22	+0.34	+0.24	+0.34	+0.22	+0.09	+0.66
B/C	+0.25	+0.29	+0.52	+0.39	+0.51	+0.21	+0.50	+0.24	+0.02
B/D	—	+0.07	+0.41	+0.08	+0.30	+0.22	+0.11	+0.07	+0.12
B/E	+0.67	+0.24	+0.47	+0.27	+0.66	+0.20	+0.37	+0.09	+0.16
B/F	—	−0.04	+0.26	+0.20	+0.40	+0.13	+0.17	+0.25	+0.36
C/D	—	+0.14	+0.46	+0.22	+0.27	+0.19	+0.16	+0.21	+0.19
C/E	+0.31	+0.52	+0.51	+0.39	+0.46	+0.48	+0.34	+0.43	+0.49
C/F	—	+0.33	+0.40	+0.43	+0.53	+0.28	+0.09	+0.36	+0.36
D/E	—	+0.18	+0.46	+0.20	+0.30	+0.22	+0.37	+0.25	+0.37
D/F	—	+0.28	+0.39	+0.32	+0.24	+0.08	+0.11	+0.24	+0.35
E/F	—	+0.12	+0.50	+0.43	+0.47	+0.61	+0.35	+0.13	+0.48
SIGNIFICANCE AT 1%	+0.28	+0.28	+0.31	+0.28	+0.29	+0.31	+0.31	+0.45	+0.42
AT 5%	+0.20	+0.21	+0.24	+0.21	+0.23	+0.24	+0.24	+0.35	+0.33

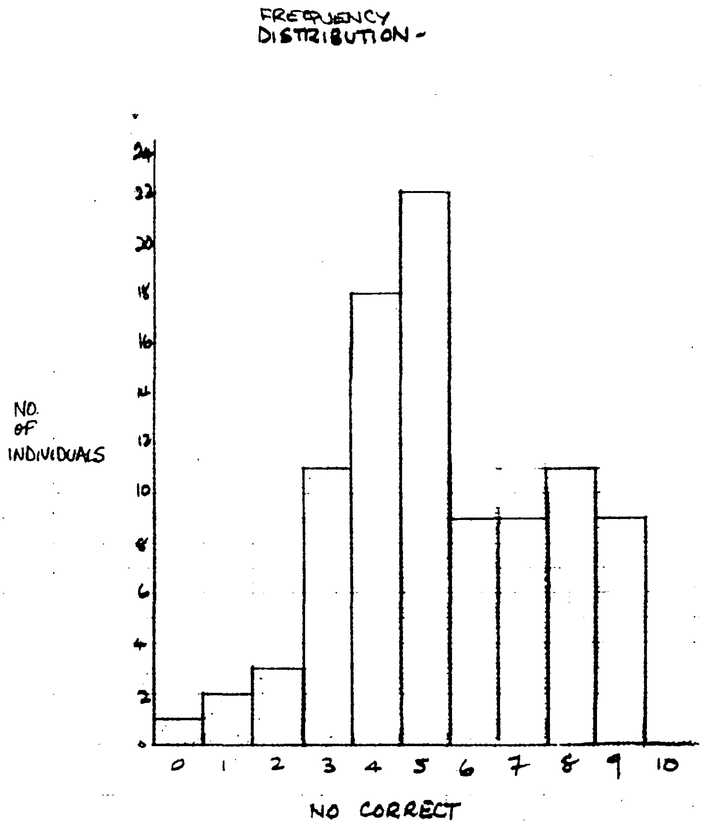
Ⓐ P4/5 AGED 8-9
N = 106

FREQUENCY DISTRIBUTION -



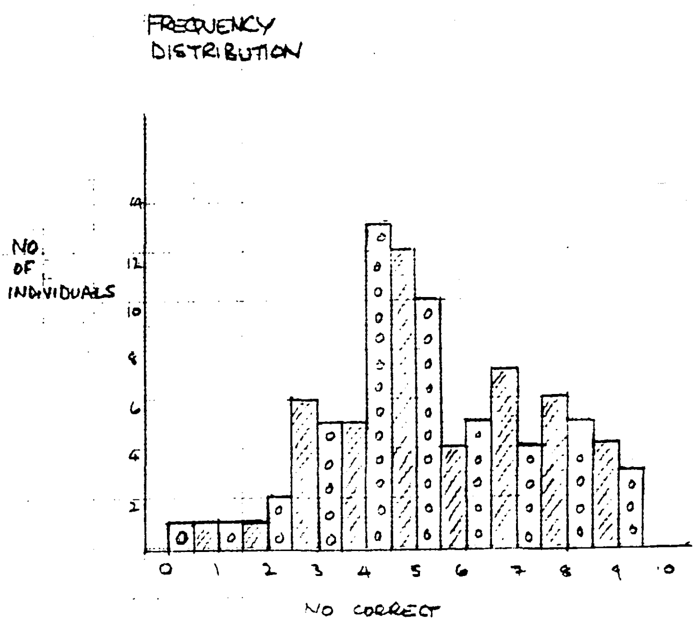
♂+♀ N = 106 MEAN 3·74 SD. 1·5.

(A) P7
AGED 10-11
N = 95



♂·♀ N=95 MEAN: 5.31 SD: 2.1

A. P7
AGED 10-11



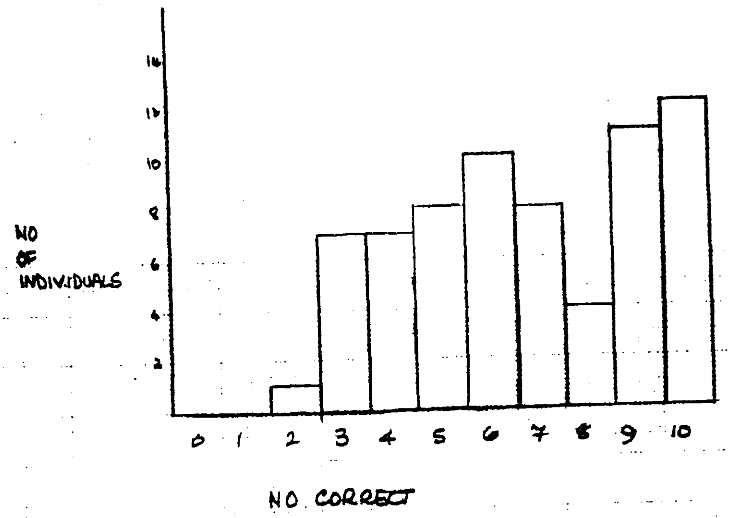
MALES ▨ N=46 MEAN 5.60 SD = 2.1

FEMALES ☐ N=49 MEAN 5.04 SD = 2.1

Ⓐ S2 AGED 13-14

N = 68

FREQUENCY DISTRIBUTION -

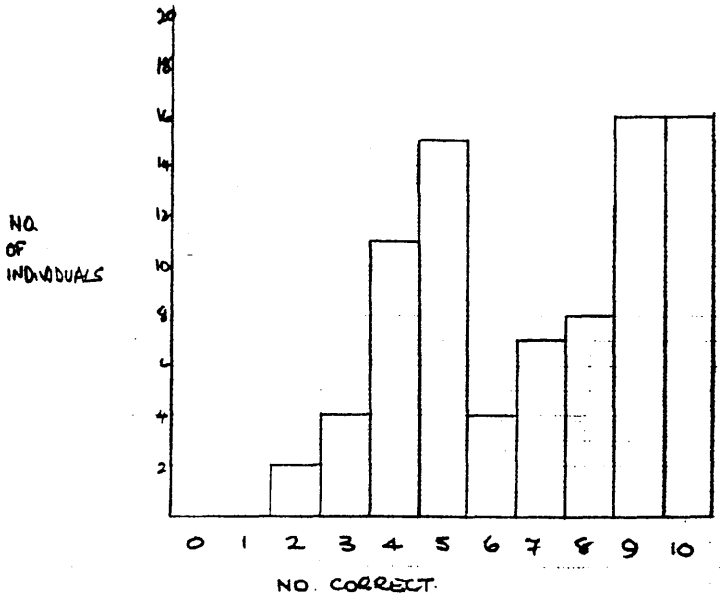


♂+♀ N=68 MEAN = 6.7 S.D. 2.5

Ⓐ S4 AGED 15-16

N= 83

FREQUENCY DISTRIBUTION -

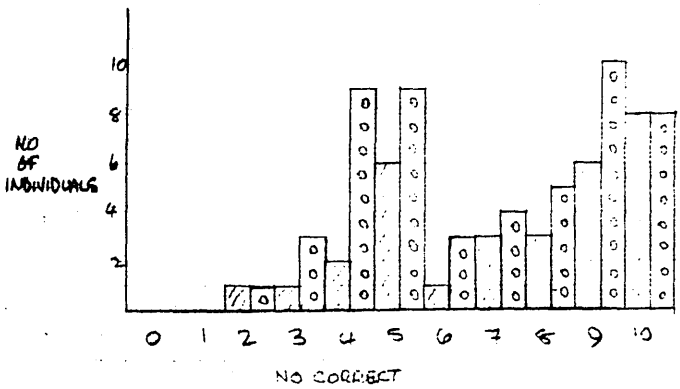


♂+♀ N=83 MEAN - 6.93 S.D 2.6.

(A) S4

AGED 15-16

FREQUENCY DISTRIBUTION

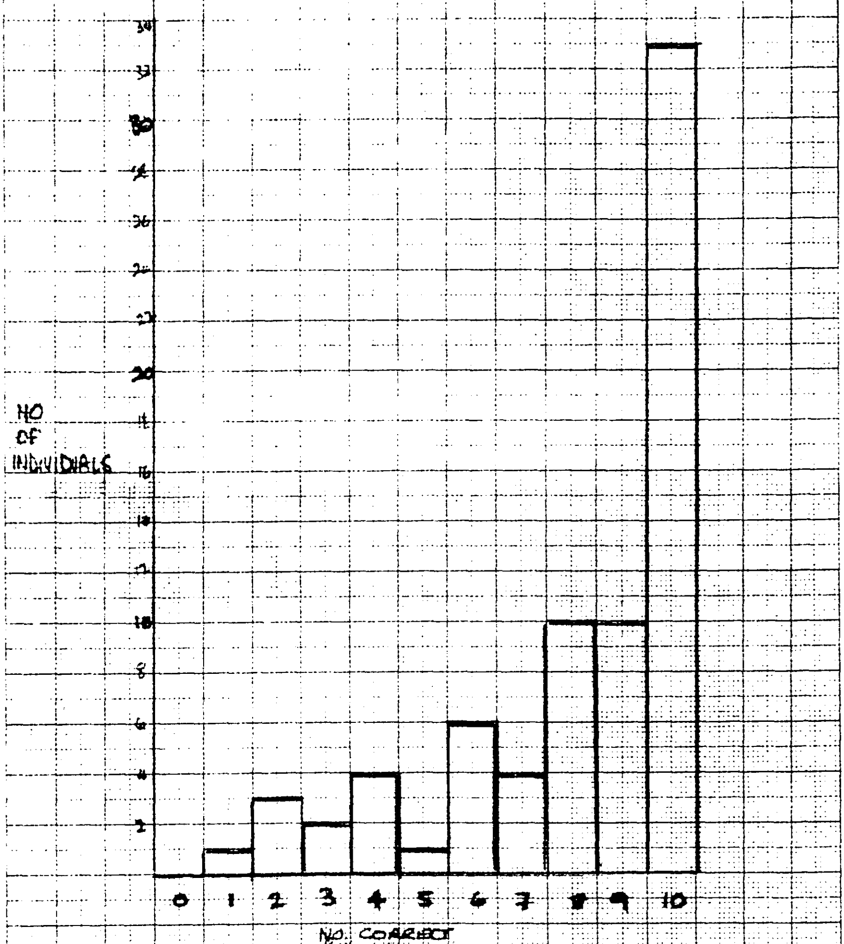


MALES ▨ ♂ N = 31 MEAN = 7.35 SD 2.4

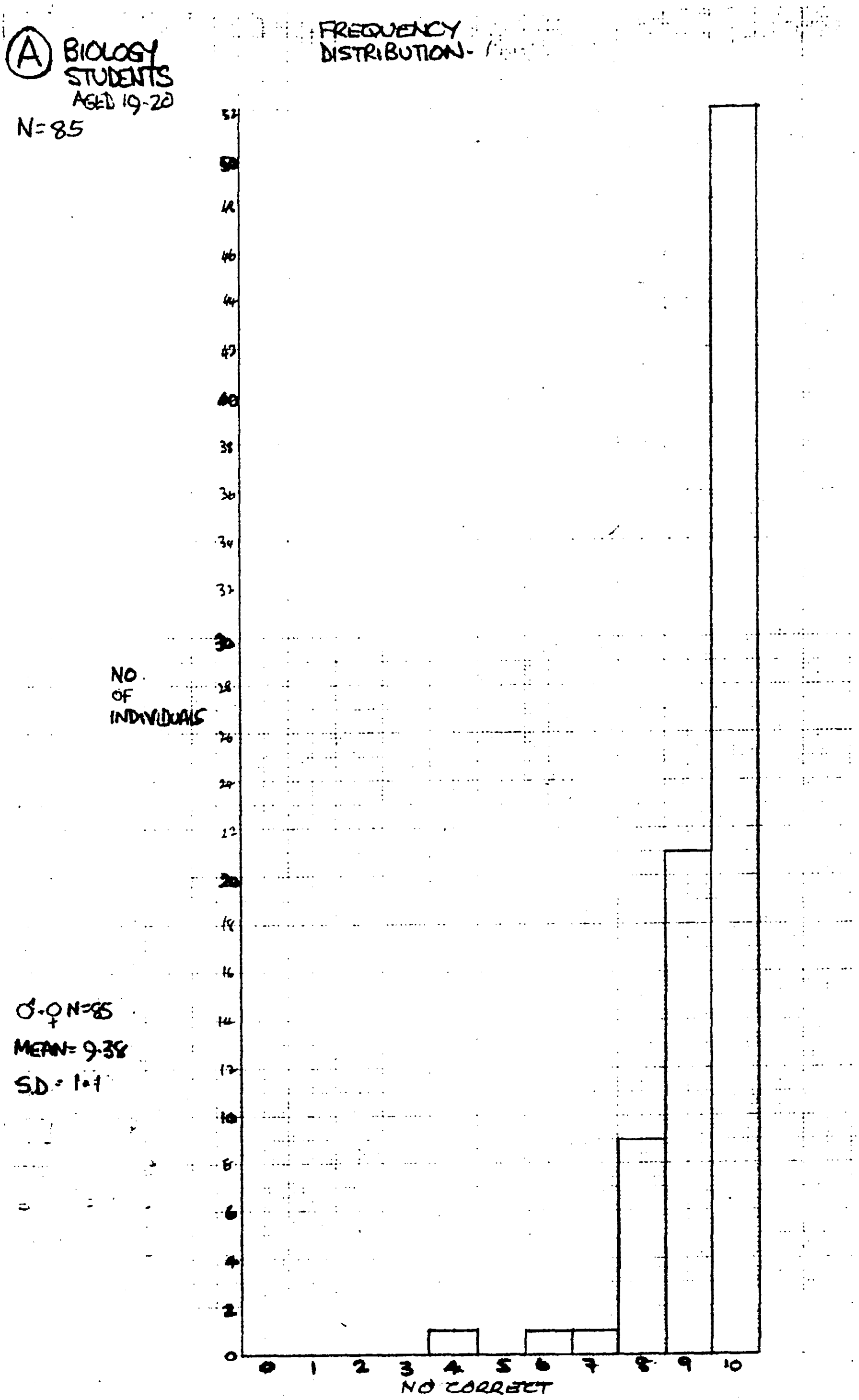
FEMALES ⊡ ♀ N = 52 MEAN = 6.69 S.D 2.5

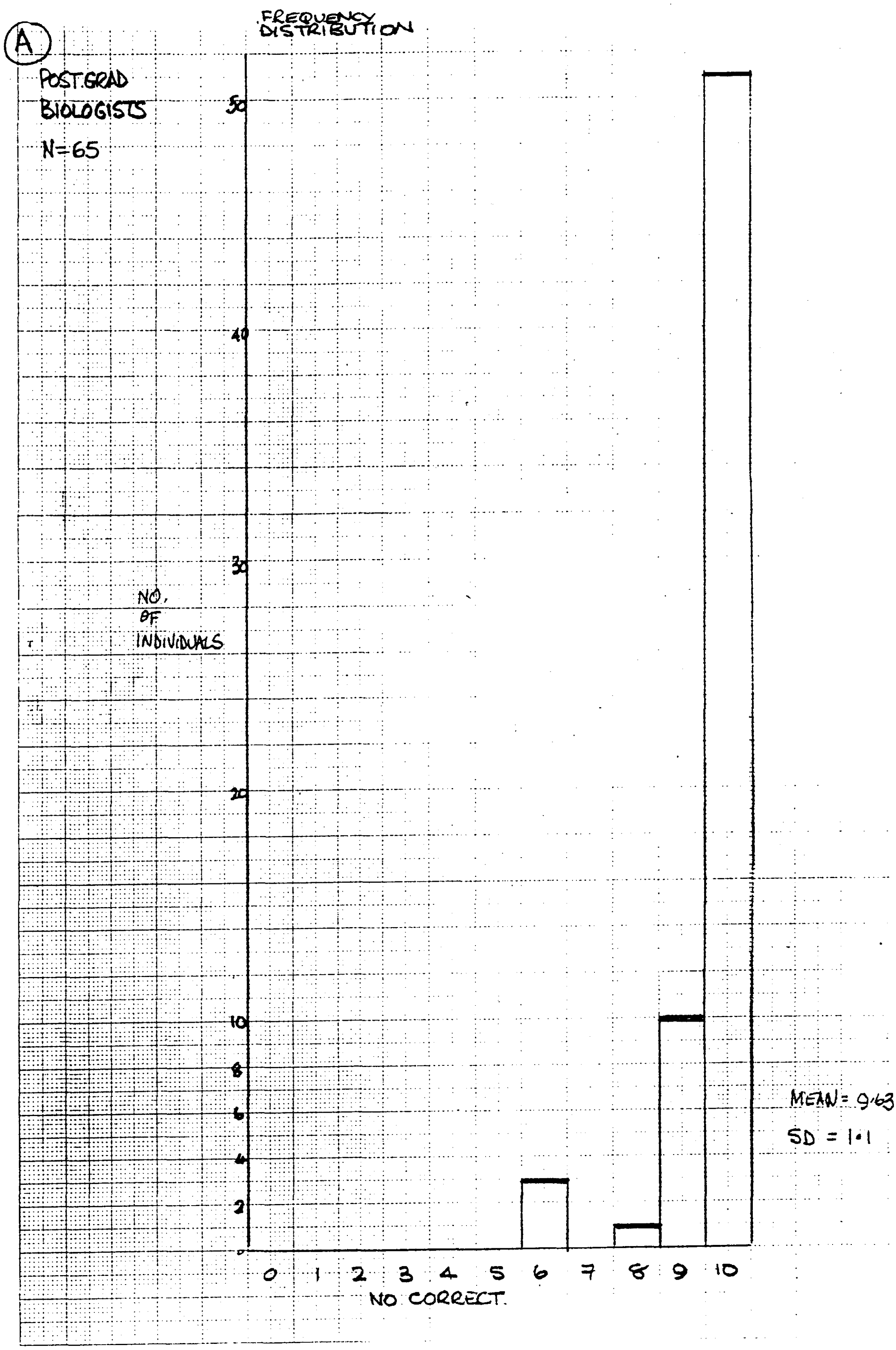
(A) S6 AGED 17-18 FREQUENCY DISTRIBUTION

N = 74



♂+♀ N = 74 MEAN = 8.08 S.D. = 2.6

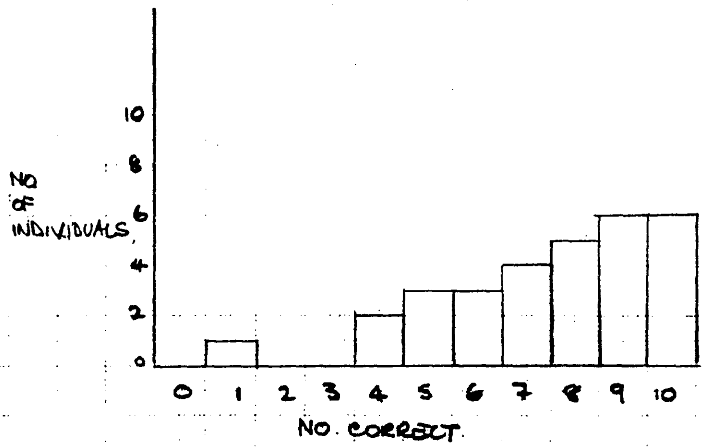

(A) BIOLOGY STUDENTS AGED 19-20
N=85
FREQUENCY DISTRIBUTION
NO OF INDIVIDUALS
NO CORRECT
0
1
2
3
4
5
6
7
8
9
10
♂-♀ N=85
MEAN= 9.38
S.D = 1.1


FREQUENCY DISTRIBUTION
A
POST.GRAD
BIOLOGISTS
N=65
NO.
OF
INDIVIDUALS
50
40
30
20
10
8
6
4
2
0 1 2 3 4 5 6 7 8 9 10
NO CORRECT.
MEAN = 9·63
SD = 1·1

(A) NON SCIENCE STUDENTS

FREQUENCY DISTRIBUTION

N=30

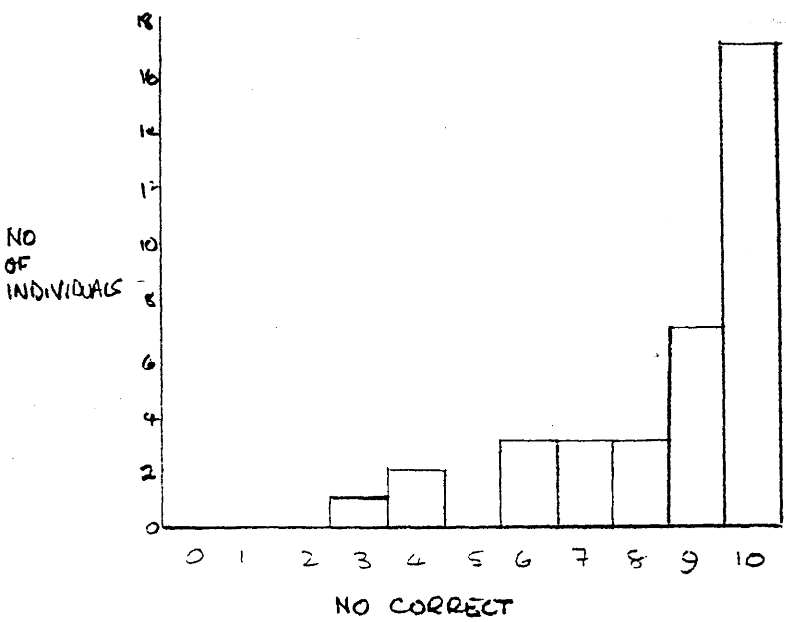


N=30 MEAN= 7·16 SD· 2·3

(A) NON SCIENCE POST GRADS

FREQUENCY DISTRIBUTION

N= 36

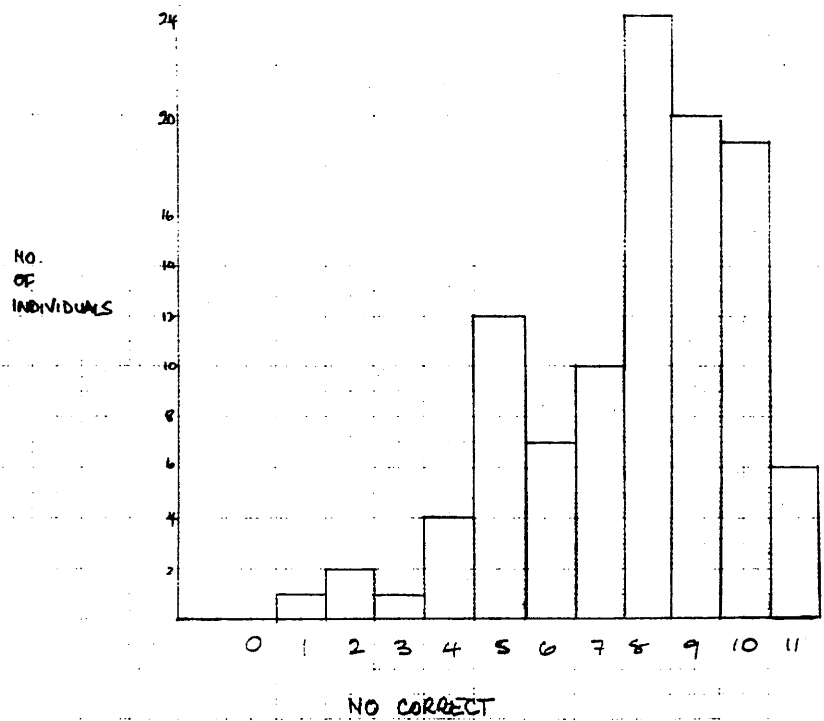


N=36 MEAN= 8·52 SD 2·0

B

P4/5
AGED 8-9
N=106

FREQUENCY
DISTRIBUTION



N = 106 MEAN = 7.77 S.D = 2.2

A

B

P7 AGED 10-11

N=95

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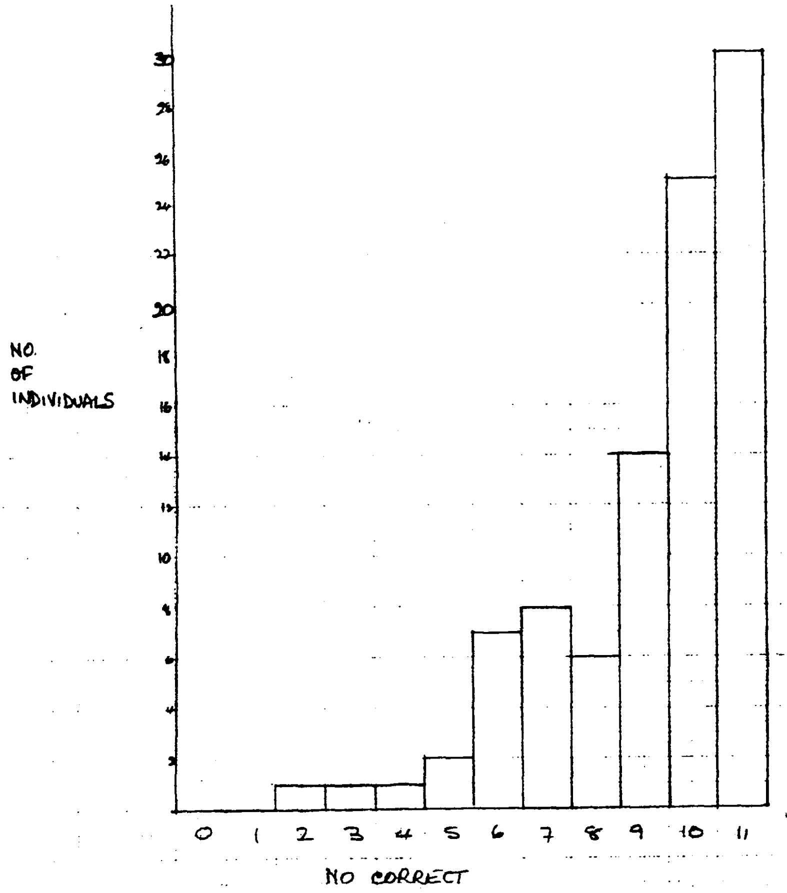

N=95 MEAN= 9.16 SD=2.0

B.

S2 AGED 13-14

N=68

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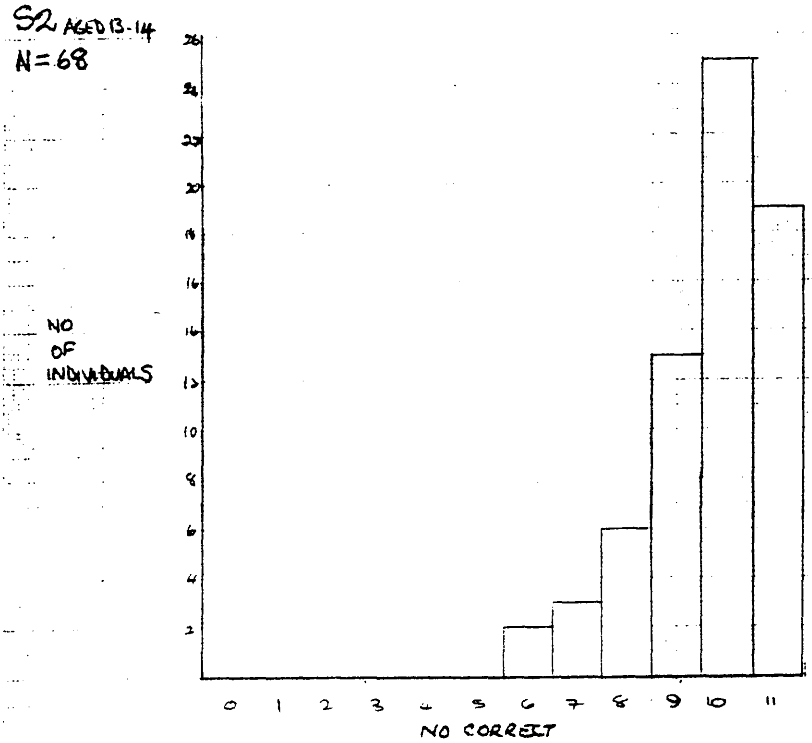
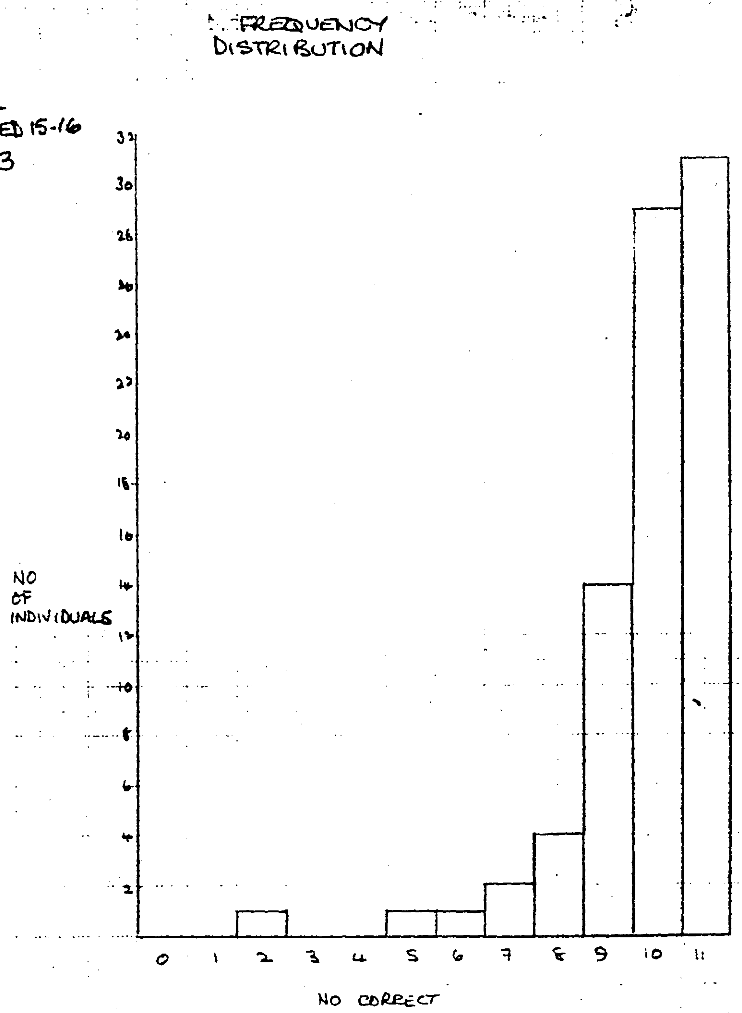


♂+♀ N = 32+36 = 68 MEAN = 9.67 SD = 1.4

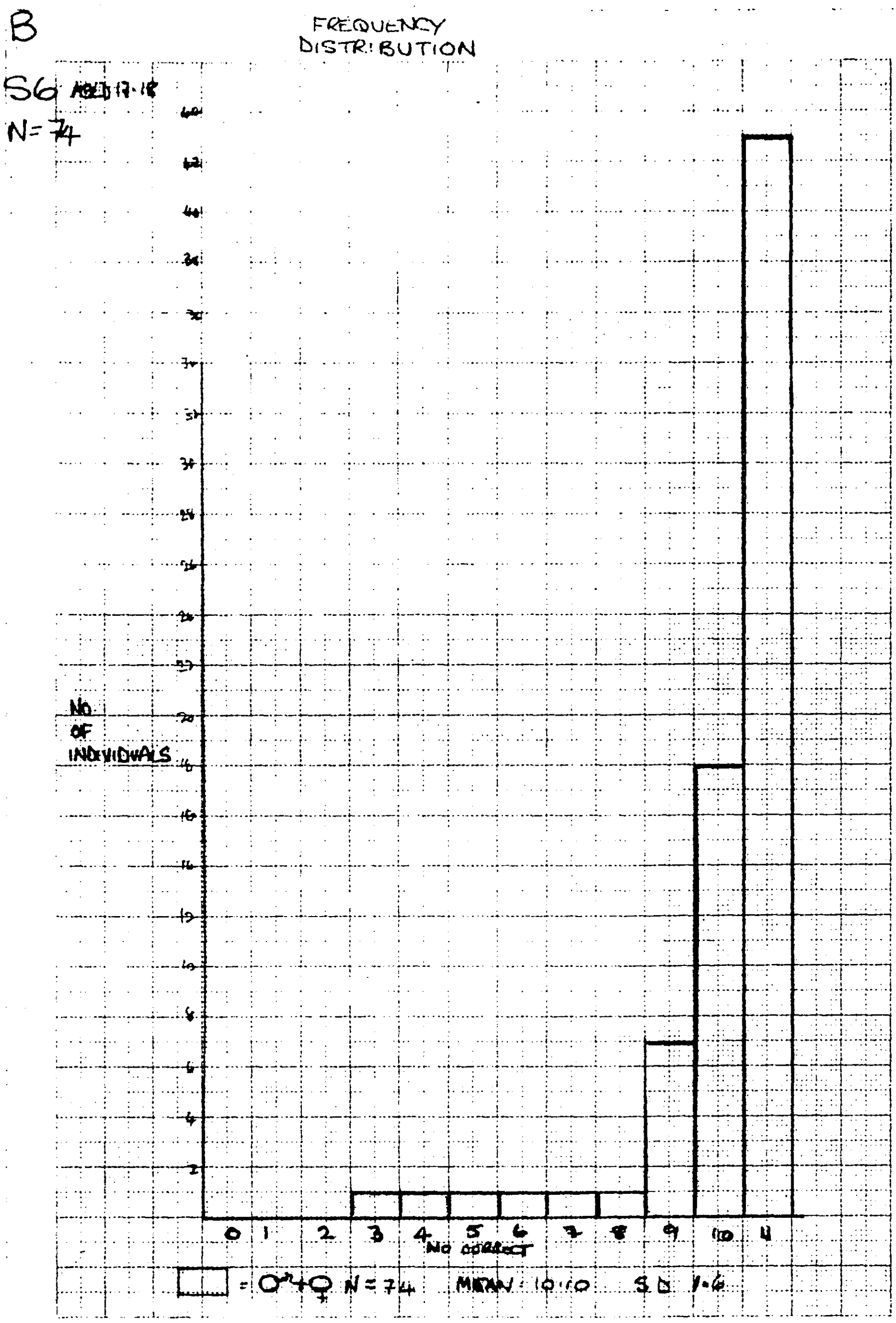
B

S4
AGED 15-16
N=83



N = 83 MEAN = 9.81 SD 2.0

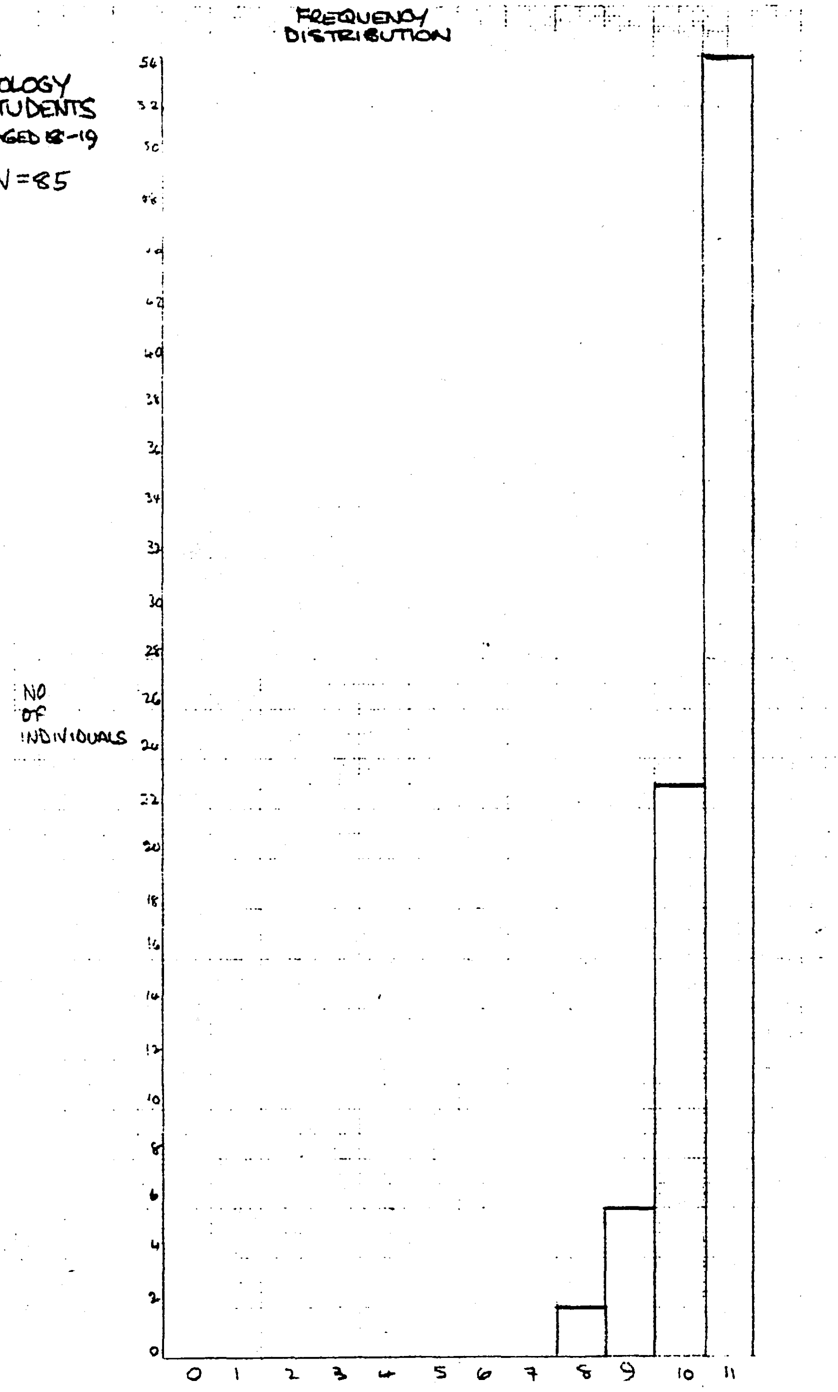
A


B
S6 AGED 17-18
N=74
FREQUENCY
DISTRIBUTION
NO
OF
INDIVIDUALS
0 1 2 3 4 5 6 7 8 9 10 11
NO CORRECT
= ♂+♀ N=74 MEAN 10·0 SD 1·6

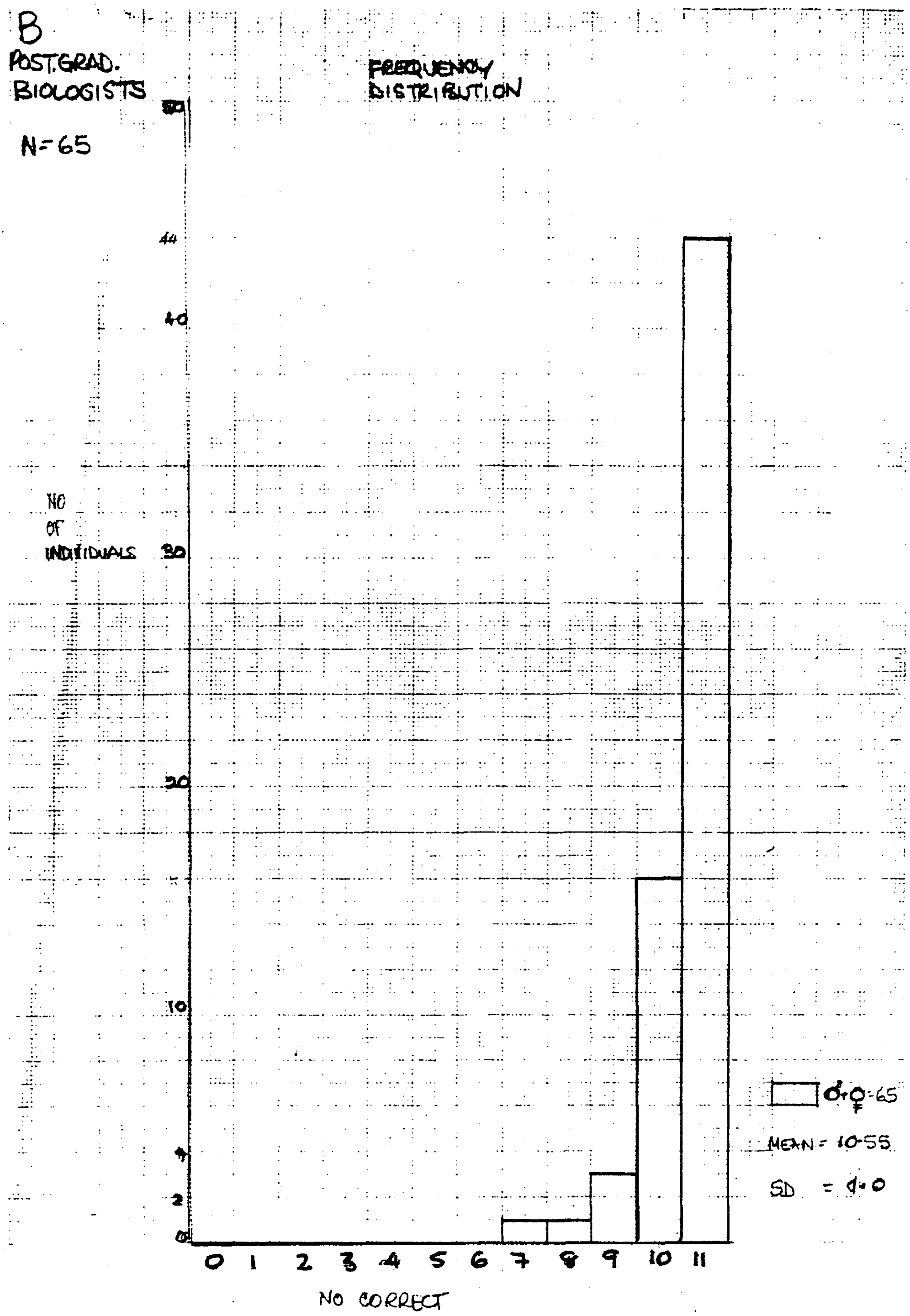
B

BIOLOGY STUDENTS AGED 18-19

N=85



♂+♀ N=85 MEAN: 10·51 SD 0·9

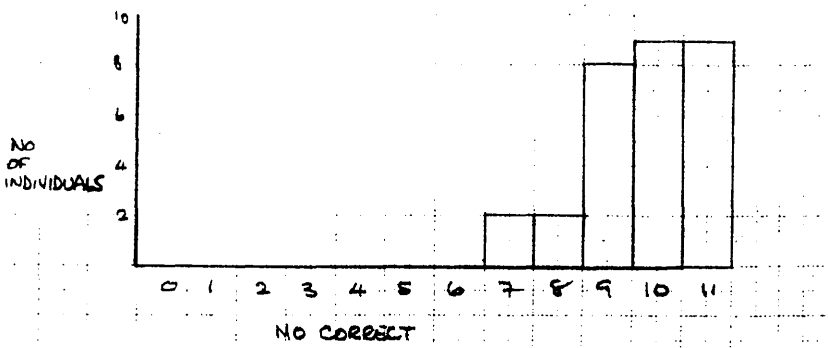

B
POST.GRAD.
BIOLOGISTS
N=65
FREQUENCY
DISTRIBUTION
NO
OF
INDIVIDUALS
44
40
30
20
10
4
2
0
0 1 2 3 4 5 6 7 8 9 10 11
NO CORRECT
♂+♀ 65
MEAN = 10·55
SD = 1·0

B

NON SCIENCE STUDENTS

FREQUENCY DISTRIBUTION

N = 30



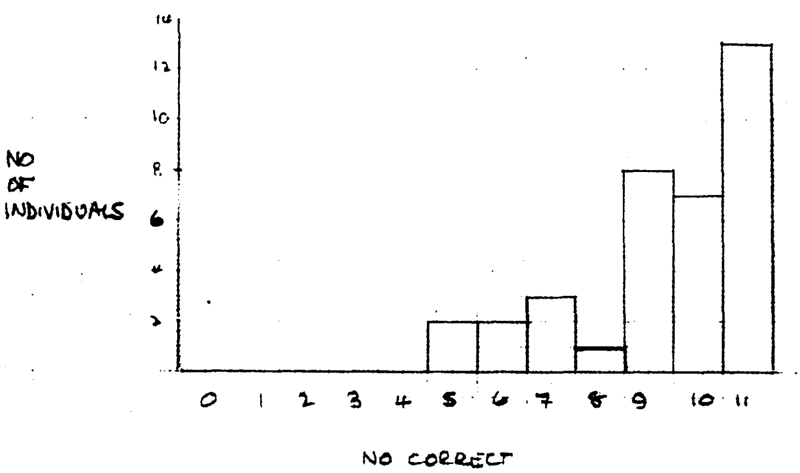
N = 30 MEAN = 9.70 SD = 1·4

B

NONSCIENCE POST.GRADS

FREQUENCY DISTRIBUTION

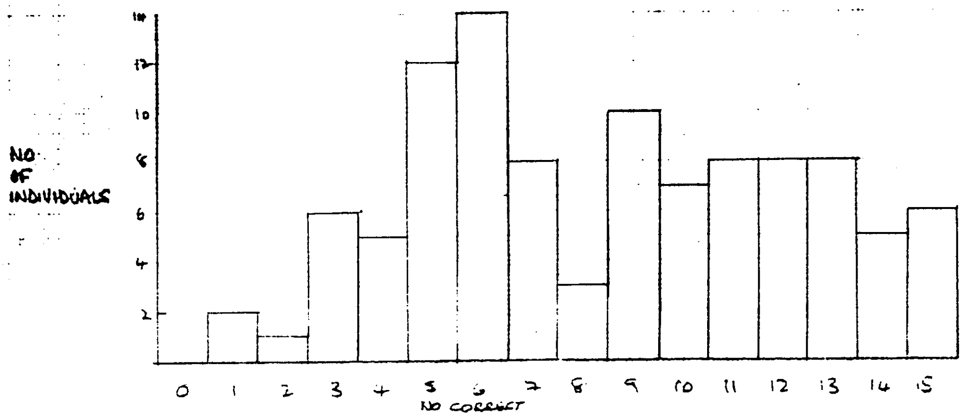
N = 36



N = 36 MEAN = 9·33 SD · 1·8

C
P4/5
AGED 8-9
N= 103

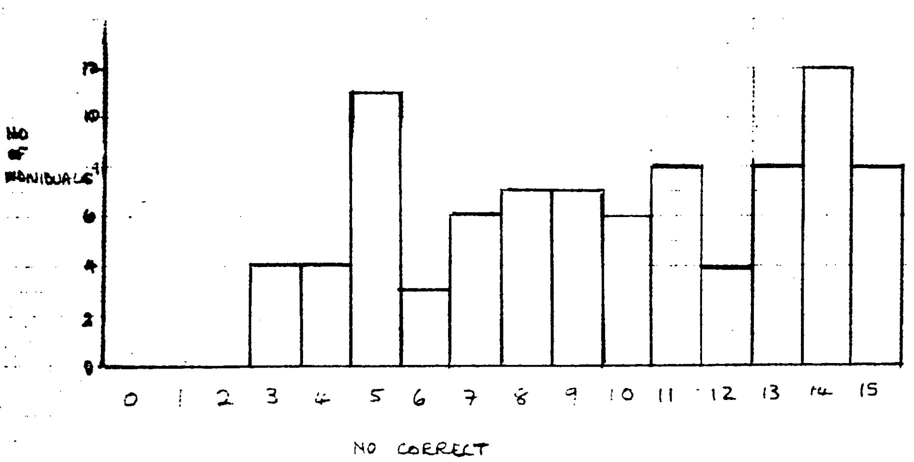
FREQUENCY DISTRIBUTION



N = 103 MEAN = 8.48 SD = 3.8

C
P7
AGED 10-11
N= 88

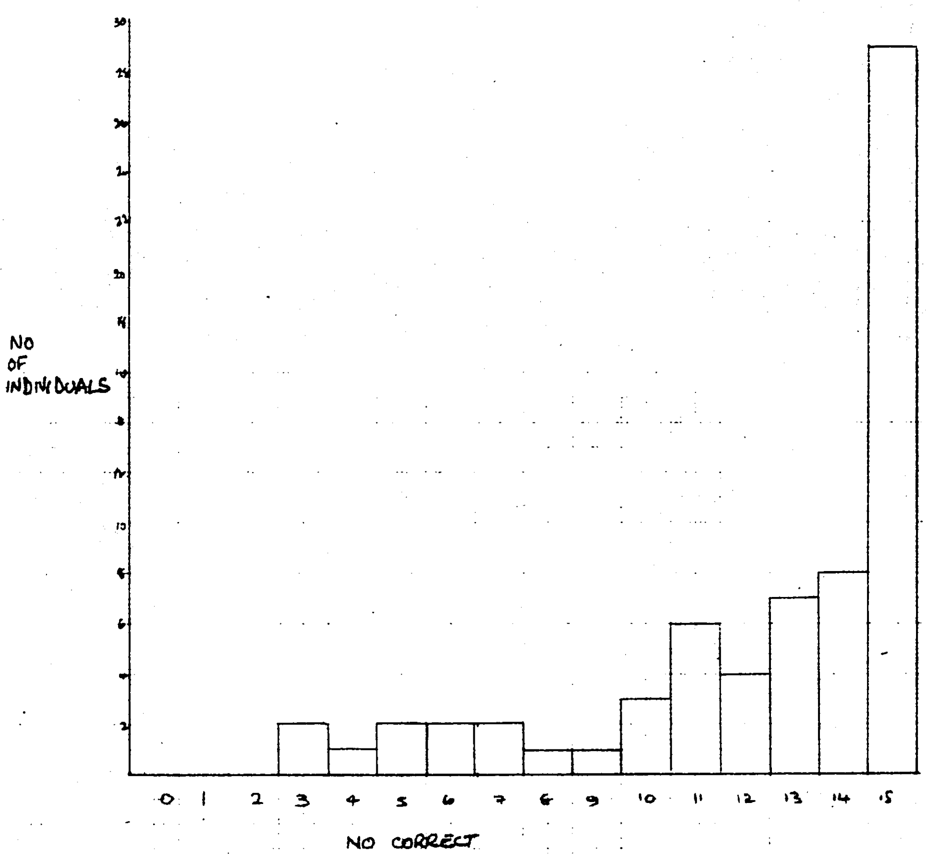
FREQUENCY DISTRIBUTION



N= 88 MEAN = 9.65 SD = 3.6

C
S2
AGED 13-14
N=68

FREQUENCY DISTRIBUTION



N = 68 MEAN = 12.43 S.D = 3.4.

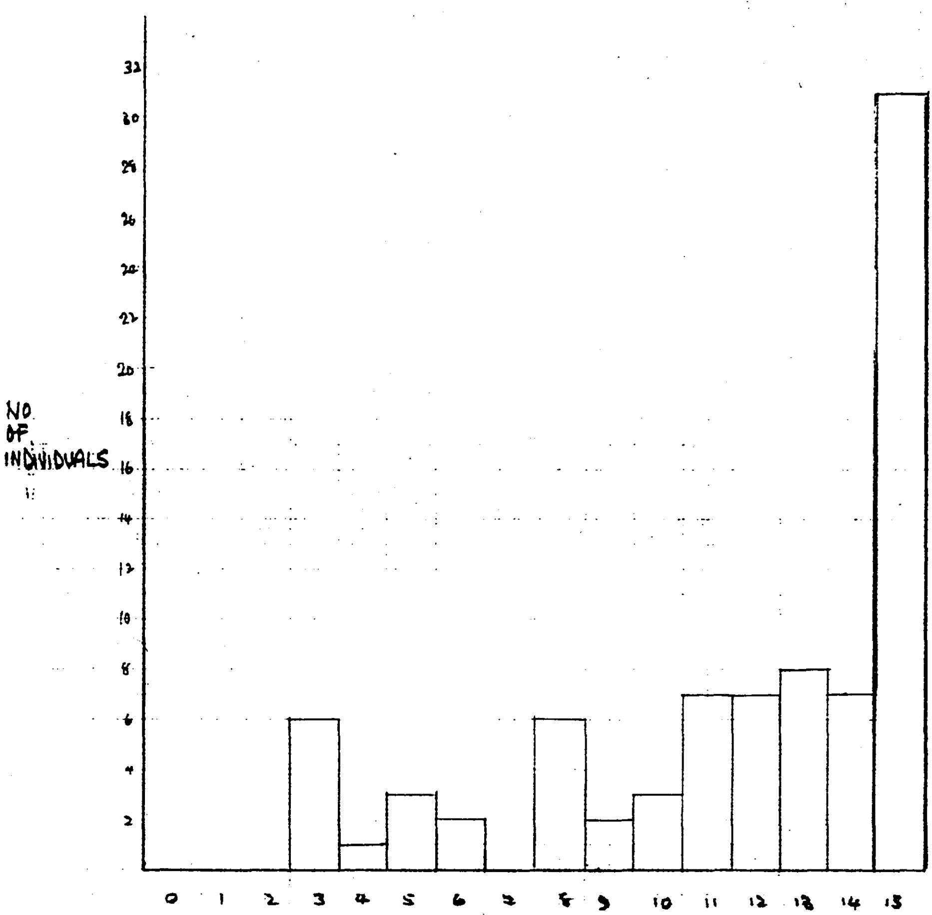
C

S4

AGED 15-16

N=83

FREQUENCY DISTRIBUTION

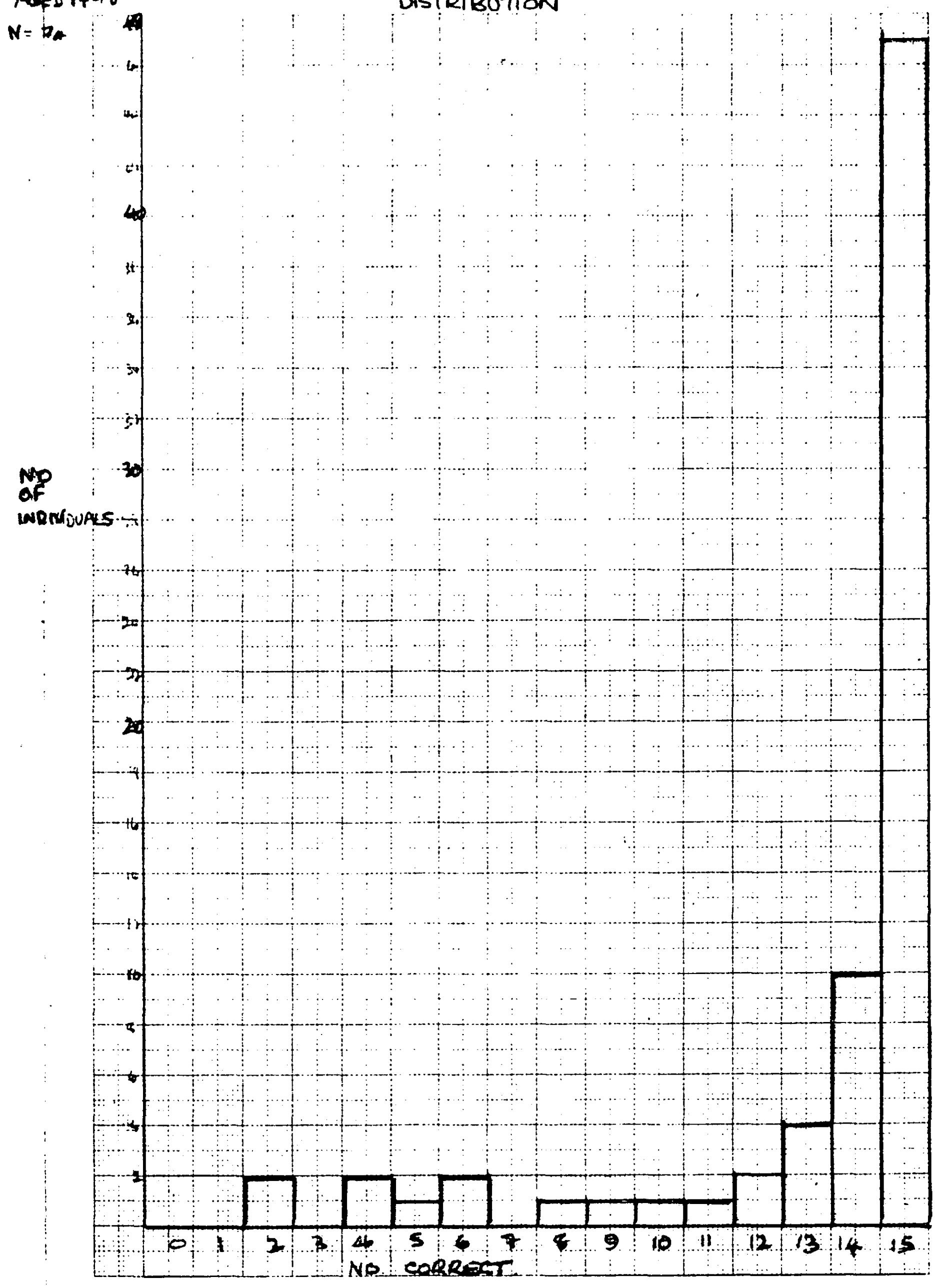


N = 83 MEAN = 11·72 SD· 3·48

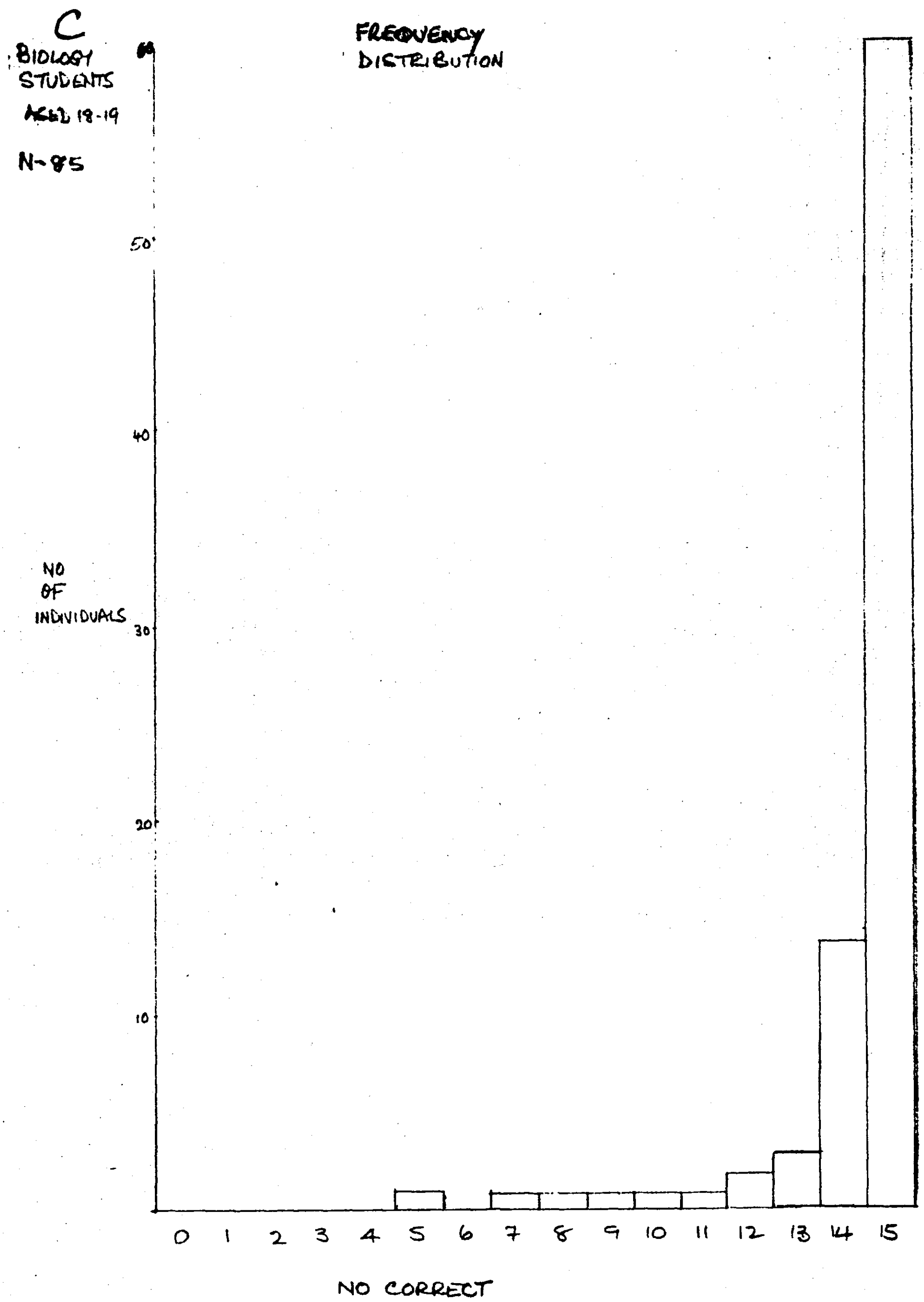
C

S6

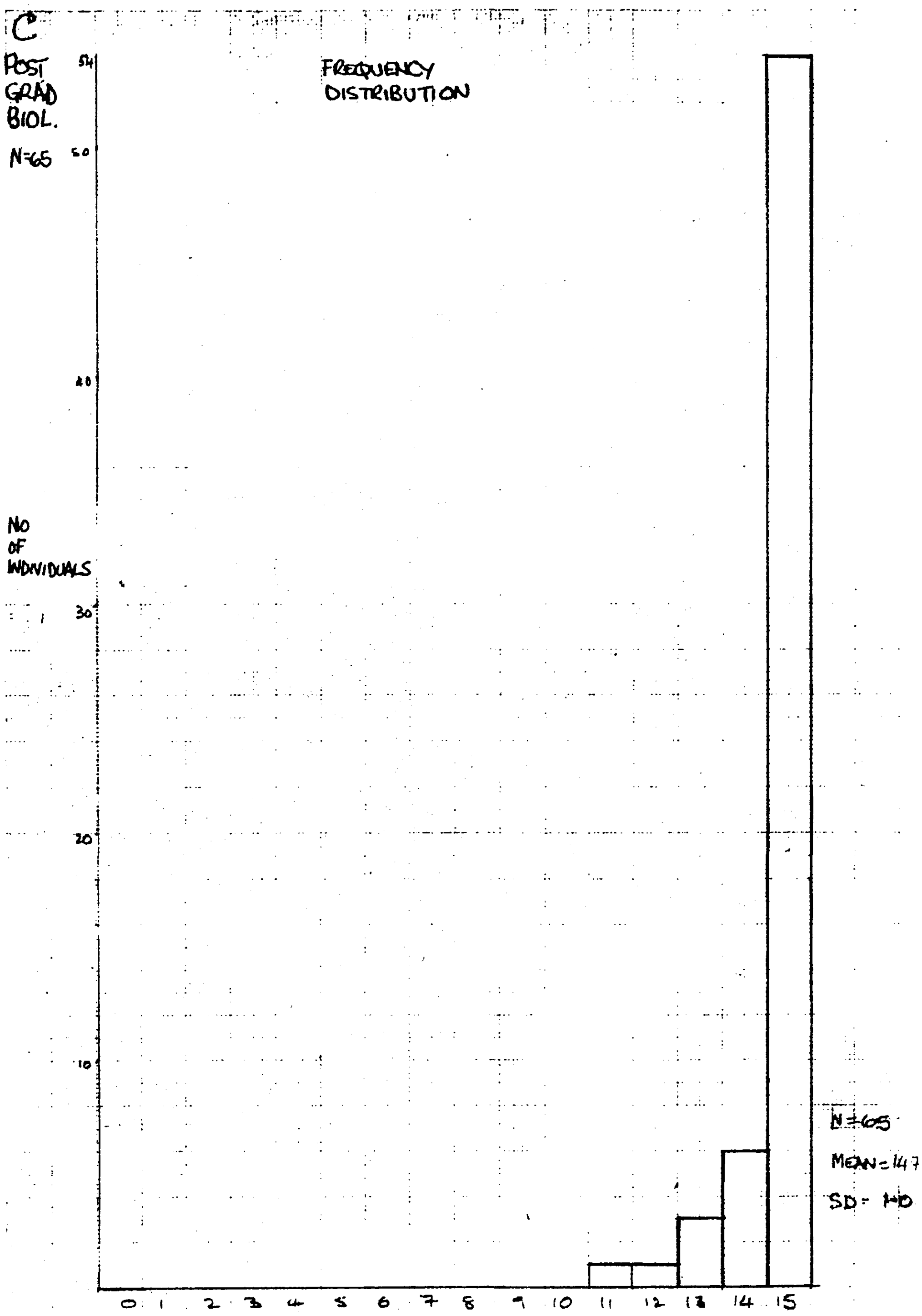
AGED 17-18



N = 74 MEAN = 13.35 S.D. = 3.3



N=85 MEAN: 14·29 SD.: 1·7

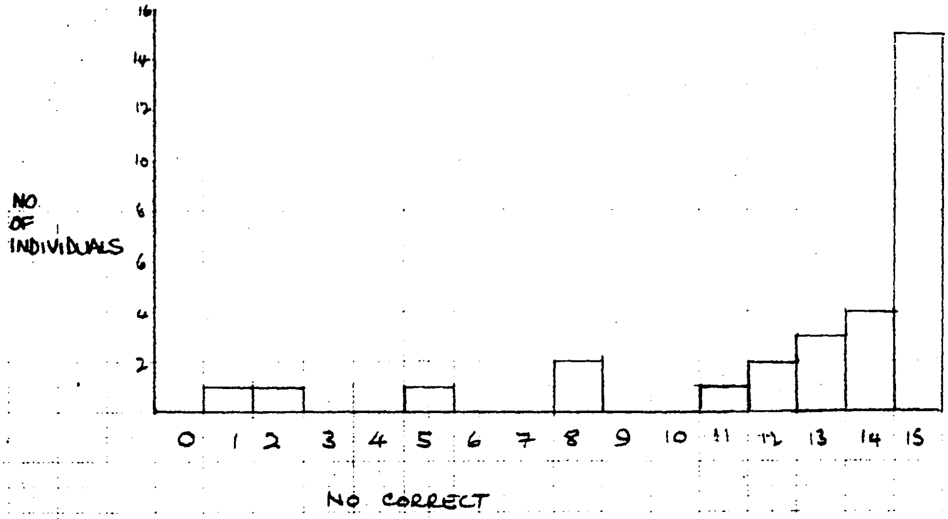

C
POST GRAD BIOL.
N=65
FREQUENCY DISTRIBUTION
No of INDIVIDUALS
54
50
40
30
20
10
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
NO CORRECT
N=65
MEAN=147
SD= 1·0

C

NON-SCIENCE STUDENTS

N= 30

FREQUENCY DISTRIBUTION



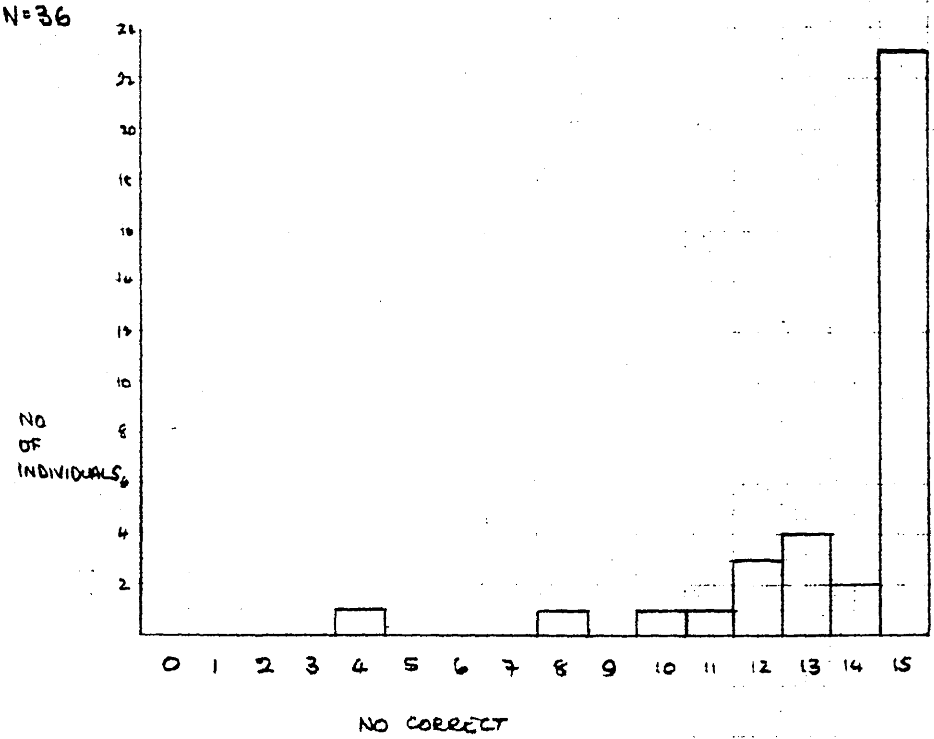
N = 30 MEAN = 12.62 SD - 3.9

C

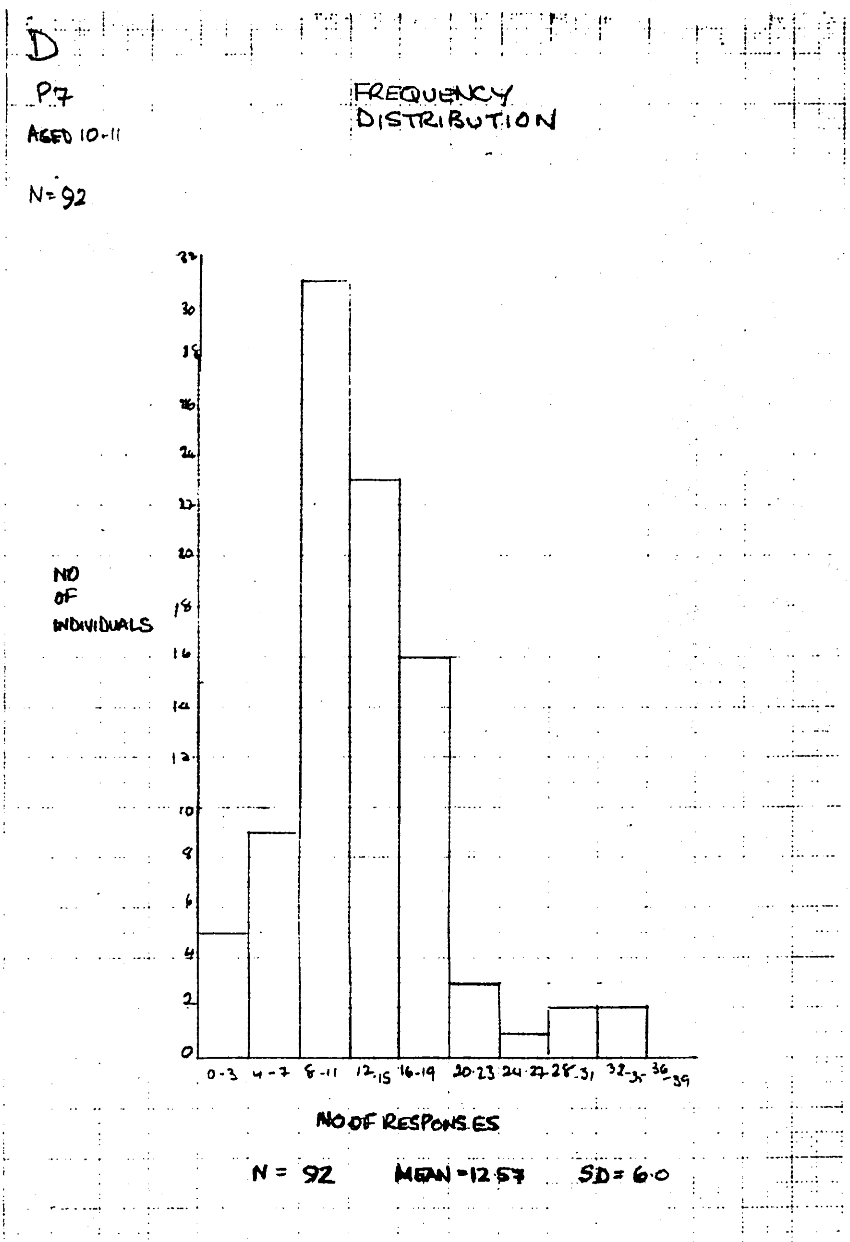
NON SCIENCE POST GRADS

N=36

FREQUENCY DISTRIBUTION



N = 36 MEAN - 13.72 SD - 2.3


D
P7
AGED 10-11
N=92
FREQUENCY DISTRIBUTION
NO OF INDIVIDUALS
0-3
4-7
8-11
12-15
16-19
20-23
24-27
28-31
32-35
36-39
NO OF RESPONSES
N = 92
MEAN = 12.57
SD = 6.0

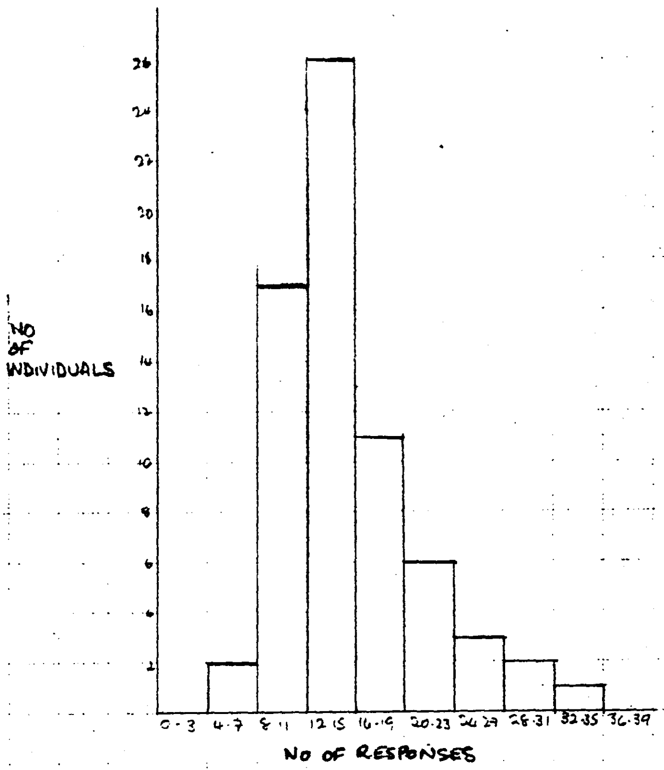
D

S2

AGED 13-14

N=68

FREQUENCY DISTRIBUTION

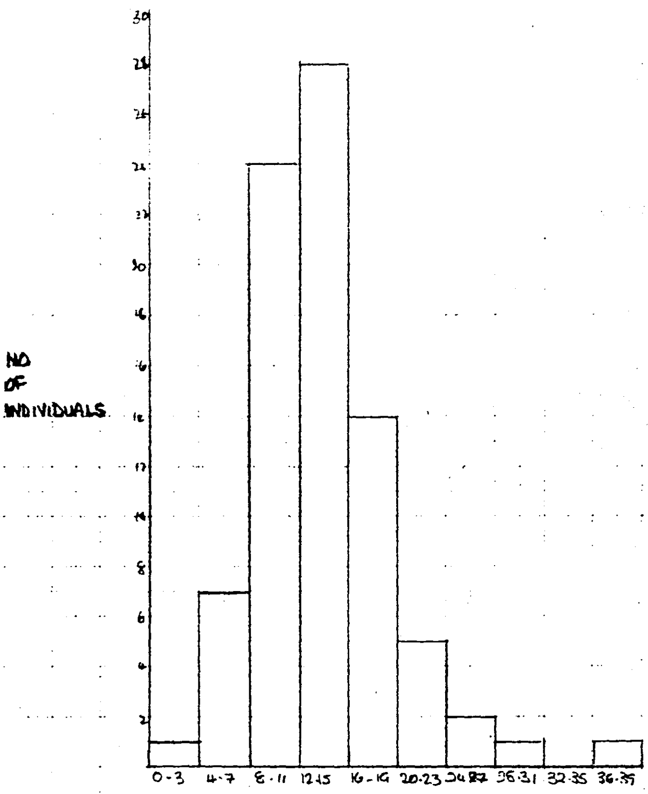


N=68 MEAN=15·00 SD: 5·5

D

S4
AGED 15-16
N=83

FREQUENCY
DISTRIBUTION



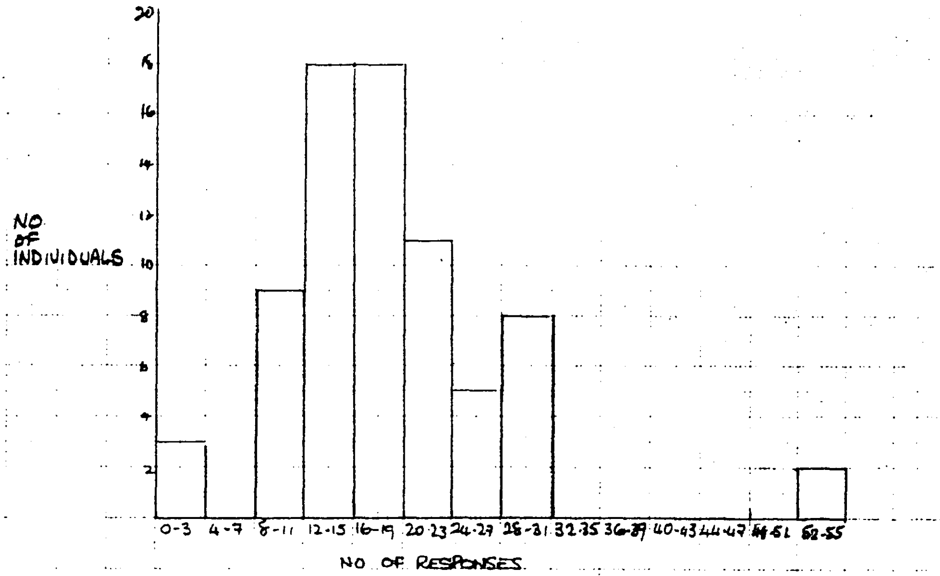
N = 83 MEAN = 13.44 SD. = 5.4

A

D
S6
AGED 17-18

N = 74

FREQUENCY DISTRIBUTION

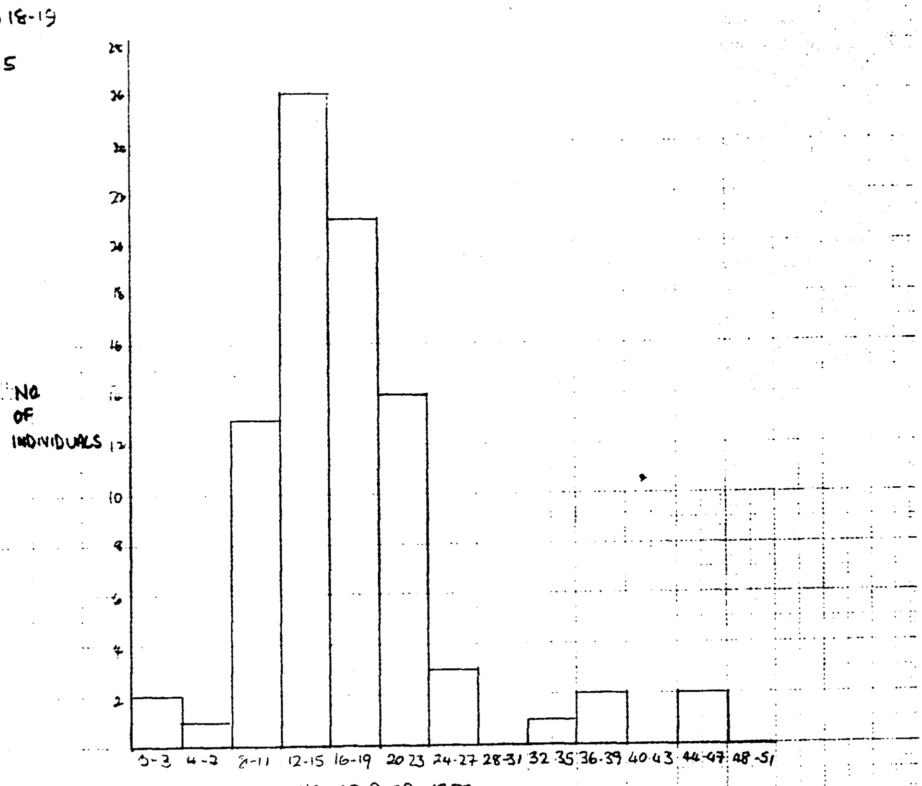


N = 74 MEAN = 17.77 SD = 9.2

D
BIOLOGY STUDENTS
AGED 18-19

N = 85

FREQUENCY DISTRIBUTION



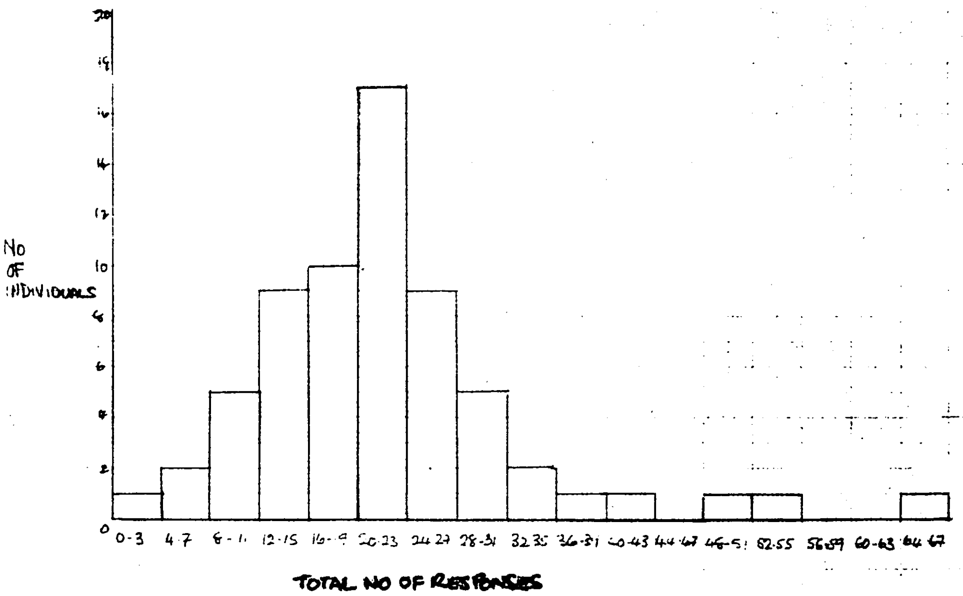
N = 85 MEAN = 16.63 SD = 7.7

D

POST GRAD BIOLOGISTS

N = 65

FREQUENCY DISTRIBUTION



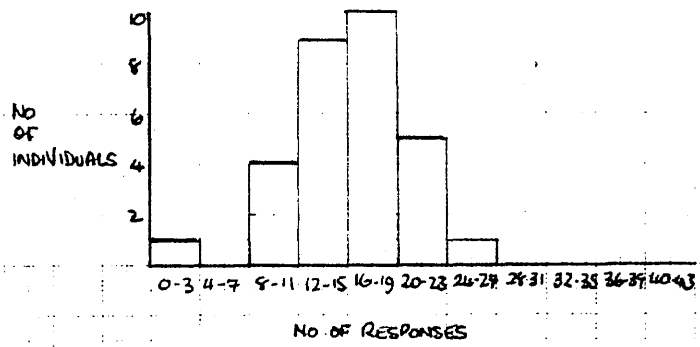
N = 65. MEAN = 21·89 SD = 10·8

FREQUENCY DISTRIBUTION

D

NON SCIENCE STUDENTS

N=30



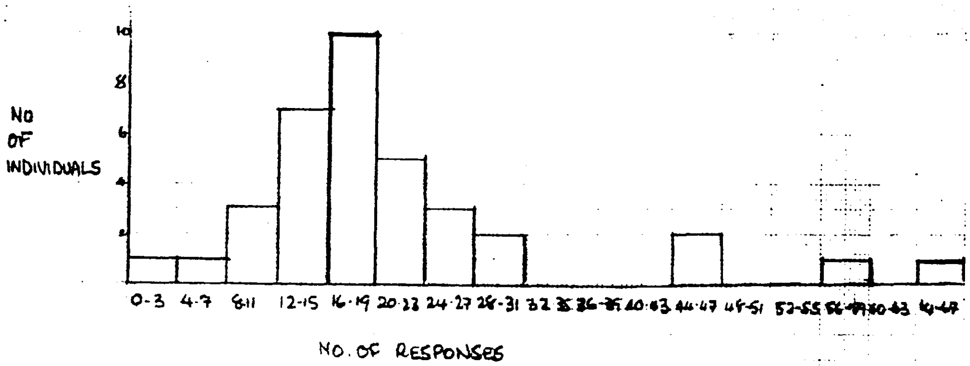
N= 30 MEAN = 15·60 SD= 5·2

FREQUENCY DISTRIBUTION

D

NON SCIENCE POST GRADS

N=36

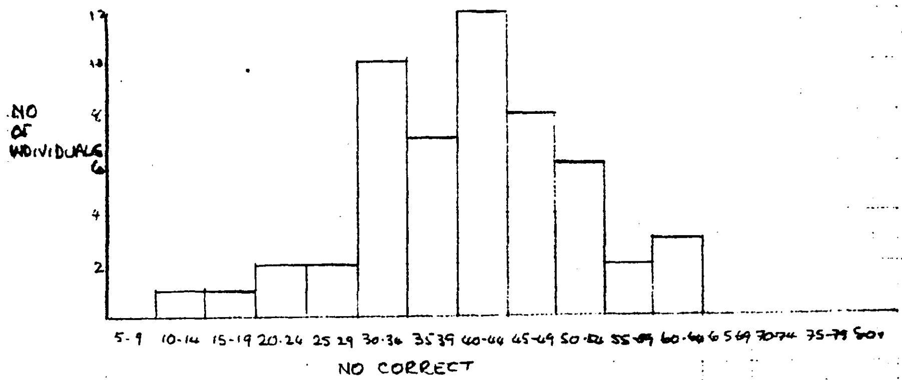


N=36 MEAN = 21.22 SD = 13.0

E

P4 - AGED 8
N = 54

FREQUENCY DISTRIBUTION

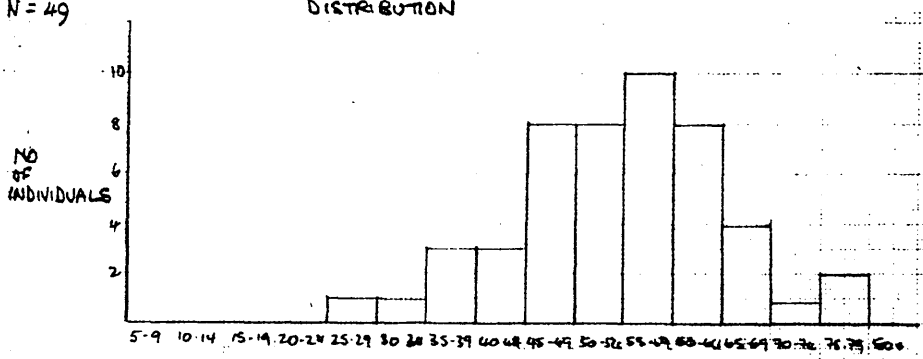


P4 N= 54 MEAN- 40.4 % MISSED - 50.7 NO IMAG^D/PERSON - 1.42
SD = 10.7

E

P5 - AGED 9
N = 49

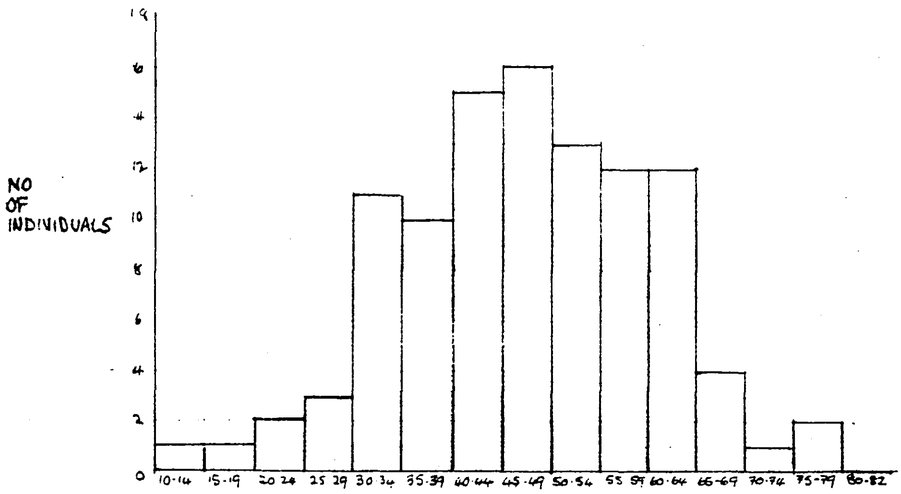
FREQUENCY DISTRIBUTION



P5 N= 49 MEAN - 53.8 % MISSED - 34.3 NO IMAG^D/PERSON - 1.75
SD = 10.4

E
P4/5
AGED 8-9
N=103

FREQUENCY DISTRIBUTION

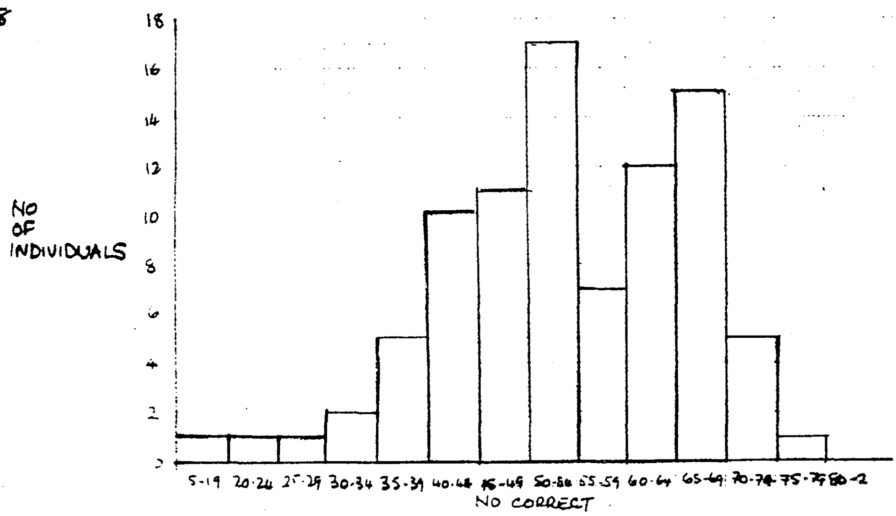


N=103 MEAN-46·77 SD: 12·7

% MISSED = 40·4 NO IMAGINED/PERSON = 1·58

E.
P7.
AGED 10-11
N=88

FREQUENCY DISTRIBUTION



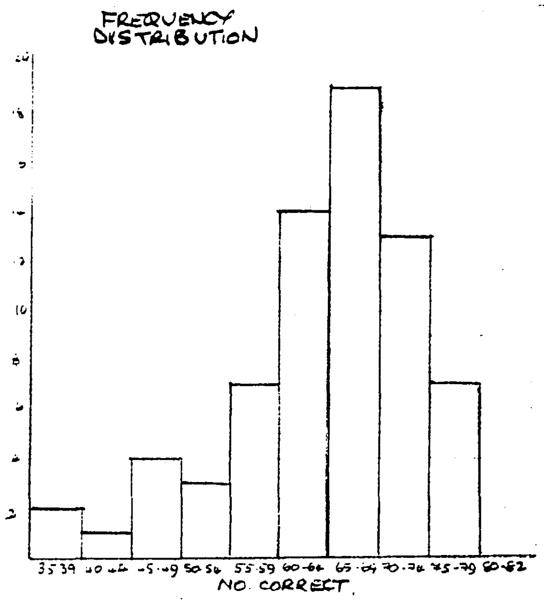
N = 88

MEAN = 53·73 SD = 12·1

NO IMAGINED/PERSON = 4·44

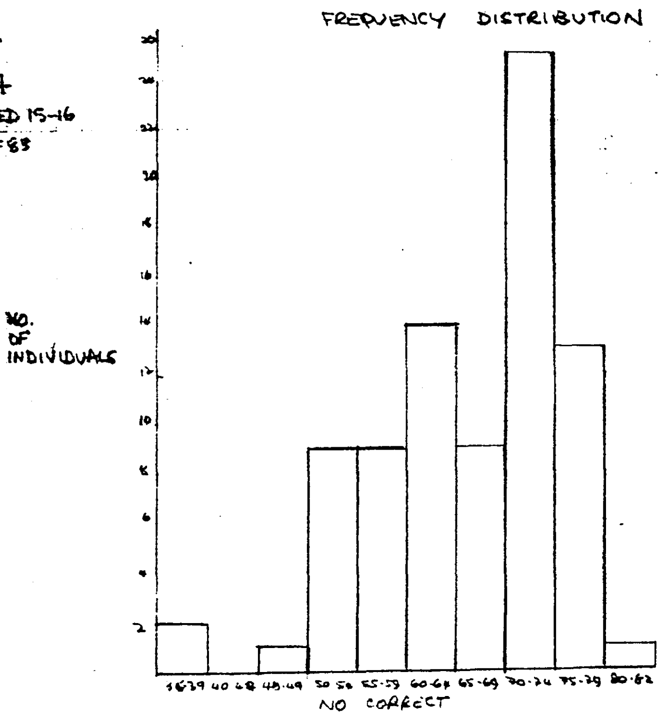
% MISSED = 30·3%

E
S2
AGED 13-14
N=70

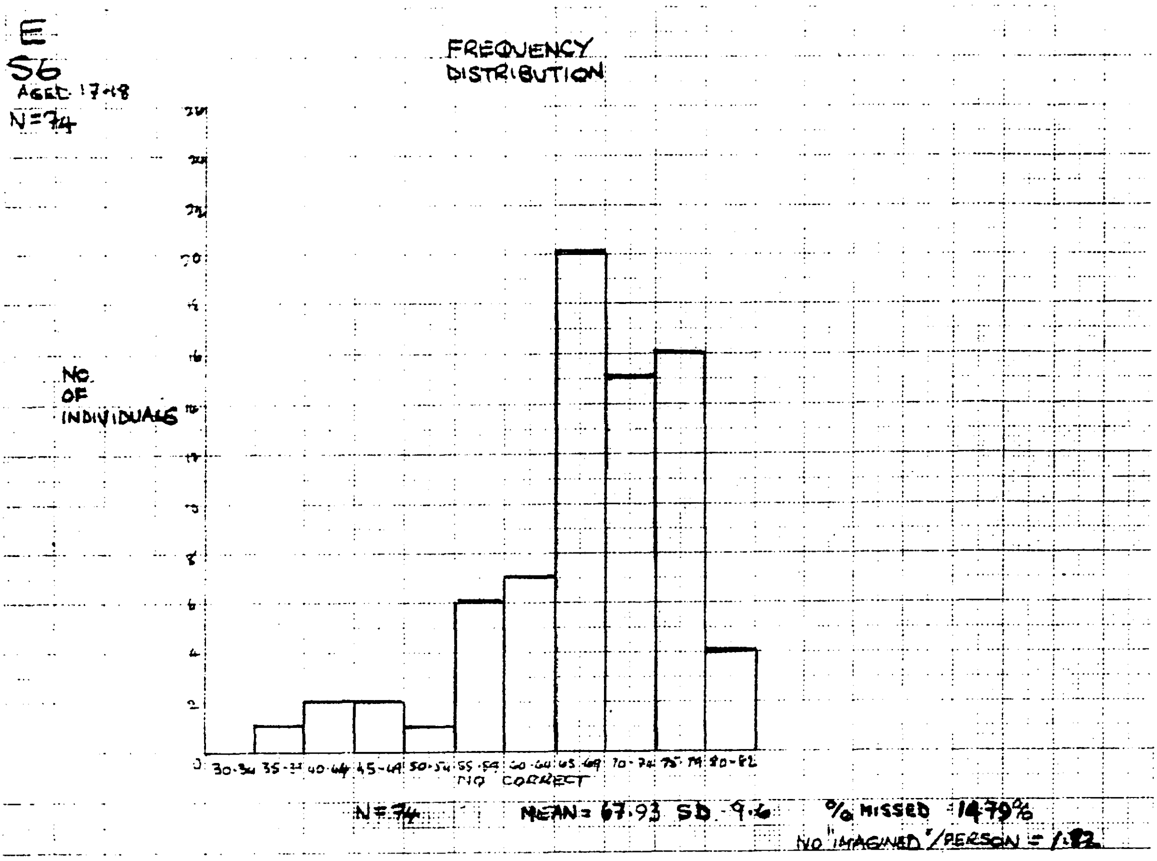


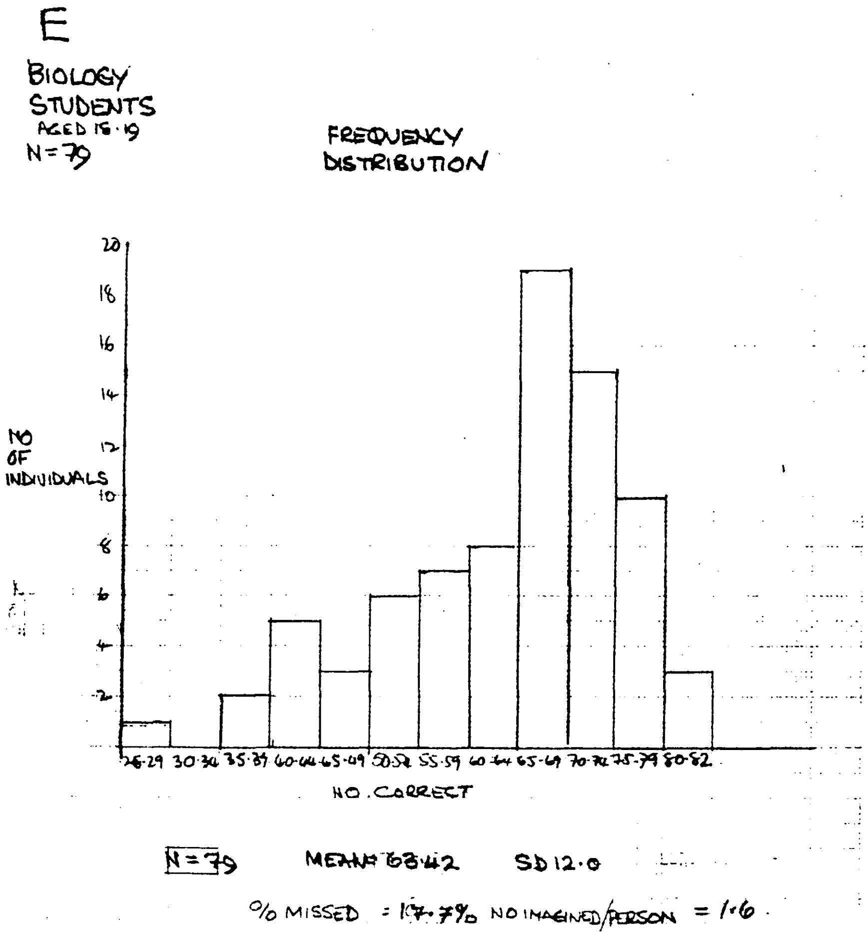
N=70 MEAN = 63·67 S.D. = 9·0
% MISSED : 20·78 NO "IMAGINED"/PERSON = 1·37

E
S4
AGED 15-16
N=83



N=83 MEAN = 65·90 SD. = 9·6 NO IMAG/INDN = 1·55 % MISSED = 17·8%


E
S6
AGED 17-18
N=74
FREQUENCY DISTRIBUTION
NO. OF INDIVIDUALS
30-34 35-39 40-44 45-49 50-54 55-59 60-64 65-69 70-74 75-79 80-82
NO CORRECT
N=74
MEAN= 67.93 SD 9.6
% MISSED 14.79%
NO "IMAGINED"/PERSON = 1.82

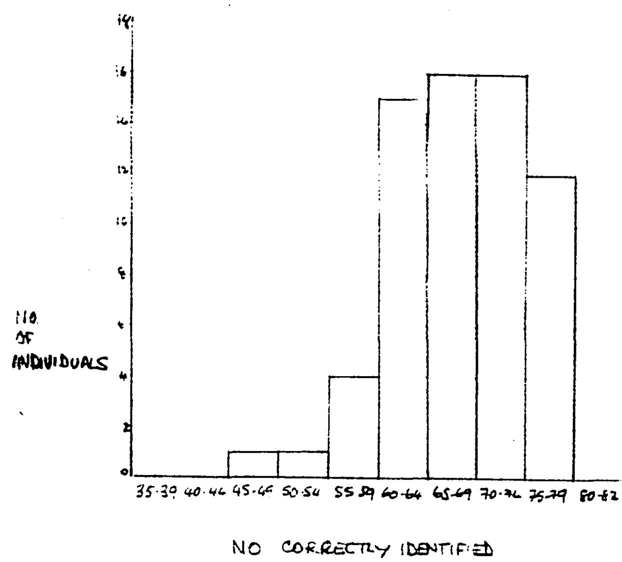

E
BIOLOGY STUDENTS
AGED 15-19
N=79
FREQUENCY DISTRIBUTION
NO OF INDIVIDUALS
20
18
16
14
12
10
8
6
4
2
26-29 30-34 35-39 40-44 45-49 50-54 55-59 60-64 65-69 70-74 75-79 80-82
NO. CORRECT
N=79
MEAN 63.42
SD 12.0
% MISSED = 17.7%
NO IMAGINED/PERSON = 1.6

E

POST.GRAD
BIOLOGISTS

N=65

FREQUENCY
DISTRIBUTION



N=65 MEAN = 68.15 SD = 6.6

% MISSED = 16.88

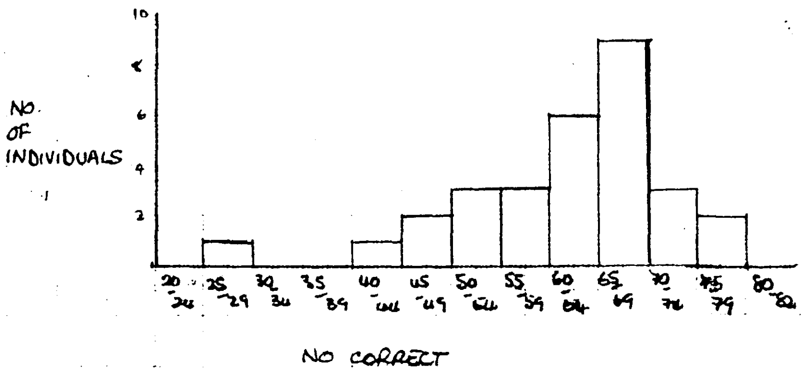
NO IMAG^D/PERSON = 0.50

E

NON SCIENCE STUDENTS

N = 30

FREQUENCY DISTRIBUTION



N = 30 MEAN = 61.13 SD = 11.0

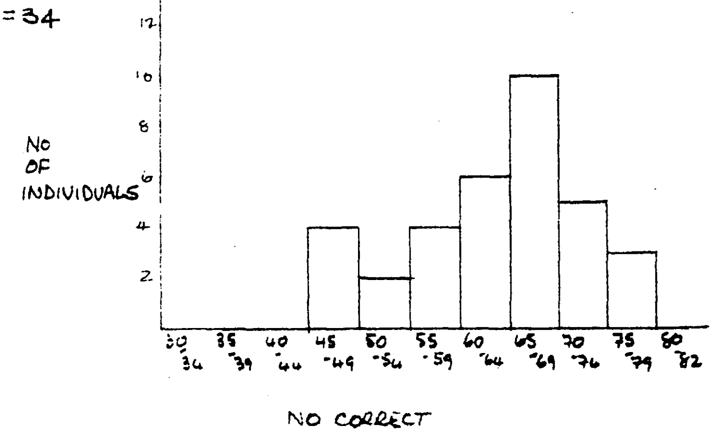
% MISSED = 25.44 NO. IMAG^D/PERSON = 1.46

E

NON SCIENCE POST GRADS

N = 34

FREQUENCY DISTRIBUTION



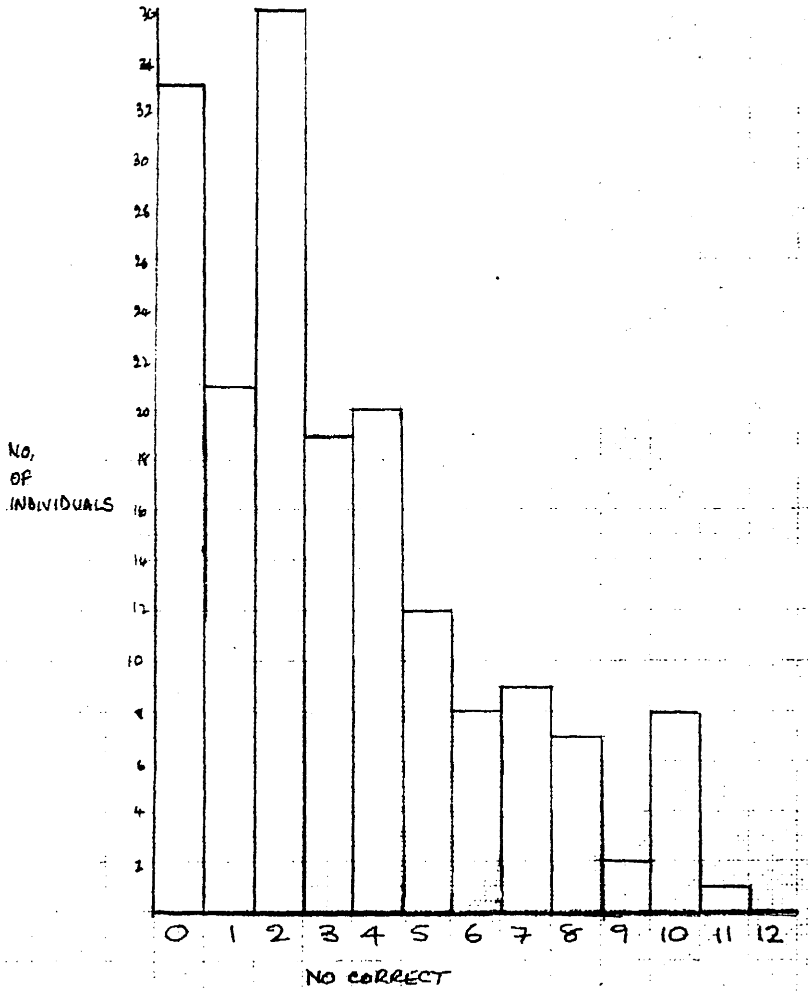
N = 34 MEAN = 63.02 S.D = 8.7

% MISSED = 23.13 NO IMAG^D/PERSON = 0.67

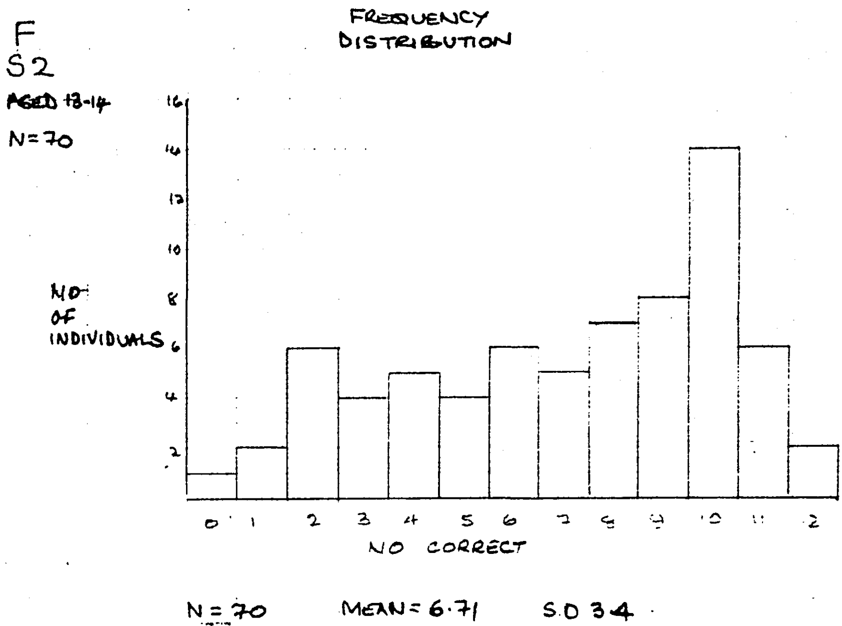
F

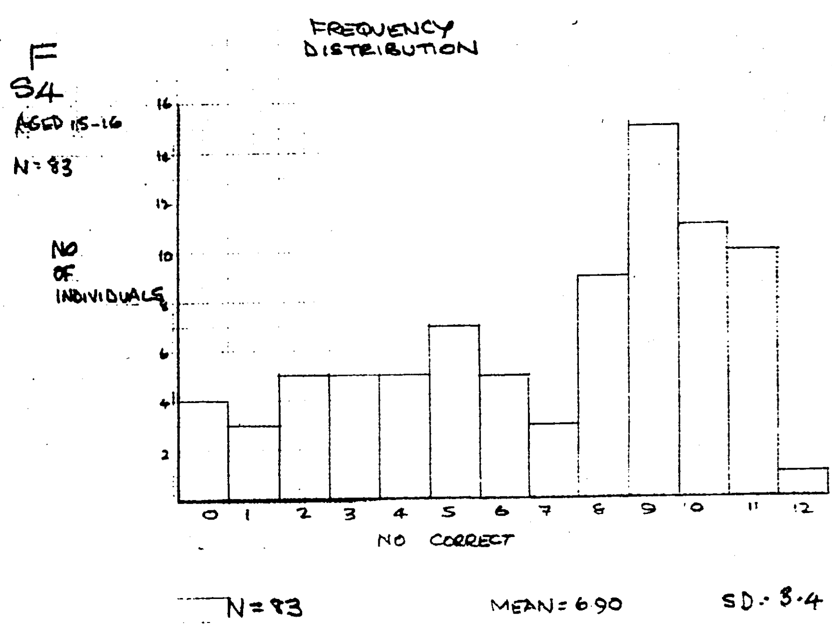
FREQUENCY DISTRIBUTION

P7
AGED 10-11
N = 176



N=176 MEAN 3.21 SD=2.8


FREQUENCY
DISTRIBUTION
F
S2
AGED 13-14
N=70
NO OF INDIVIDUALS
NO CORRECT
N = 70
MEAN = 6.71
S.D 3.4


FREQUENCY
DISTRIBUTION
F
S4
AGED 15-16
N=83
NO OF INDIVIDUALS
NO CORRECT
N=83
MEAN=6.90
SD. 3.4

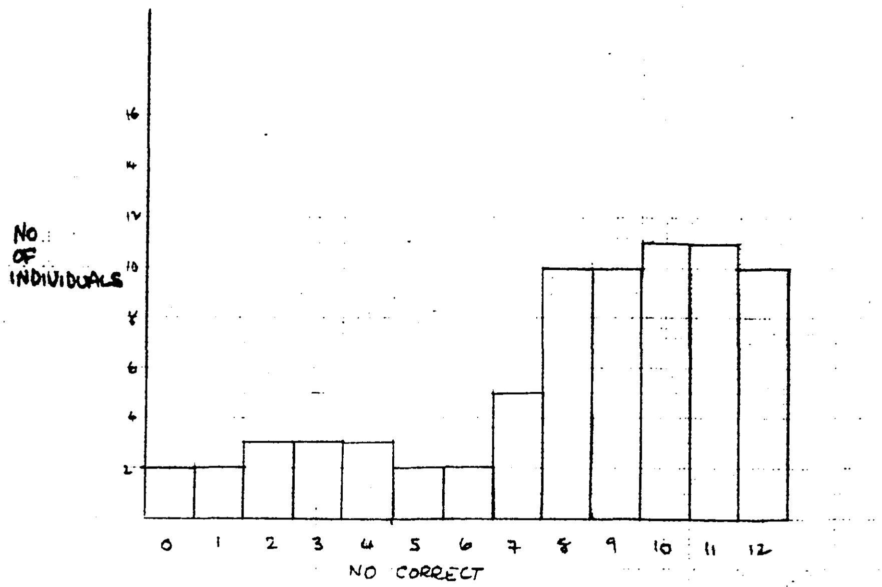
F

S6

AGED 17-18

N=74

FREQUENCY DISTRIBUTION



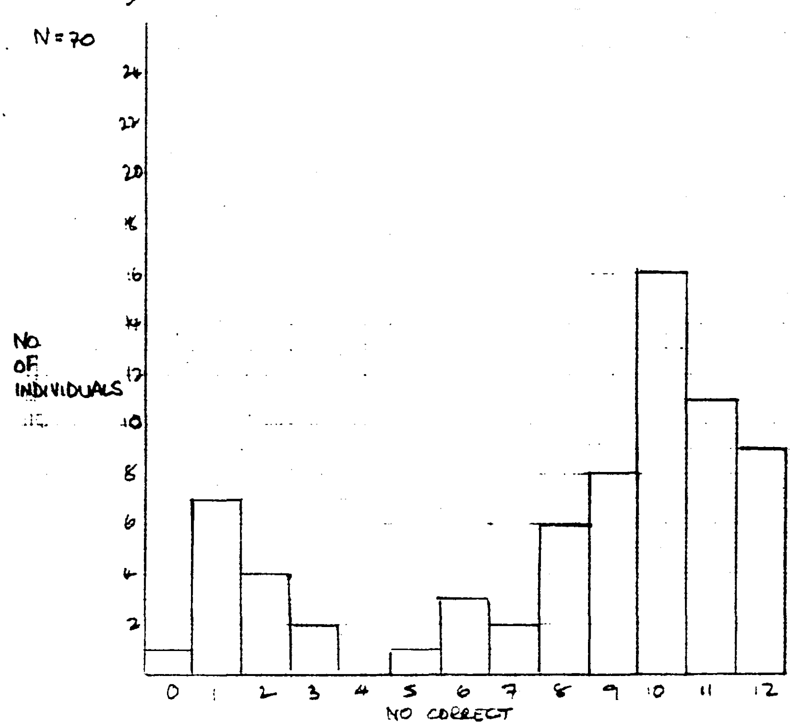
N=74 MEAN=8.21 SD=3.8

F

BIOLOGY STUDENTS AGED 18-19

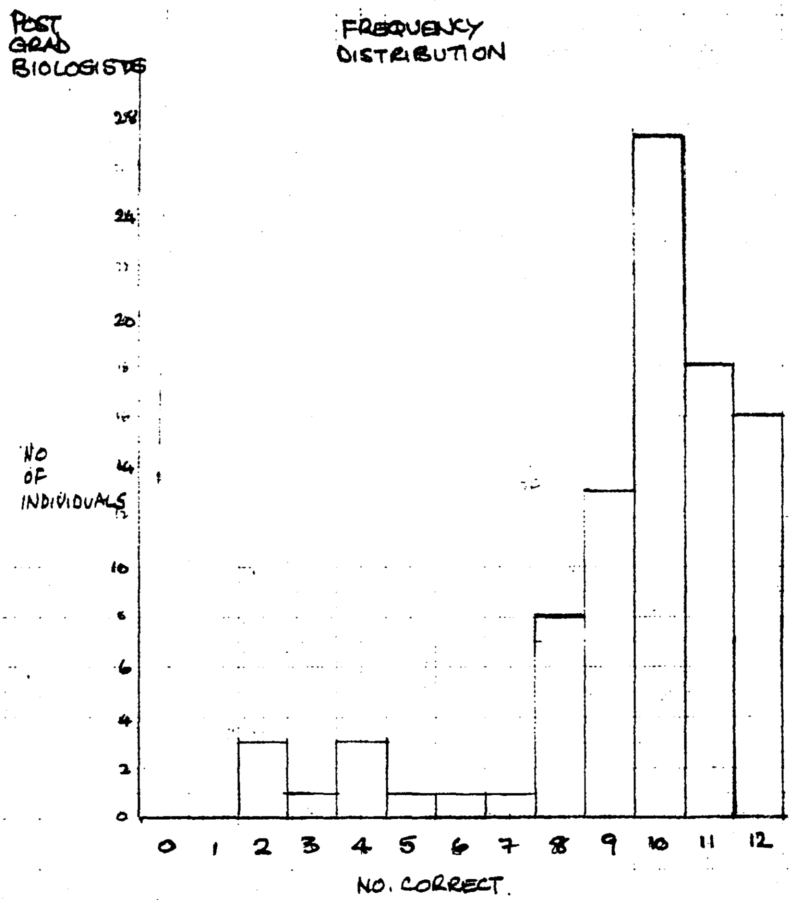
N=70

FREQUENCY DISTRIBUTION



N = 70 MEAN = 8.10 SD = 3.7

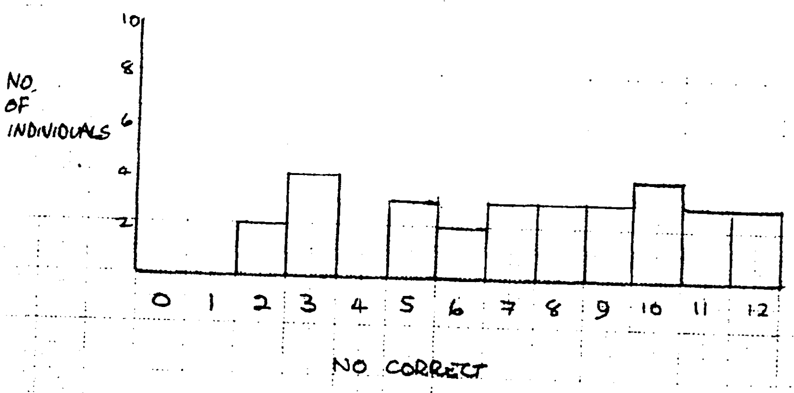
F



N = 92 MEAN = 9.56 S.D 2.3

F
NON SCIENCE STUDENTS

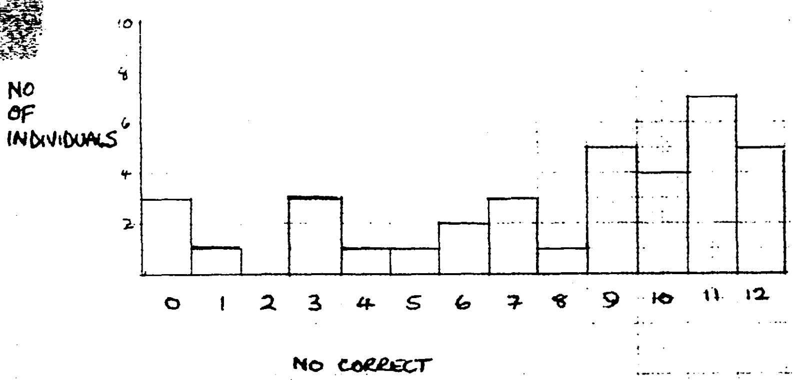
FREQUENCY DISTRIBUTION



N = 30 MEAN = 7.46 S.D. = 3.2

F
NON SCIENCE POST GRADS

FREQUENCY DISTRIBUTION



N = 36 MEAN = 7.83 SD = 3.8