THE HIGH SCHOOL CURRICULUM

AND

CHANGE IN COGNITIVE FUNCTIONS

OF

GRADE ELEVEN STUDENTS

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ABSTRACT

Many students find abstract subjects such as physics and chemistry difficult to learn, and there is reason to believe that part of this difficulty is associated with the students' cognitive development. Curricula could be designed and delivered to match the student's cognitive level of functioning, but would that promote the intellectual development of the student? Before new curricula are designed and introduced, the existing programmes should be examined.

The purpose of this study was to determine whether there was a change in the level of formal-operational reasoning of transitional students as measured by a test, who were in a nine month academic programme, and whether this change was independent of the programme of studies which the student was taking.

The change in the formal-operational reasoning of the students was measured by a pre- and post-test which was assembled for this study. The name given to this test has been "Formal Operation Aptitude Test", and will be referred to as FOAT. This author modelled the FOAT after an instrument developed by Anton Lawson (1978).

The results indicated that the students' level of formal-operational reasoning as measured by FOAT does change, and that this change is not independent of the programme of studies which the student was taking. Students in both the 00- and the 01- 200 level courses showed about the same degree of change if their combination of courses were the same.

CHAPTER I

DEFINITION AND SCOPE OF STUDY

Need for Study

Many students find abstract subjects such as physics difficult to learn, and there is reason to believe that part of this difficulty is associated with the student's intellectual development as described by Piaget and Inhelder (1969). According to Piaget's theory, the formal stage of intellectual development starts at 11- to 12-years of age and the individual becomes fully formal at age 15-16.

There is experimental evidence that individual differences in cognitive development exist in a group of students of the same school grade and with similar background (Herron, 1975; Lawson & Renner, 1975; McKinnon & Renner, 1971). Renner (1976) cites research showing that 50% of Oklahoma's entering college freshmen and 66% of its high school seniors still occupy the concrete operational stage. Sund (1976) reports that fewer than 50% of the adults in the United States ever reach the formal operational stage of thinking. Research has also shown (1) that formal-operational students achieve more than concrete-operational students when taught formal concepts, and (2) that formal-operational students learn more, even when the lessons are over concrete concepts (Cantu & Herron, 1978).

In November of 1980 many students in grade 11 in Manitoba participated in the Science Assessment Programme. The science tests were designed to assess knowledge, understanding, and skills in order to provide an indication of students performance for a number of curricular areas of science. The tests were not designed for the assessment of specific courses.

The overall conclusions for the grade eleven students based upon this assessment were:

1) that performance was more than satisfactory on nature of science and on application of science content (with the students scoring an average of 75% on these test items);
2) that performance was satisfactory on higher cognitive level thinking and on processes of science (with the students scoring an average of 44% on these test items);
3) that performance on safety and laboratory technique was less than satisfactory (with the students scoring an average of 55%), as was knowledge and comprehension of science content.

The Manitoba Department of Education released a pilot programme guide for physics 200-300 for the period of 1982-83 with the following as part of its rationale:

> An increased amount of information and debate about the effects of science and technology upon the environment and society has led to changing perceptions concerning the potential role of science in society and of science education in preparing students for the future. In addition, continuing research resulting in new perceptions of the needs and abilities of high school students has necessitated a review of the purposes, emphases, and design of science programming. As part of the review, the K-12 Science Working Party surveyed high school physics teachers and reviewed the literature related to education in physics. Information obtained by the Working Party indicated that the following factors in the design of the physics curriculum should be adjusted:
>
> 1) the number of recommended topics should be decreased in order to provide a more flexible

program;

2) a review of the nature and need for articulation with post-secondary institutions should be conducted in order to provide a clearer definition of how physics education in high school can prepare students for potential future vocations;
3) some emphasis upon the relationship between science, technology and society should be introduced into the program;
4) the level of the program should be related to presently understood knowledge of the developmental levels of students (1982, p. 2).

The statements made in the aforestated rationale are ambiguous and do not correlate well with the conclusions from the Science Assessment Programme. For example, it was concluded that the knowledge of content is already poor, and yet a Department of Education Curriculum Committee (Science Working Party) recommends that the number of topics be decreased to allow for more flexibility in the programme. While this flexibility is not defined, the Science Working Party calls for articulation with post-secondary institutions and for a clearer definition of how physics education in high school can prepare students for potential future vocations. With a clear definition of how physics education in high school can prepare students for potential future vocations, and articulation with post-secondary institutions would indicate less flexibility within the high school programme.

The flexibility which the committee is referring to seems to be related to the topics which would be covered, and these topics would be determined by the vocation which the student has chosen or by post-secondary institutions. This would indicate that the programme would be less flexible within classrooms and from student to student? If the programme is flexible in the topics to be covered, will the level of the programme also be related to the developmental levels of individual students?

The committee has stated that the level of the programme should be related to presently understood knowledge of the developmental levels of students. Experimental evidence indicates that individual differences in cognitive development exist in a group of students of the same grade level. Which level should the programmed be related to, or should the students be placed in classes based upon their developmental skills? Should the programmes of study enhance the intellectual development of students? The committee is vague on these points.

If the enhancement of intellectual development of students is what is really important, then the stages of development themselves are not as important as what happens in the transition from one stage to another. Before we can develop procedures which can be used to enhance the intellectual development of students, we must determine whether these procedures exist, and identify them. In reviewing the literature, there appears to be a lack of studies which have addressed the intellectual development of students during a full school year.

A study done by Cantu and Herron (1978) led to the following conclusions:

> No matter whether concrete or formal concepts are being taught, one should expect the achievement of formal-operational students to be greater than the achievement of concrete-operational students. ....We believe that no teaching strategy will eliminate the difference in achievement observed between concrete- and formal-operational students, that many important ideas of science require formal reasoning for total understanding, and that, because of this, we should continue our efforts to develop

procedures which can be used to enhance the intellectual development of students.

The introduction to the pilot programme guide seems to be indicating that physics will become a course which will train students for a vocation, and that the flexibility will be determined by the vocation which the student has chosen. While the future vocation of a student is important, it would seem that the role of the school should be to promote the intellectual development of the students. The flexibility within the curricula should be orientated towards the students' cognitive needs.

It just might be that the way neurons are connected might play a part in determining how well the mind will function. These networks of connections would be developing as impulses are processed by the growing infant brain, and the neural network would become better established the more they are travelled. It just might also be that the strength or weakness of these networks may determine the level of certain mental abilities.

With the amount of information from research on brain function and development being made available in recent years, it would seem only logical that any study on cognitive function would be done with these studies in mind. The research done by the neuroscientists can be described as either "top down" or "bottom up". The "top down" refers to the study of the brain as a whole, while the "bottom up" refers to the study of the single brain cell. There is disagreement as to which of these procedures will ultimately demonstrate the "processes" of the mind. Actually both procedures are involved and it is for this reason that a brief summary of the literature on both the "bottom up" and the "top down" processes is done in chapter 2.

Purpose

The purpose of this study was to determine whether in a nine-month period there was a change in the level of formal-operational reasoning of secondary school age students, and whether there was a correlation between the amount of change in the level of formal-operational reasoning of secondary school age students and the courses which the student was taking.

Problem Statement

There were two problems to this study. The first problem was to develop an instrument which would: (1) measure concrete- and formal-operational reasoning; (2) be feasible for administration to classes of secondary school age students in a relatively short period of time; and (3) be easily scored. The second problem was to determine: (1) whether there was a change in the level of formal-operational reasoning in these students; and (2) whether there was a correlation between the amount of change in the level of formal-operational reasoning and the courses which the student was taking.

Limitations of the Study

There are certain limitations inherent in a study of this type. The results and therefore the conclusions of this study depend upon the accuracy of an instrument which has been developed for this study.

The students wrote a pre- and a post-test separated by nine months. It was assumed that since nine months would separate the pre- and the post-test, that the students would not improve in their score simply because they had written it before.

There could be no prior knowledge of the make-up of the student population and therefore there was no guarantee that the sample sizes would be large enough for statistical analysis.

CHAPTER II

ASSESSMENT OF COGNITIVE LEVEL–

A REVIEW OF THE LITERATURE

Introduction

What is intelligence? Despite the vast interest by psychologists in intellectual ability and its measurement, there has been little agreement about definition. The nature of intelligence has been debated continuously and definitions of it have undergone change as new information has been acquired. Even though there has been little agreement upon the definition of intelligence, measurements of intelligence are continuously being made.

In 1905 Alfred Binet and T. Simon, commissioned by the minister of public education in Paris, devised the first successful test of intellectual ability, called the "Metrical Scale of Intelligence". Composed of thirty problems in ascending order of difficulty, its goal was to identify children who were likely to fail in school, so that they could be transferred to special classes. Systematic comparisons were then made between normal and mentally retarded children. Later revisions of the test in 1908 and 1911 were based on the classroom observations of characteristics that teachers called "bright" and "dull" as well as a considerable amount of trial-and-error adjustment. Scores obtained on the revisions agreed strongly with teachers' ratings of intellectual ability.

One focus of concern about intelligent behaviour has revolved around the question of whether it is innate or learned. The dominant view until the late 1940's emphasized innate factors. Underlying this view was a belief that intelligence was fixed at a particular level and that it was predetermined by heredity (Hunt, 1961).

Theorists who view intelligence as a general attribute refer to it as the ability to learn; the capacity to adjust or adapt to the environment, especialy to new situations; or sometimes simply to all of the knowledge a person has acquired (Robinson and Robinson, 1965).

Major theorists differ as to how much of developmental change stems from experience with the environment and how much stems from maturation guided by genetic inheritance. Piaget sees the child's cognitive adaptation in terms of two basic processes, *assimilation* and *accommodation*. Assimilation is a process whereby the child interprets reality in terms of his or her internal model of the world constructed from previous knowledge. Accommodation is the complementary process of improving one's model of the world by adjusting it to external reality (Flavell, 1977, p. 7). Over the past 60 years Piaget has written a great deal about the assessment of cognitive level. With the increase in awareness of a need to adapt curricula to the developmental levels of students, the need for reliable and valid measures of those levels has also increased.

Because this study is concerned with concrete to early formal reasoning ability, the review of the literature on assessment studies and training studies was restricted to those which related to the period of the adolescent's reasoning at the junior and senior high school age. The review of the literature on neuroscience was on both the single cell and hemispheric studies.

Assessment Studies

The Karplus Islands Puzzle (Karplus & Karplus, 1970) has received widespread attention because of its apparent relationship to Inhelder and Piaget's measures of operational thinking. Researchers and teachers also want to bypass the time-consuming clinical interview technique for a pencil-and-paper test which can be group-administered.

While the Karplus Islands Puzzle may measure deductive logic, evidence (Blake, Lawson, and Nordland, 1976) indicates that it is not measuring the same abilities as measured by other tasks such as bending rods, balance beam, and cylinders. Blake, Lawson, and Nordland (1976) advised against the use of the Islands Puzzle as an instrument to assess Piagetian operations or to characterize an individual's cognitive level.

One of the major problems with pencil-paper-tests must be the reading level of the student who is taking the test. Raven (1973), in the test Raven's Test of Logical Operations (RTLO), provided assistance to the students when they experienced difficulty in reading. The problems in the RTLO were presented in pictorial form with a brief question following. The results indicated that the RTLO items measured the logical operations for which they were designed.

Harris (1974) designed and validated a pencil-and-paper test against the clinical interview technique with junior high students. This test consists of a series of illustrations which show rods bending under a variety of circumstances. Each illustration is accompanied by questions. Coulter (1976), in a student-curriculum mismatch study, utilized the Rods test in evaluating the grade 10 students in his study.

Shayer and Wharry (1975) developed a format which created a clinical situation and allowed many students to be tested at the same time. Demonstrations were conducted infront of the class and questions were then asked. The students responded to the questions in a student record book.

Lawson (1978) responded to the Shayer and Wharry study by stating that a sufficient variety of formal level problems were not developed. Lawson adopted this method and expanded the number and variety of problems used in his instrument. The items which were selected for inclusion on the test required the isolation and control of variables, combinatorial reasoning, probabilistic reasoning, and proportional reasoning. Lawson also included one item involving conservation of weight, and one item involving displaced volume. He felt that these items had been used extensively in clinical interviews and had been found to be good indicators of late concrete and early formal operational reasoning.

The major conclusion of Lawson's study was:

> .... that the same psychological parameters measured by classical Piagetian interview tasks were measured by a series of classroom demonstration test items with a fairly high degree of reliability. The demonstration test items were easily administered to entire classes of students in a short period of time

and quickly scored.

Training Studies

Flavell (1963) describes Piaget's stage of formal thought as:

> ... not so much this or that specific behaviour as it is a generalized orientation, sometimes explicit and sometimes implicit, towards problem solving: an orientation towards organizing data (combinatorial analysis), towards isolation and control of variables, towards the hypothetical, and towards logical justification and proof. (p. 211)

The development of problem-solving processes is of the utmost importance to educators. The findings that formal thought is normally demonstrated by only about 50% of the subjects in most adolescent and even adult samples in studies in Canada and the United States (Renner, 1976; Sund, 1976; Herron, 1975; Lawson & Renner, 1975; McKinnon & Renner, 1971) suggests a very real educational problem, if one of our goals is for the students to develop formal thought.

The acquisition of formal operational schemata is of considerable importance to the science teacher. Embedded within numerous physical and biological concepts and principles such as air pressure, the chemical law of definite composition, diffusion, gravitational acceleration, Snell's law of refraction, and photometry, is the understanding of proportional relationships. The formal operational schemata not only play a role in student understanding of important science content, but also play a major role in the process of scientific investigation.

Piaget's theory does not imply that maturation of the nervous system is sufficient for the development of formal thought. If this were the case, then the majority of the people would need to only sit and wait for the arrival of the formal level of thought. It could well be that people who are at the level of concrete operations are not naturally exposed to enough experiences of cognitive conflict. The opportunity for them to accommodate their cognitive structures to the high level of formal operations has not existed for them. For these people, concrete-operational thought is more than adequate for daily living. Training programmes, and indeed education curricula, then should not be viewed as to accelerate intellectual development as mentioned by Inhelder and Matalon (1960). Rather, these training programmes and our education programmes are there to avoid what might be called "stage-retardation" (Lawson & Wollman, 1976).

A number of recent science curriculum development projects (e.g., Project SOAR, JW Carmichael Project Director, Xavier University, New Orleans; Project ADAPT, R. Fuller Project Director, University of Nebraska, Lincoln; Project DOORS, Thomas Campbell Project Director, Illinois Central College, East Peoria; Project DORIS, Frank Collea Project Director, California State University, Fullerton) have been initiated with the explicit objective of increasing students' ability to employ scientific or "formal" reasoning strategies. The assumption underlying these projects is that an increased ability to utilize formal reasoning strategies will not only enhance problem solving and achievement in the natural sciences but will improve performance in other academic pursuits as well. While Ausubel argues that such general advances in problem solving are unattainable:

> Knowledge of scientific method, in other words, tends to be discipline-specific and cannot be learned apart from the content of the discipline, and once learned it cannot be transferred to discovery learning or problem-solving in other disciplines. (Ausubel,1979),

another study, which looked at the correlation among the formal reasoning measures and achievement in various subject areas, demonstrated that formal reasoning is related to general achievement and not achievement in science and mathematics alone. (Lawson, 1982)

Lawson and Wollman (1976) did a study involving both grades seven and five children. The purpose of this study was to encourage the transition from concrete to formal cognitive functioning. The Longeot examination was used as the measure of nonspecific transfer of training. It has been shown in other studies that the Longeot examination has been an effective instrument to measure general levels of concrete- and formal-operational thought (Lawson & Blake, 1976; Wheehan, 1970). Each student in the experimental group met with an experimenter for four 30-minute individual training sessions. The sessions were conducted over a period of approximately two weeks. The researchers concluded that while the training was effective in promoting formal thought with regard to one aspect of formal reasoning, it was limited in extent.

Shyers and Cox (1978) did a training study for the acquisition and transfer of the concept of proportionality in remedial college students. The study was done during the third week of an eight-week introductory summer session for remedial students. Delayed posttests were given during the seventh week. The researchers concluded that in the short-term training study, transfer appeared to depend more on the presence of identical elements than on the presence of identical structures. Two tasks of direct proportion not involving identical elements were seen by the subjects as being independent.

Lawson, Blake, and Nordland (1975) did a study where 30 high school students attended four training sessions which involved both instruction and experience with apparatus. The conclusions were that the students improved in ability to do a problem taught in the study, but showed no gains in ability to contol variables when presented with a new problem.

Case and Fry (1973) did a study which involved the training of 15 high school students to control variables. Their programme consisted of twelve 40-minute training sessions which involved both written materials and apparatus. On tasks which were similar to those in the training sessions, the subjects performed significantly better. The subjects were not tested on less familiar tasks.

These studies suggest that programmes which aim to teach scientific reasoning will be most successful if they emphasize recognizing and organizing relevant information rather than if they simply emphasize a particular strategy such as "make all other things equal" to control variables. (Levine and Linn, 1977).

There appears to be a definite lack of training studies which span a school year and which are part of the school curriculum. If the cognitive functioning of a person is a measure of brain development, and if the experiences which a person is living are affecting the development of their brain, then time must be given for some changes to occur within the brain. We do not know if these changes are specifically chemical in nature, at the level of the single neuron, or at the level of the hemispheres communicating.

If science concepts are to be learned, not just memorized, then the student must be in a programme which allows the student to assimilate the information around him. This assimilation must take some time and therefore would indicate that training programmes must be longer than a few days or a few weeks.

Neuroscience

Lateralization of Cognitive Functions

It is now well documented that our brain has two very differently functioning hemispheres (Blume et al., 1973; Bogen, 1969a, 1969b,; Diamond and Beaumont, 1974; Fedio and Weinberg, 1971; Gazzaniga, 1970, 1975; Kinsbourne and Smith, 1974; McNeil and Hamre, 1974; Milner, 1971; Nebes, 1974; Ornstein, 1977; Risse and Gazzaniga, 1978; Schmitt and Worden, 1974; Segalowitz and Gruber, 1977; Sperry, 1973).

In normal right-handed adults the different hemispheric functions can be summarized as in the following table (Rose, 1979)

Left Hemisphere	Right Hemisphere
analytic	synthetic
verbal	visuo-spatial
linear	holistic
rational	intuitive
logical	analogical
propositional	appositional
abstract	imaginative
sequential	simultaneous
convergent	divergent
deductive	inductive
temporally linear	temporally cyclic
symbolic	visually imaginative
exclusive	inclusive
singular	multiple
causal	coincidental
realistic	idealistic
mathematical	artistic

The left hemisphere is specialized for analytic, verbal, logical, linear, and sequential tasks which are abstract and time related. This is the centre for verbal and mathematical tasks. The right hemisphere is specialized for synthetic, visual, spatial, holistic, and intuitive tasks. It processes nonverbal information and is responsible for visual imagery and imagination. The right hemisphere is mute but can comprehend simple language. Each hemisphere has a specialized cognitive style, and there is a relationship between both brain development, lateralization of cognitive functions, and cognitive development as described by Jean Piaget.

Some authors feel that as the student becomes a formal thinker he is becoming left hemisphere dominant.

> At about age 12, most children enter the apex of logical conformity, the formal operations stage. He/she will have given up intuitive, analogic explanations for those that are factual and explicit. In other words, the student will have become left hemisphere dominant. (Samples, 1977, p.689)

Several studies have demonstrated that language is predominantly a left hemisphere function (Gazzaniga and Sperry, 1967; Hermelin and O'Connor, 1971; Liberman, 1972; Penfield and Roberts, 1959; Rasmussen, 1964; Searleman, 1977; Subirana, 1961, 1964; Trevor-Roper, 1970). Samples relates the language as a left hemisphere function to Piagetian development when he says:

> The result is that to become expert in the logical manipulation that is necessary to engage in Piaget's formal operations stage, one must become expert in language use. (1977, p.689)

A study done by Dilling (1976) supports this theme. They investigated the differences in hemispheric brain activity of concrete and formal operational persons. Lateral EEG recordings were made while the subjects performed seven tasks. The last three tasks used were Piagetian tasks. These were conservation of volume, control of variables, and a logic problem.

Their results indicated that formal thinking persons were relatively more left hemispheric in their cognitive functioning than were concrete thinking persons. This was especially true in the two formal tasks, control of variables and logic.

Another study which agrees with Samples is Lawson and Wollman (1975). The design of this study was based on the assumptions that visual input from the left eye will reach the left visual cortex before it reaches the right visual cortex. This is because the neural pathways are shorter from the left eye to the left visual cortex than from the left eye to the right visual cortex, thereby giving the left hemisphere priority. The authors also put forward the idea that eye dominance is caused by hemisphere dominance.

They hypothesized that:

> the functioning of the brain's left hemisphere, because of its logical, verbal mode, facilitates conservation reasoning while functioning of the brain's right hemisphere, because of its nonverbal, spatial mode, inhibits conservation reasoning. (1975, p.3)

Therefore, left-eye dominant children viewing the material with their left eye only (LL) will demonstrate a greater frequency of conservation responses than right-eye dominant children viewing the material with their right eye only (RR). It was also hypothesized that left-eye dominant children viewing the materials with their right eye only (LR) and the right-eye dominant children viewing the material with their left eye only (RL) would demonstrate an intermediate frequency of responses.

The predicted sequence of LL > LR = RL > RR was found, and the LL and RR group differences were significant. They concluded that intellectual development in the Piagetian sense is largely a function of the left hemisphere's verbal and linear functioning and its ability to dominate the right hemisphere's more spatial and holistic mode of operation.

There is a vast amount of research which disagrees with the idea that Piagetian development refers to the left hemisphere only. Galen (1972) demonstrated the utility of EEG as an indicator of lateralized cerebral activation during the performance of cognitive tasks selected for their demand on left or right hemispheres. In this study, a 13-year old girl who had "outgrown" a mild dyslexia showed a failure to shift hemisphere-dominance in relation to task and also failed to show more normal oscillation of dominance activity during task performance.

The key to cognitive development is interhemispheric communication, which is primarily a function of the corpus callosum. The desired developmental goal is the ability to recognize and use the mental mode best suited for a specific task, utilizing information stored in both hemispheres. At the formal operations stage, the corpus callosum must be capable of rapid communication.

Olson (1977) found that gifted children who demonstrated formal operational thought used their left hemisphere or right visual field for verbal questions and their right hemisphere or left visual field for spatial questions. This sorting did not occur with students who were at the concrete operational stage. The concrete operational student used their right visual field (left hemisphere) predominately on all tasks.

Kraft (1976) lends strong support to the theory that Piagetian development includes both hemispheres and the corpus callosum. She investigated lateral asymmetry in children's hemispheric brain functioning during performance of Piagetian and curriculum related tasks by measuring lateral EEG activity during the performance of those tasks. The 18 children involved in the study were right handed and between the ages of 6 and 8 years. The Piagetian tasks that were used were two conservation tasks and two time-related tasks.

From the data she concluded that the Piagetian tasks which had initial visuo-spatial components during the stimulus period tended to elicit right hemispheric activity during that period. If the task had verbal or logical components during the subsequent response period, then left hemispheric activity tended to be elicited. However, high performers on these tasks tended to show a greater proportion of right hemispheric activity during the response period than low performers. This would indicate that the verbal left hemisphere of the high performers had a greater ability to tap the visuo-spatial right hemisphere's knowledge about the stimulus. Kraft (1976) suggests that Piaget's tasks are behavioural component of interhemispheric communication and selective inhibition and further, that the ontogeny of Piagetian stages is a behavioural index of maturing neural fibres which facilitate these processes.

It is well known that the callosum is slow to myelinate and in particular the association areas with their callosal connections are the last of all to be myelinated (Tilney, 1933; Jacobson, 1963; Davison et al., 1966; Yakovlev and Lecours, 1967). There is good reason to believe that the young child up to and through the age of 8-years or so lays down engrams in both cerebral hemispheres for language and perceptions of all kinds. Basser (1962) has shown that cerebral injury to children results in a dysphasia no matter which hemisphere is damaged. Studies on language and speech function in brain-bisected patients have revealed that the right hemisphere is capable of correctly responding to printed or spoken nouns but not to verbs (Gazzaniga et al., 1967; Gazzaniga and Sperry, 1967; and Gazzaniga, 1970). Gazzaniga and Hillyard (1972) have shown that the right hemisphere has little or no capacity for syntax. These results suggests that as dominance is established in the left hemisphere, inhibitory processes develop which suppress the upper cognitive level and decision-making capacity of the right hemisphere.

Since the callosum is slow to myelinate, it could be that the inhibitory mechanism cannot come into play until this time. The presence of such a mechanism might explain why children seem to lay down bilateral engrams with respect to early cognitive functions and why the system starts to subside after the early childhood years.

Much of the recent research (Serafetinides, 1966; Fedio and Weinberg, 1971; Blume, Grabow, Darley, et al., 1973; and Risse and Gazzanaiga, 1978) indicates that each system has its own working memory. Serafetinides (1966) observed that recall of specifically verbal material was impaired only following injection of sodium amytal on the left hemisphere, whereas successful recall of pictorial (nonverbal) material was not lateralized. Risse and Gazzaniga (1978) assessed verbal and nonverbal recall of simple tactual stimulus in patients receiving left intracarotid injections of sodium amytal. During the period of dominant hemisphere anethetization, a common object was presented to the left hand, right hemisphere, but was kept out of view. Following recovery from the drug, six of the eight patients were unable to recall the object verbally, but recognized it immediately in a visual multiple-choice array. These results demonstrate a dissociation of verbal and nonverbal memory mechanisms which suggests that delayed interhemispheric transfer of a functional sensory message is highly improbable. Memory has been encoded independently of the language mechanism.

Epstein (1974a, 1974b, 1978) has found that there are growth spurts during brain development. He hypothesizes that these growth spurts are periods of maximum cognitive potential, and that these growth spurts intervals correlate closely with Piaget's developmental stages. These growth spurts occur during the age intervals of 3 to 10-months, and from 2 to 4, 6 to 8, 10 to 12, and 14 to 16-years of age. Except for the first and last intervals, the relationship with Piagetian stages is clear. The growth spurt from 2 to 4 coincides with the transition from sensorimotor to preoperational, the spurt from 6 to 8 coincides with the transition from preoperational to concrete operational, and the growth spurt from 10 to 12 coincides with the transition from concrete to formal operational. Arlin (1975) has proposed that there is a fifth Piagetian stage, one which appears at about the age of 14 to 16 years.

The basic intercellular interactions which initiate and sustain myelination remain unknown. Even the initial condition for myelination is little understood.

Neuron Development

The function of glial cells during development, once considered important only during myelination, are slowly becoming more fully apparent. For example, the importance of microglial response to death of neurons has assumed a greater significance since the ubiquity of nerve cell death during normal development has become known (Jacobson and Baker, 1969; Jacobson, 1970a, 1970b; Cowan, 1973). The role of astrocytes is still puzzling, but it is now thought that one of their specialized functions during development is to guide some neurons during their outward migrations from the germinal zones to their final resting positions in the cerebral cortex and cerebellar cortex (Boulder Committee, 1970; Barry and Rogers, 1965; Barry et al., 1964a, 1964b).

It is very likely that glial cells function in a similar way in other places where young neurons have to migrate through a complex terrain. Recent evidence indicates that glial cells are a source of nerve growth factor (NGF). The fact that glial cells can be substituted for NGF to maintain neuronal growth in vitro indicates that glia are a source of NGF or a similar substance (Burnham et al., 1972; Varon et al., 1974a). Neuronal growth can be supported by glia without the addition of NGF to the tissue culture medium, but NGF alone is unable to sustain the growth of neurons cultured in the absence of the glial cells (Veron et al., 1974a; Monard et al., 1975). That NGF antiserum inhibits the effect of glial cells on neuronal outgrowth indicates that the effect is mediated by NGF (Varon et al., 1975b).

NGF plays an essential role in stimulating the growth of developing axons from neurons of the spinal sensory ganglia and sympathetic ganglia. Stimulation of axonal growth toward a source of NGF has been demonstrated in tissue culture (Chamley et al., 1973; Ebendal and C. O. Jacobson, 1976). This suggests that NGF may lure axons toward their targets during normal development.

NGF has the function of stimulating axonal outgrowth and probably attracting nerve fibres to their targets during development. It probably continues to regulate the number of terminal branches of adrenergic nerve fibres throughout life.

This appears to involve a tissue homoeostatic mechanism in which increased NGF production by the target organ stimulating sprouting of adrenergic nerve terminals, while reduced systhesis of NGF results in a reduced density of the terminal plexuses of adrenergic neurons.

Several conditions are associated with an increase in the number of glial cells. A proliferation of glial cells have been observed in the brains of mice and rats reared in an "enriched environment" (Altman and Das, 1964; Diamond et al., 1964, 1966; Krech, 1972). Several other conditions are associated with an increase in the number of glial cells. Proliferation of glial cells has been observed around neurons undergoing chromatolysis after their axons have been cut (Cammermeyer, 1963; J. Sjostrand, 1965, 1966a, 1966b; W. E. Watson, 1965, 1974; Chow and Dewson, 1966). An increase in the number of glial cells around morot neurons in the spinal cord of the mouse has been reported after greatly increased motor activity. Dehydration of rats results in an increase in the proliferation of glial cells in the hypothalamus (M. Murray, 1968).

Studies of the effects of sensory stimulation and deprivation on development of dendrites and synapses leave no doubt that long-lasting changes occur as a result of experience (Volkmar and Greenough, 1972; Greenough and Volkmar, 1973; and Greenough et al., 1973).

Visual deprivation studies (Sherk and Stryker, 1976; Wiesel and Hubel, 1974; Hirsch and Leventhal, 1976; Van Essen and Kelly, 1973; Kelly and Van Essen, 1974; Rakic, 1977; Wiesel and Hubel, 1965; Hubel et al., 1975; Hubel and Wiesel, 1974; Hubel and Wiesel, 1965b) give conflicting reports of the proportion of visual cortical cells in the cat and monkey that have normal functional properties at birth or develop normally in the absence of visual stimulation. These conflicting results may be resolved by the findings that some cortical cells retain their orientation preferences while other cells appear to lose them in cats that have been raised in the dark for up to a year after birth (Hirsh and Leventhal, 1976). In such visually deprived cats some of the simple type of cell, which receives X cells inputs, retain orientation selectivity, while the complex type of cell, which receive Y cell inputs, has orientation preferance. The effects of visual deprivation on the visual cortex are largely or entirely on the pyramidal stellate cells. This can be correlated with the observations by J. P. Kelly and Van Essen (1974) that pyramidal cells are complex cells while stellate cells are simple cells. There is considerable evidence that the pyramidal neurons receive input from Y cells while the stellate neurons receive input from X cells (J. Stone and Dreher, 1973).

The majority of the striate cortical cells in the monkey and cat are binocularly driven. Most of these binocular cells are dominated by one eye. Using autoradiography after injection of [^{3}H] proline into one eye in a series of newborn kittens at different ages, segregation of the geniculostriate fibres into columns can be demonstrated. Cells with the same ocular dominance are arranged in walls or columns about 500 um wide and several millimetres long, alternating with the columns of cortical cells dominated by the other eye. Ocular dominance columns in the striate cortex of the cat develop gradually from 2 to 16 weeks after birth, but appear to be fully formed at the time of birth in the superior colliculus. In the rhesus monkey, ocular dominance columns start appearing more than 3 weeks before birth in the superior colliculus and striate cortex (Rakiac, 1977). Those in the superior colliculus of the rhesus monkey appear to be fully developed at birth (Rakiac, 1977), but those in the striate cortex continue developing postnatally, and are then vulnerable to monocular visual deprivation.

The effects of monocular deprivation are known to be different from those of binocular deprivation. The type of deprivation may also affect the result. After binocular suture of the eyelids of the kitten for the first 3 months after birth, most neurons in the visual cortex respond to visual stimuli, and more than half of the neurons are quite normal (Wiesel and Hubel, 1965). Monocular lid suture for 2 or 3 months after birth results in a significant reduction of the cells in the striate cortex that can be driven by the deprived eye. Those that can be driven by the deprived eye have very abnormal receptive fields. Monocular visual deprivation of monkeys from birth results in an increase in width of the cortical ocular dominance columns of the normal eye and a proportionate decrease in width of the ocular dominance columns of the deptrived eye (Hubel et al., 1975). Development of ocular dominance columns and orientation columns occurs in animals deprived of visual experience in both eyes (Hubel and Wiesel, 1974), and it is only when visual deprivation is monocular that the columns develop abnormally. It seems that, for each neuron, the dominant eye has taken over. The effect is not due to visual deprivation but to lack of correspondence or cooperation between the two eyes. A similar effect can be produced by placing an opaque shield over the left or right eye on alternate days (Hubel and Wiesel, 1965b; Blake and Hirsch, 1975).

The effects of selective visual stimulation on orientation selective neurons have been done on kittens (Hirsch, 1970; Hirsch and Spinelli, 1970, 1971; Leventhal and Hirsch, 1975; Stryker et al., 1976). The results suggest that some neurons are inherently predisposed to develop vertical or horizontal orientation selectivity, while others require appropriate visual stimulation.

The ability of the system to recover from deprivation diminishes with age. For example, the cerebral lateralization of functions such as language is already present at birth in man, but recovery of function occurs after removal of or damage to the dominant cerebral hemisphere provided that the damage occurs before the age of 3 or 4 years.

It is clear that there are critical periods of development in birds and animals. The critical period is fairly specific for each form of deprivation in a particular species. It seems that at present, virtually nothing is known about the mechanisms by which the critical conditions produce changes in the development of nerve cells that result in permanent changes in neuronal functions and behaviour.

Piagetian and Brain Development Theory

Piaget's theory outlines four major periods of mental development: sensory-motor, preoperational, concrete operational, and formal operational. The order of these stages is a constant and each stage is necessary for the development of the next stage. Each stage is not a static level, instead the child progresses through them in a continuous manner.

The sensory-motor period lasts from birth until approximately 2 years of age. During this time, important changes occur within the structures of the brain. Hewitt (1962) has found that at birth the corpus callosum is structurally and functionally incomplete. Communication between the hemispheres does not start until around age 2 years. This means that during this period the child is functionally "split-brain" (Gazzaniga, 1970, pp.131-134). Myelination begins in the ventral roots and in the ventral and lateral tracts of the spinal cord, and then extends in a rostrocaudal direction, with the first myelin appearing in the brain in the internal capsule and posterior commissure and starting last in the corpus callosum and associated areas of the cerebral cortex (F. Tilney, 1933; S. Jacobson, 1963; A. N. Davison et al., 1966; Yakovlev and Lecours, 1967). The sequence of myelination of neurons occurs in the same order as their time of origin and differentiation.

There are two prevalent theories about the structure of the brain at birth. One is that each hemisphere is functionally identical and has the same potential for development (Lenneberg, 1967). The other is that the hemispheres are specialized at a very early age or preprogrammed from birth (Kinsbourne and

Hiscock, 1978, pp.214-220). The important question which must be asked here is, if the infant is split-brained during the sensory-motor period with each hemisphere experiencing different input, could this difference in experiences facilitate the lateralization of cognitive functions?

The sensory-motor child grows from being reflex dominated to a dynamic, reacting child. At birth, the child has no language abilities. As the axons grow and the neurons move outward, the child makes tremendous gains in being able to speak words and in his vocabulary. The sensory-motor child learns to perceive and identify objects, and is able to recognize the names of objects. This child also acquires object permanence and recognizes himself as an object.

Two abilities that appear that are later dominant in the right hemisphere are his rudimentary sense of direction and the realization that objects do not change in shape even though viewing them from different vantage points makes it appear that they do. These indicate a refinement of visuo-spatial abilities.

The sensory-motor child shows the beginning of linear, logical, left hemispheric reasoning. The child learns to perform simple experiments on objects to learn some of their properties, and demonstrates means-ends activity. At around age 2 years, the child recognizes sequence and duration of events, he becomes aware of linear time.

The preoperational period begins at approximately age 2 years and lasts until approximately age 7. During this period two important neurophysiological changes are taking place. One is that the corpus callosum becomes capable of intercommunication at around age 2 or 3 years, and completes the major part of its development at around age 6 or 7 (Yakovlev and Lecours, 1967). The other is the brain growth spurt that occurs between the ages 2 and 4 years which Epstein (1974a, 1974b, 1978) hypothesizes is a period of maximum cognitive growth potential.

As Epstein (1974a) points out, the brain growth between ages 1 and 4 years is not due to myelination alone, but he does say that myelination is the major contributor. The emphasis on myelination as an indication of functional maturation of the brain (F. Tilney and Casamajor, 1924; Langworthy, 1928a, 1928b, 1933; F. Tilney, 1933; Windle et al., 1934) was once popular, but should now be regarded as an oversimplification. Although it is obvious that the behavioural capacities of newborn animals and children increase during the period of myelination, there is no reason to regard the former as a direct consequence of the latter. Myelination cannot be taken as an index of maturity of the unmyelinated fibres. Impulse traffic starts in axons during development, before they develop myelin sheaths (Ulett et al., 1944; J. del Castillo and Vizoso, 1953; F. G. Carpenter and Bergland, 1957).

The preoperational child can be described by the following three characteristics:

1. He is perception bound, indicating visuo-spatial dominance. This is a right hemisphere function.
2. He cannot think logically. The child does posses a partial logic, but he lacks the crucial property of operational reversibility. Logical thinking is a left

hemisphere function.

3. He cannot perform operations that are dependent upon thinking linearly, analytically, sequentially, and causally, all of which are left hemispheric functions.

During this period, the child's language and verbal abilities develop greatly. These are predominately left hemispheric.

Several left hemispheric abilities, besides language and verbalization, show their early beginnings in the latter portion of this stage. The child develops a partial logic. This logic is limited to forward-direction thinking only. The child cannot think reversibly or reflectively, and he cannot reason inductively or deductively. The child does begin to reason transductively, from particular to particular. This often leads to faulty conclusions, but it is the beginning of reasoning sequentially and causally. The preoperational child also gains a better understanding of linear time, including short periods into the past and future.

During this period the preoperational child develops representational thought. This is dependent upon visual imagery---the ability to imagine an action, or series of actions, and the possible results. A broadening concept of space and direction, increased ability to image and fantasize, and a greater sense of intuition are part of the development of the preoperational child. All of these are right hemispheric functions.

It is during this period the hemispheres begin to communicate with each other. With this communication comes a new ability---to use both hemispheres concurrently and supportively. It seems that for the visual system to develop properly, there must be correspondence or cooperation between the two eveys when they are stimulated. Even though each hemisphere might be preprogrammed, their normal development might be dependent upon interhemispheric communication..

From approximately age 7 to 11 years, the child is in the concrete operational stage. During this period the brain undergoes a growth spurt (Epstein, 1974a, 1974b, 1978).

The concrete operational child now uses his mind to think rationally (left hemisphere) instead of relying solely on perception (right hemisphere). This leads to the attainment of conservation of various types. Beginning with the conservation of substance and ending with conservation of volume, this development occurs sequentially from ages 6 to 11 years. This development would indicate and increase in left hemispheric development.

Other cognitive abilities appearing during this time are the understanding of number and the ability to perform mathematical operations, the ability to classify objects, and a better understanding of linear time. These are predominantly left hemispheric functions.

The concrete operational child is also undergoing right hemispheric development. The child has an increased understanding of space, especially geographic space. He develops an increased ability for mental imagery, imagination, and intuition. He also gains an understanding of part-whole relationships, which has been shown by Nebes (1971) to be a right hemispheric function. The discovering of how concepts are interrelated is a major importance in the concrete stage. This ability to synthesize information is also a right hemispheric function. It is obvious that the right hemisphere is developing.

Around age 11 or 12 years, the child enters into the formal operational period. This coincides with a brain growth spurt between the ages of 10 and 12 (Epstein, 1974a, 1974b, 1978) and the completion of the development of the corpus callosum at around age 10 (Yakovlev and Lecours, 1967).

The formal operational period is characterized by systematic and logically complex reasoning processis. The left hemisphere's processing mode is linear, analytical and logical. Formal operational abilities which might be classified as left hemispheric are: understanding linear time, hypothetical-deductive thinking, propositinal thinking, reflexive thinking, abstract thinking, using proportions and ratios, understanding and using probability, and constructing a hierarchial classification system.

Formal operational abilities which appear to be obvious right hemispheric abilities are: conceptual thinking, broadening a spatial concept, and imagining idealistically. A few activities which utilize both hemispheres are: mentally representing operations (right) and operating on them (left), performing combinational logic--combining elements (right) or eliminating elements (left) which do or do not affect a situation, and creating theories.

Implications for Education

Based upon the stated cognitive functions of the right and left hemisphere for both the concrete operational and formal operational child, the curricula of our schools are left hemisphere biased. This could be a major developmental problem with our educational system. It is the opinion of this author that the schools should be promoting the development of the whole brain, a balance of both hemispheres.

Not all problems will be presented to students in either a pictorial form or in a demonstration. Students, who are formal thinkers, should be able to take written problem and formulate a mental picture. After building an image of the whole, the student should then be able to mentally manipulate the parts or the variables.

Lawson et al. (1978) found that students who were obvious formal thinkers did poorly on propositional logic questions. Grant (1976) found that 74% of the physics students were at the formal level of operation and that 40% of the potential physics students were at the formal level. Arons (1976), reporting on students in an introductory physical science course, found that about 25% had attained the level of formal operations, about 25% were transitional between concrete and formal levels, and that about 50% were essentially concrete operational. Renner (1976) cited research showing that 50% of Oklahoma's entering college freshmen and 66% of its high school seniors still occupy the concrete operational stage. Sund (1976) reported that fewer than 50% of the adults in the United States ever reach the formal operatinal stage of thinking.

A greater percentage of physics students attain the level of formal operations than other students. Are the tests biased to give this result? Are more students who are at the formal level going into physics? Is there something within the physics curricula which promotes formal level of operation?

Much educational research has focused on the concept of discrete, well-delineated stages in which the transition from stage to stage is represented by a period of abrupt cognitive change. Chiapetta (1976) notes that

> ...the majority of adolescents and young adults function at the concrete-operational level and not at the formal-operational level in understanding a great deal of the science subject matter taught at the secondary and college level.

Other research challenges this concept. Pallrand (1979) found that in completing combinations and proportions tasks, only gradual increases in the ability to complete tasks at the fully formal level were observed. He showed that no one who was concrete on combinations was at a higher level on proportions. For a student to be formal on the proportions tasks, a student had to be at least at the early formal level on the combinations tasks. It was found that a student could score "formal" on the combinations and still be "concrete" on the proportions. It seems that proportions tasks are somewhat more advanced.

Since there are so many people who do not reach the formal level of thought, it would appear that a child does not just mature from one stage into another. As Kraft (1976) noted, superior thinkers are more able to use the visuo-spatial knowledge of the right hemisphere when performing left hemisphere operations.

> It was established that the frontal, temporal, and parietal areas, which are mainly implicated in crystalized intelligence, are engaged during the actual process of concept learning.
>
> Event-related potentials (ERPs) evoked at the right frontal, temporal, and parietal, as well as the left parietal, regions, significantly distinguished below- from above- average concept learners. As hypothesized, poorer concept learners engaged these hemispheric sites less, and manifested more variability at them, than better learners. (Federico, 1984)

To promote the development of these higher level operational abilities, the schools must emphasize an increased interhemispheric communication. The corpus callosum is mostly developed by age 6 years and is fully developed by age 10 (Yakovlev and Lecours, 1967). Its potential has not been demonstrated, but it does seem clear that the development of the corpus callosum would be dependent upon its use and this would be dependent upon the utilization of both hemispheres.

One of the most consistent messages to teachers is the need for the abundant use of concrete materials and hands-on experiences (Sund, 1976). Even with formal operational persons, a new concept should first be introduced concretely (Arons, 1977; Levin and Linn, 1977; Goodstein and Howe, 1978; Lawson, 1978). The use of concrete objects involves the right hemisphere, particularly adept at perception, or both hemispheres when both hands are used for sensory input.

Lawson et al. (1978) suggests that mathematics and science be taught by the same teacher. A very important point which they miss though, is that ideas or theories are most often laid out for the student. Students of science can use positive results to verify or build a theory (left hemisphere), but they cannot use negative results to verify or build a theory (right hemisphere). The student must engage in data gathering activities and then be allowed the opportunity to apply the appropriate quantitative relations or to build theories. The combination of mathematics, data calculating relationships, and building of theories will help to promote the use of both hemispheres.

If school curricula are to help to promote the use of both hemispheres, and if there is a relationship between both brain development, lateralization of cognitive functions, and cognitive development, then sufficient time must be allowed for this development to occur.

Summary

Lawson and others have shown that test items can be good indicators of late concrete and early formal operational reasoning in students. The development of formal operational thought and problem-solving processes is important to educators. Yet, formal thought is normally demonstrated by only 50% of the adolescent and adult population.

The teacher of physics can use a great deal of mathematical concepts and models as well as science concepts and models. By developing the models for light, both positive and negative results can be used to verify or develop ideas. To promote the use of the left hemisphere, activities which require analytic, verbal, logical, linear, and sequential manipulation should be encouraged. To promote the use of the right hemisphere, activities which require a synthetic, visual, spatial, holistic, and an intuitive approach should be encouraged. Both sets of activities can be encouraged within the physics programme.

If a student takes a programme of studies which allows the student to tackle problems a variety of methods, then would these students show a larger cognitive growth during a school year?

CHAPTER III

METHOD AND DATA

The Problem

The purpose of this study was to determine whether there was a change in the level of formal-operational reasoning of secondary school age students after nine-months in an academic programme, and whether this change was independent of the programme of studies which the student was taking.

There were two problems to this study. The first problem was to develop an instrument which would: (1) measure concrete- and formal-operational reasoning; (2) be feasible for administration to classes of secondary school age students in a relatively short period of time; and (3) be easily scored. The second problem was to determine whether: (1) there was a change in the level of formal-operational reasoning in these students; and (2) the change was independent of the curriculum which the student was taking.

METHOD

EXPERIMENTAL DESIGN

The basic design of this study was diagrammed to include the steps and tasks involved.

* Design of the Formal Operation Aptitude Test (FOAT)
    - selection of questions
    - scoring criteria for FOAT

* Administration of Tests (Rods and FOAT)
    - Definition of Samples

* Scoring of Rods and FOAT
    - Identification of Transitional Group using FOAT Scores
    - Categorization of Transitional Students According to their Curriculum
    - Record the Transitional Students' FOAT Score as their Pre-Test Score

* Statistical Treatment
    - Spearman Rank Correlation Coefficient between the Rods and FOAT Scores
    - Calculation of Regression Equation between the Rods and FOAT Scores

* Administration of Post-Test (FOAT)

* Scoring of Post-Test (FOAT)
    - Record the Post-Test Score
    - Calculate the Change in the FOAT Score

* Statistical Treatment
    - Kruskal-Wallis H Test

* Report of Findings

Figure 1. Diagram of Basic Design

Selection of Test Items for the Formal Operation Aptitude Test (FOAT)

Harris (1973) designed a test, the Rods test, to identify students who were in the transition between concrete and formal operations. She developed a scoring guide which classified students into stages IIA, IIB, IIIA, IIIB (See apendix A for sample items). These scores were then transfered onto a scale of 0 - 15, which was not assumed to be linear. While the Rods test would have been an adequate instrument for the purpose of this study, the amount of time for the evaluation of the test is too great. Therefore, an instrument which would require considerable less time was desirable.

Lawson (1978) constructed 15 items for a clasroom test. Each item involved a demonstration using some physical materials and/or apparatus. For each item, the demonstration was used to pose a question or call for a prediction. The students responded to each item in writing in individual test booklets. The booklets contained the questions followed by a number of possible answers. Students were instructed to respond by checking the box next to the best answer and then explain why hey chose their answer.

Based upon this study described by Lawson (1978), a 15-item pencil and paper test, called the Formal Operational Aptitude Test (FOAT), was developed to measure the cognitive level of the students. While Lawson's test was one of demonstrations, the FOAT involved the presentation of the items in written form. Items which Lawson had selected for inclusion on the test required the isolation and control of variables, combinatorial reasoning, probabilistic reasoning, and proportional reasoning. Lawson did not include any items which might be considered to directly require correlational reasoning, since he felt that an easily administered item of this type was not available. In addition, one item involving conservation of weight and one item involving displaced volume were included. Lawson felt that both of these items have been used extensively in clinical interviews and have been found to be good indicators of late concrete and early formal operational reasoning respectively.

In Lawson's study, 513 students were administered the classroom test. A subsample of 72 students were randomly selected and individually administered a battery of four Piagetian tasks. The individual interviews were conducted by three trained interviewers. The scores for the entire sample on the classroom test ranged from 0 to 15. The distribution of scores approximated a normal curve with a mean of 7.41, standard deviation of 4.27, and a standard error of measurement of 2.0. The Kuder-Richardson 20 estimate of reliability was 0.78.

To assess validity of the classroom test as a measure of formal reasoning, a panel of six judges examined the test. These judges were considered experts due to their professional involvement with Piagetian research, and the responded with 100% agreement that the test items appeared to require concrete and/or formal reasoning.

Another assessment of the validity of the classroom test was the comparison of individual test results to the classroom test results for the subsample of 72 students. Pearson product-moment correlations between the classroom test total score and level of response on the bending rods and balance beam tasks were 0.75 and 0.65, respectively. These correlation coefficients were found to be statistically significant ($p < 0.001$).

As a third type of evidence of the classroom test's validity, Lawson submitted the classroom test and all four interview tasks to a principal components analysis. These results, with the previous two results, indicate that the classroom test has factorial validity as well as face validity and convergent validity.

Construction of the Formal Operation Aptitude Test (FOAT)

The FOAT contained 15 items in all. Each item was in a question form with some questions accompanied by a diagram. The students would respond to each question with either a written response or with a diagram, or with both. The students were encouraged to discuss their answers (See appendix A for sample test booklet).

Items were scored correct only if the correct answer was given. Each correct answer received a value of 1, making the maximum score for the test equal to 15. A brief description of the 15 items from the test follows:

Item 1: The Conservation of Weight (Piaget & Inhelder, 1962)

This item involves two balls of clay which are identical in size, shape, and weight. The students are told that the clay balls are balanced at opposite ends of a balance beam. One of the balls is flattened into a "pancake" shape and the students are asked about the relative weights of the pieces.

Item 2: Displaced Volume (Karplus & Lavatelli, 1969)

Using two solid metal spheres of equal size but of different density (light & heavy), the students are shown the level of water displaced by the lighter cylinder and asked to predict the level of water displaced by the heavier cylinder.

Item 3: Proportional Reasoning-1 (Suarez & Rhonheimer, 1974)

Using two plastic cylindrical containers of equal height but with different diameters, the students are told that a given quantity of water rises 4 units in the wide container and rises a corresponding 6 units when poured into the narrow container. The students are then asked to predict how high a given quantity of water that rises 6 units in the wide container would rise if poured into the narrow container.

Item 4: Proportional Reasoning-2 (Suarez & Rhonheimer, 1974)

Using the same plastic containers from question 3, 11 units of water are poured into the narrow container and the students are asked to predict how high the water would rise if poured into the wide container. The numbers of this item are more complex and therefore Item 4 should be more difficult.

Item 5: Proportional Reasoning-3 (Inhelder & Piaget, 1958, chap. 11)

The student is shown a diagram of a balance beam and hanging weights. The students are asked to predict where a 5-unit weight should be hung to balance a 10-unit weight which is hung 7 units of length from the fulcrum.

Item 6: Proportional Reasoning-4 (Inhelder & Piaget, 1958, chap. 11)

The same balance beam is refered to, and the students are asked to predict where a 10-unit weight should be hung to balance a 15-unit weight which is hung 4 units of length from the fulcrum.

Item 7: Controlling Variables-1 (Inhelder & Piaget, 1958, chap. 4)

Three pendulums are shown in a diagram (two of equal length but with bobs of 50 g and 100 g, the third longer with a 50-g bob), the students are asked to select which of the pendulums should be used in an experiment to find out if the variable of length effects the period of the pendulum.

Item 8: Controlling Variables-2 (Inhelder & Piaget, 1958, chap. 4)

Using the same three pendulums from item 7, the students are asked to select which pendulums should be used in an experiment to find out if the weight of the bob effects the period of the pendulum.

Item 9: Controlling Variables-3 (Wollman, 1975)

A ramp and three different metal spheres are used in this item. For the sphere which the student will release from some height, the student can select light, the same, or heavy. The student is not told whether the target sphere is light, heavy, or the same as the one which is released.

The student is shown a diagram of a ramp and the initial positions of two spheres along with the final position of the target sphere. The student is told that a sphere is allowed to roll down the ramp and hit a target sphere. The target sphere then moves as shown in the diagram. The student is then asked to select the correct sphere (light, heavy, or the same) to release from a high position to find out if the variable of release position effects how far the target sphere will travel after it has been struck.

Item 10: Controlling Variables-4 (Wollman, 1975)

Using a ramp as in Item 9, a situation is described to the students in which two metal spheres (A and B) roll down the ramp from the same starting position and strike two target spheres of different densities. They are then asked to decide whether or not the experiment constitutes proof that metal A can displace a target further than metal B.

Item 11: Combinatorial Reasoning-1 (DeLuca, 1977; Sills & Herron, 1976)

A metal box with four colour-coded switches and a light are described to the students. The students are told that the light can be turned on by flipping a certain combination of the switches. They are then asked to list all the possible combinations of the four switches that they would have to try to discover which combination or combinations will turn the light on.

Item 12: Combinatorial Reasoning-2 "Permutations" (Longeot, 1965; Piaget & Inhelder, 1975, chap. 8)

The students are told that four stores (a barber shop, a discount store, a grocery store, and a coffee shop), are going to be arranged side by side on the ground floor of a new shopping centre. The students are asked to list all the possible ways in which the stores could be arranged side by side.

Item 13: Probability-1 (Lawson, 1978)

The students are told that three yellow wooden squares and three red wooden squares are placed into a sack. The students are asked to predict the chances of drawing out a red square on the first draw.

Item 14: Probability-2 (Lawson, 1978)

The students are told that three red squares, four yellow squares, and five blue squares are placed into a sack. Four red diamond-shaped pieces, two yellow "diamonds", and three blue "diamonds" are also placed into the sack.

The students are asked to predict the chances of drawing out a red piece on the first draw.

Item 15: Probability-3 (Lawson, 1978)

Using the same wooden pieces as in Item 14, the students are asked to predict the chances of drawing a red or blue "diamond" on the first draw.

Sample and Procedure

The FOAT was administered to students enrolled in grade 11 at a large urban high school. The students of this school came from a variety of social and ethnical backgrounds. Since most students must take English, the FOAT test was administered during the students' English class, and therefore most grade 11 students would make up the sample. The Rods test was administered to 65 randomly chosen students from this sample. A correlation between the students' score on the Rods test and the FOAT test was done.

To examine the question of whether any change in formal-operational reasoning is independent of the courses which the student takes, seven groups of students were determined. Each group was determined by the courses taken by the student as follows:

Group 1 - physics + a science (chemistry and/or biology) at the 00-level.

Group 2 - physics + no other science course.

Group 3 - no physics + chemistry and/or biology at the 00-level.

Group 4 - physical science + biology at the 01-level.

Group 5 - physical science + no other science at the 01-level.

Group 6 - no physical science + biology.

Group 7 - no science courses at any level.

Most students who take the sciences at the 00-level, will also take math at the 00-level. Since this is also true at the 01-level, the math levels are not mentioned in the above listing. There was no attempt to correlate the student's academic achievement with a change in cognitive test score.

A comparison between students who were initially at the same cognitive level was desired. Since students might choose their courses according to their level of formal-operational reasoning, students who initially scored as transitional were selected to make up the sample for the second part of this study. This allowed a comparison between students who initially were at the same cognitive level.

Statistical Treatment

To determine the consistency of the FOAT and the Rod's test in measuring the cognitive score of a student, the Spearman rank correlation coefficient was chosen. Since we did not know if a linear relationship existed between the two variables, the nonparametric measure of association was chosen. There are some advantages in using r_s rather than r. For instance, we no longer assume the underlying relationship between X and Y to be linear and therefore, when the data possess a distinct curvilinear relationship, the rank correlation coefficient will likely be more reliable than the conventional measure. A second advantage in using the rank correlation coefficient is the fact that no assumptions of normality are made concerning the distributions of

X and Y. Perhaps the greatest advantage occurs when one is unable to make meaningful numerical measurements but nevertheless can establish rankings (Kerlinger, 1973, pp. 286-296; Winkler and Hayes, 1974, pp. 867-870).

The Spearman rank correlation coefficient may be employed as a test statistic to test an hypothesis of "no association" between two populations. Population 1 represents the students' FOAT score and population 2 represents the students' corresponding Rod's test score. It is assumed that the *n* pairs of observations, (X_i, Y_i), have been randomly selected and therefore "no association between the populations" would imply a random assignment of the *n* ranks within each sample. It is possible to calculate the probability that r_s assumes a large absolute value due solely to chance and thereby suggests an association between poplulations when none exists (Mendenhall, 1975).

Since we are concerned with the question of whether we can use the FOAT test as an alternative to the Rod's, we are concerned only in a positive correlation between the two test scores. Therefore we shall only use a one-tailed test with a 95% confidence interval. For $n = 30$ students and with a 95% confidence interval, the critical value of Spearman's rank correlation coefficient would be 0.305 (Mendenhall, 1975, p. 427).

$$r_s = 1 - \frac{6 \sum_{i=1}^{n} d_i^2}{n(n^2 - 1)}$$

r_s is the Spearman rank correlation coefficient.

$d_i = X_i - Y_i$

$n =$ the number of students who wrote both tests.

When X and Y are independent, the distribution of the r_s values approaches a normal distribution with a mean of zero and a standard deviation of $1/\sqrt{n - 1}$ as n increases. Consequently, when n exceeds 30, one could test for a significant correlation by computing

$$z = \frac{r_s - 0}{1/\sqrt{n - 1}} = r_s \sqrt{n - 1}$$

and comparing with critical values obtained from the standard normal curve (Walpole and Myers, 1978, p. 495). Since the hypothesis is concerned with only one tail of the distribution the z value encompassing 5% of the distribution is of concern. For this case $z = 1.645$ (Winkler and Hays, 1975, table I).

To determine whether the change in the students' cognitive level of functioning is independent of the curriculum which the student is taking, the Kruskal-Wallis H test was chosen. The Kruskal-Wallis test is a generalization of the Wilcoxon two-sample test to the case of $J > 2$ samples or experimental groups. It is used to test the null hypothesis Ho that J independent samples are from identical populations. The test is an alternative nonparametric procedure to the *F* test for testing the equality of means in a one-factor analysis of variance when the experimenter wishes to avoid the assumption that the samples were selected from normal populations.

$$H = \frac{12}{N(N+1)} \left[\sum_j \frac{T_j^2}{n_j} \right] - 3(N+1)$$

(Hays, 1973, p.782-784)

T_j = sum of ranks for group j.

T = sum of the rank sums.

J = the number of groups.

n_j = the number of students in each group

N = the total number of students

The H statistic is approximated very well by a chi-square distribution with J - 1 degrees of freedom for a test of the hypothesis that all J population distributions are identical.

With seven groups of students and using a 0.05 level of significance with J - 1 = 6 degrees of freedom, the chi-square value is 12.592 .

<u>Expected Results and Implications</u>

The questions used in the FOAT had been chosen by Lawson (1978) very carefully and were found to be a valid measure of the students' formal-level reasoning. Since Lawson demonstrated each item and the FOAT is a paper-and-pencil test, the measure of the students' formal-level reasoning from the FOAT might tend to be a little lower. The pencil-and-paper measures increase the demand on reading and writing skills which, although related to

Piagetian operations, are not one and the same. For each question there still should be the same trends for both the demonstration method and the FOAT.

A high correlation between FOAT and the previously validated Rods test would strengthen the confidence one could place on the FOAT. The small sample size of 65, however, could influence the results and a low correlation coefficient could reflect this.

The number of students who would be identified as transitional and then make up each of the seven groups for the study, was unknown. A small number of students in these groups could greatly influence the results.

DATA

The sample of students was chosen from a large urban high school in Winnipeg. The students of this school came from a variety of social and ethnical backgrounds. The school year is non-semestered.

Since most students in grade 11 take either English 200 or 201, the FOAT test was administered during the English class early in September 1981. Of this group of students, 65 students were then randomly selected to write the Rods test a few days later. A total of 311 grade 11 students wrote both the pre- and post-FOAT test. Based upon the FOAT scores, the students were categorized as concrete, transitional, and formal. All students who were identified as transitional were included in the study. A total of 209 transitional students wrote both the pre- and post-FOAT test. The post-FOAT test was written during the first week of April 1982.

Table 1

Categorization of Students into Operational Levels

	Concrete	Transitional	Formal	Total
Number of Students	67	209	35	311
Proportion of Sample	.215	.672	.113	1.00

Appendix A contains the questions from the Rods Test and the scoring criteria for each question. Appendix B contains questions from the FOAT test.

Categorization of Students

Based on the results from FOAT students were categorized into their operational level. Then the students were ranked according to FOAT test and the Rods test so that a comparison of the two score could be done.

The students who were identified as transitional were then grouped into one of seven groups according to the subjects taken.

Table 2

Foat and Rods Test Scores with Corresponding Rankings

FOAT	RANK	RODS	RANK	Difference in the Rank Scores (d = FOAT - RODS)	d^2
11	41	6	6	35	1225
9	29	10	33.5	- 4.5	20.25
5	5	10	33.5	-28.5	812.25
11	41	9	23	18	324
7	15.5	6	6	9.5	90.25
7	15.5	9	23	- 7.5	56.25
6	9	4	1.5	7.5	56.25
6	9	8	16	- 7	49
8	22	9	23	- 1	1
7	15.5	7	10.5	5	25
7	15.5	7	10.5	5	25
11	41	12	54	-13	169
9	29	9	23	6	36
12	49	11	45	4	16
15	64.5	13	61.5	3	9
13	57	13	61.5	- 4.5	20.25
6	9	8	16	- 7	49
6	9	7	10.5	- 1.5	2.25
12	49	12	54	- 5	25
13	57	12	54	3	9
4	3.5	4	1.5	2	4
3	1.5	5	3	1.5	2.25
9	29	10	33.5	4.5	20.25
10	35	10	33.5	1.5	2.25
7	15.5	7	10.5	5	25
9	29	10	33.5	- 4.5	20.25
12	49	11	45	4	16
12	49	13	61.5	-12.5	156.25
12	49	13	61.5	-12.5	156.25
6	9	8	16	- 7	49
13	57	12	54	3	9
7	15.5	10	33.5	-18	324
13	57	12	54	3	9
14	62	12	54	8	64
11	41	11	45	- 4	16
11	41	11	45	- 4	16
15	64.5	12	54	10.5	110.25
8	22	9	23	- 1	1
9	29	10	33.5	- 4.5	20.25
8	22	8	16	6	36
10	35	10	33.5	1.5	2.25

Table 2 - continued

Foat and Rods Test Scores with Corresponding Rankings

FOAT	RANK	RODS	RANK	Difference in the Rank Scores (d = FOAT - RODS)	d^2
13	57	12	54	3	9
10	35	10	33.5	1.5	2.25
12	49	10	33.5	15.5	240.25
14	62	10	33.5	28.5	812.25
13	57	12	54	3	9
11	41	11	45	- 4	16
10	35	10	33.5	1.5	2.25
8	22	8	16	6	36
11	41	14	65	24	576
12	49	11	45	4	16
8	22	6	6	16	256
6	9	8	16	- 7	49
4	3.5	9	23	- 19.5	380.25
3	1.5	10	33.5	- 32	1024
9	29	6	6	23	529
12	49	11	45	4	16
12	49	8	16	33	1089
8	22	13	61.5	- 39.5	1560.25
14	62	11	45	17	289
6	9	13	61.5	- 52.5	2756.25
9	29	10	33.5	- 4.5	20.25
13	57	11	45	12	144
10	35	9	23	12	144
8	22	6	6	16	256

Selection of Subjects

From the 311 students in the survey, 209 students were identified as transitional. While all 311 students wrote the post-test at the end of the study, only the results of the 209 transitional students were compared with the corresponding pre-test results.

Change in the FOAT Score

The transitional students were grouped according to the courses which they were taking. The post-FOAT score was then compared with the pre-FOAT score which generated a change in the FOAT score. This change in the FOAT score will be referred to as the **c** score.

Table 3

Categorization and Ranking of Students in each Course Group

Group 1		Group 2		Group 3		Group 4		Group 5		Group 6		Group 7	
c	Rank	c	Rank	c	Rank	c	Rank	c	Rank	c	Rank	c	Rank
4	171	0	48	4	171	2	113	5	190	3	144	1	79.5
5	190	4	171	-1	24.5	1	79.5	5	190	2	113	2	113
0	48	1	79.5	3	144	-1	24.5	0	48	4	171	-2	12.5
1	79.5	4	171	0	48	2	113	1	79.5	2	113	1	79.5
4	171	4	171	2	113	4	171	3	144	2	113	-4	1.5
7	207	3	144	3	144	1	79.5	0	48	-1	24.5	0	48
4	171	4	171	2	113	1	79.5	1	79.5	1	79.5	1	79.5
1	79.5	1	79.5	-1	24.5	6	201.5	1	79.5	6	201.5	3	144
4	171	2	113	3	144	6	201.5	5	190	-1	24.5	3	144
1	79.5	1	79.5	0	48			3	144	0	48	0	48
5	190			1	79.5			1	79.5	-1	24.5	2	113
5	190			4	171			2	133	-3	6	-1	24.5
4	171			2	113			-1	24.5	0	48	4	171
3	133			2	133			4	171	0	48	-1	24.5
5	190			2	133			4	171	-1	24.5	-2	12.5

Table 3 - cont

Categorization and Ranking of Students in each Course Group

Group 1		Group 2		Group 3		Group 4		Group 5		Group 6		Group 7	
c	Rank	c	Rank	c	Rank	c	Rank	c	Rank	c	Rank	c	Rank
4	171			2	113			3	144	-2	12.5	0	48
2	113			-1	24.5			0	48	-1	24.5	3	144
1	79.5			0	48			0	48	0	48	2	113
1	79.5			6	201.5			0	48	3	144	2	113
3	144			0	48			0	48	-2	12.5		
4	171			4	171					0	048		
2	113			2	113					-1	24.5		
-1	24.5			2	113					4	171		
5	190			2	113					3	144		
-3	6			0	48					-3	6		
6	201.5			1	79.5					3	144		
5	190			1	79.5					2	113		
-3	6			0	48					1	79.5		
4	171			2	113					2	113		
3	144			4	171					2	113		
6	201.5			3	144					0	48		
5	190			2	113					1	79.5		
1	79.5			-3	6					3	144		
1	79.5			-1	24.5					-4	1.5		
3	144			6	201.5					6	201.5		
0	48			-1	24.5					1	79.5		
8	208			-1	24.5					-2	12.5		
3	144			5	190					-1	24.5		
6	201.5			4	171					0	48		
4	171			9	209					2	113		
3	144			3	144					2	113		
5	190			5	190					3	144		
0	48									2	113		
1	79.5									-3	6		
1	79.5									2	113		
-2	12.5									1	79.5		
6	201.5									3	144		
4	171									0	48		
2	113									1	79.5		
3	144									3	144		
3	144									1	79.5		
1	79.5									3	144		
										1	79.5		
										0	48		
										0	48		
										2	113		
										-3	6		
										-1	24.5		

CHAPTER IV

ANALYSIS OF DATA AND FINDINGS

This chapter will report on the results obtained from the data which were reported in chapter III.

Analysis of Data

The FOAT test was designed so that the formal-operational reasoning of secondary school age students could be determined quickly and easily. The Rods test, developed and validated by Harris, was chosen to be compared with the FOAT test.

The Rods test and the FOAT test were administered to 65 students. The scores on these tests will be referred to as population 1 and population 2. The Spearman rank correlation coefficient may be employed as a test statistic to test an hypothesis of "no association" between two populations. Population 1 represents the students' FOAT score and population 2 represents the students' corresponding Rod's test score. It is assumed that the *n* pairs of observations have been randomly selected and therefore "no association between the populations" would imply a random assignment of the *n* ranks within each sample. For $n = 30$ students and with a 95% confidence interval, the critical value of Spearman's rank correlation coefficient would be 0.305 . The null hypothesis can be stated as:

$Ho : r_s = 0$

If the Spearman's rank correlation coefficient is greater than 0.305, then the null hypothesis of "no association" between the two populations can be rejected at the 95% confidence level.

The observed value for the Spearman's rank correlation, based upon the data from Table 2, is 0.687. This is greater than the critical level. Thus, Ho can be rejected at the 95% confidence level and there is substantial evidence to indicate that we can reject the hypothesis of "no association" between the two populations and conclude that the two test scores are not different.

As indicated earlier, when X and Y are independent, the distribution of the r_s values approaches a normal distribution with a mean of zero and a standard deviation of $1 / \sqrt{n - 1}$ as n increases. When n exceeds 30, one could test for a significant correlation by computing $z = r_s \sqrt{n - 1}$ and comparing with critical values obtained from the standard normal curve. For a one-tailed test at the 95% confidence level, the z value would be 1.645. The null hypothesis can be stated as:

$$Ho : r_s = 0$$

If the calculated z value is greater than 1.645, then the null hypothesis of "no association" between the two test will be rejected.

The calculated value of z = 5.496 is much greater than the critical rejection level. Therefore, Ho is rejected and the alternate hypothesis of association is accepted. There is evidence which indicates that the FOAT score and the Rods test score are the same.

A regression equation was calculated for scores on the FOAT against scores on the Rods test. Where Y are the scores on the FOAT and X are the scores on the Rods test, the regression equation is $Y = 1.51 + (.83)X$. The 95 percent confidence

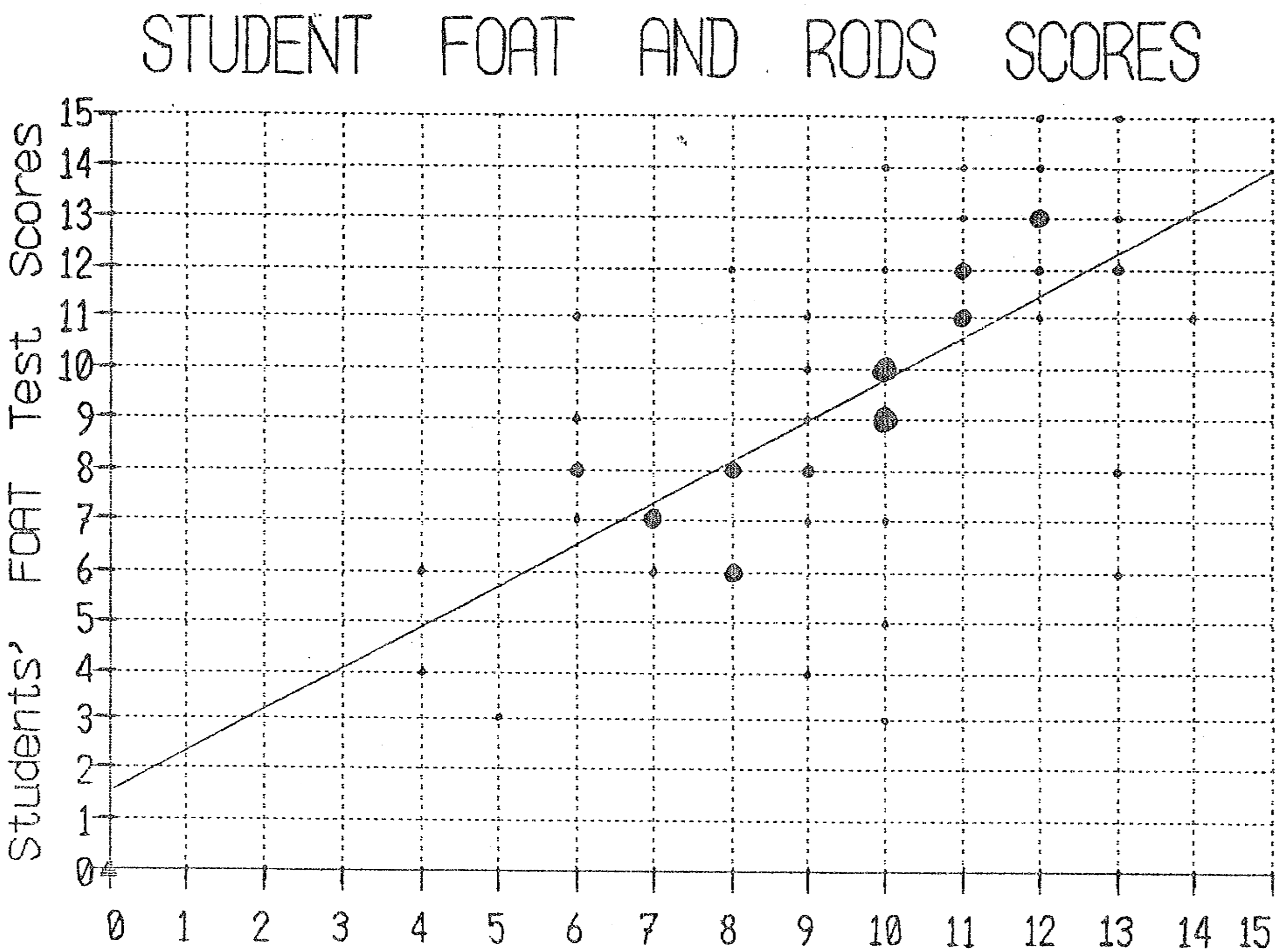

Fig. 2 Students' Rods Test Scores

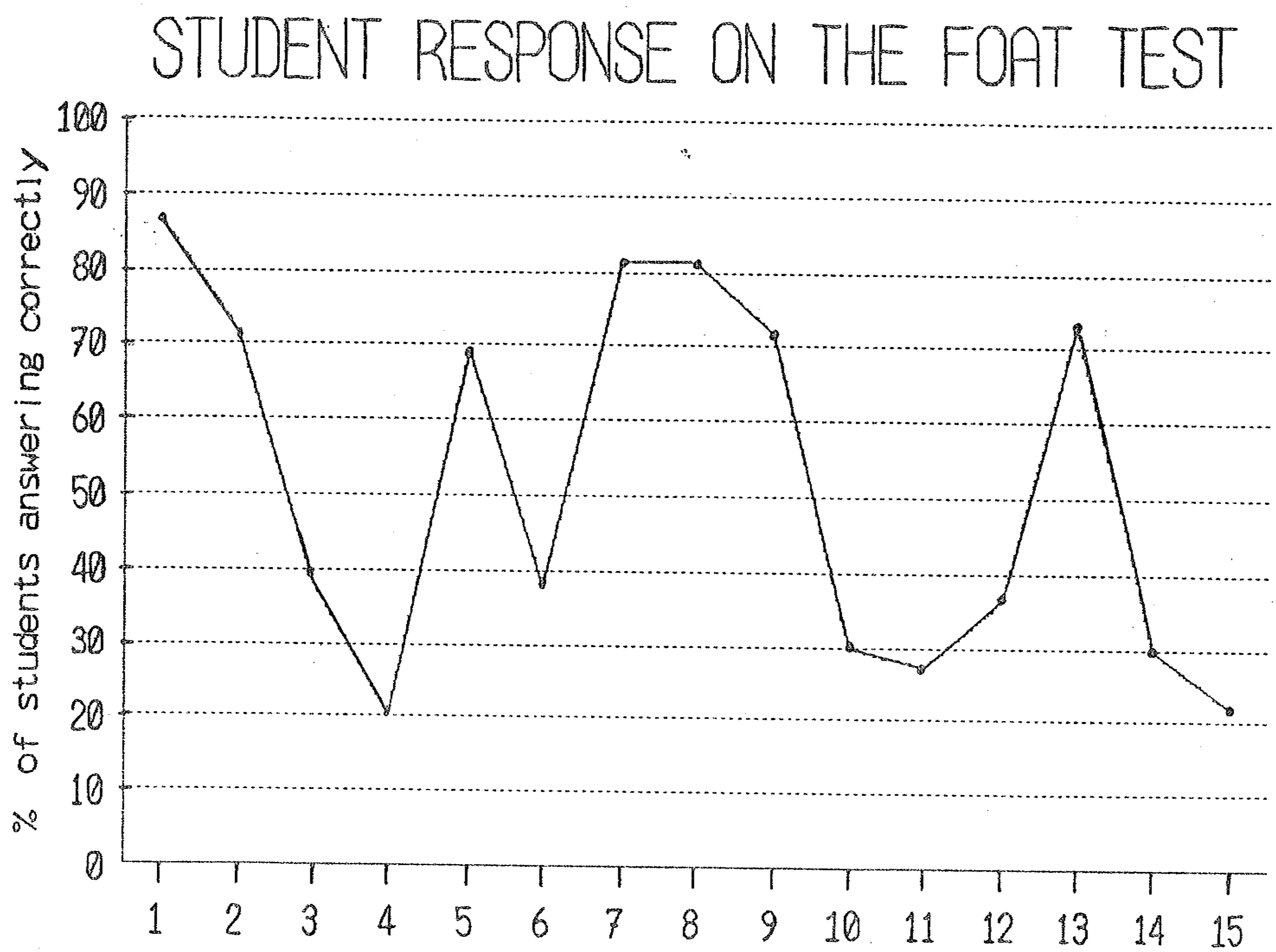

Fig. 3 Question # on the FOAT test

interval for the slope, based upon the data of Table 2, 0.83 ± 0.28.

The regression line in Figure 2 demonstrates the rather strong relationship between the FOAT and Rods test scores. The size of the points in Figure 2 are proportional to the number of students with that score. The data points which are far from the regression line are small in size and therefore represent individuals. The large data points, which represent many students who have scored the same test scores, lie close to the regression line. The scatter diagram of these scores indicates a strong, positive correlation.

Figure 3 indicates the level of difficulty for each question of the FOAT.

The second problem was the main purpose of this research. Is there a change in the level of formal-operational reasoning of secondary school age students after nine months in an academic programme, and is this change independent of the programme of studies which the student takes?

Based on the subjects which the students were taking, the students were categorized into seven groups. The difference between the pre- and post-test was indentified as *C*. The null hypothesis can be stated as:

$$Ho: C_1 = C_2 = C_3 = C_4 = C_5 = C_6 = C_7$$

The Kruskal-Wallis test, H statistic, is approximated very well by a chi-square distribution with $J - 1$ degrees of freedom for a test of the hypothesis that all J population distributions are identical. With seven groups of students and using a 0.05 level of significance with $J - 1 = 6$ degrees of freedom, the chi-square value is 12.592 . If the calculated H value is greater than 12.592 then the null hypothesis, that the change in the test scores for each group of students is the same, will be rejected.

The calculated H statistic of 26.24, based on the data from Table 3, is much greater than the critical rejection level. Therefore, the null hypothesis that there is equal change in student cognitive level as measured by FOAT is rejected. The alternate hypothesis is that there is evidence that there is an unequal change in cognitive function. This result does not indicate which group of students changed the most. We can only say that there is evidence of an unequal change in the FOAT scores between the groups tested.

Summary

Evidence, from the data presented in Table 2, supports the claim that the FOAT is a valid instrument which measures concrete- and formal-operational reasoning. This appears in the correlation ($r = 0.687$) between the FOAT and the Rods test, and in the rejection of the null hypothesis ($z = 5.496$) where Ho: $r = 0$. Since the Rods test has been shown to be a valid instrument for measuring the cognitive level of students, the FOAT test is also a good predictor of student cognitive levels.

Figure 2 shows the regression line and a scatter diagram of X (scores on Rods) and Y (Scores on FOAT). The size of the points are proportional to the number of students with that score. The scatter diagram of these scores indicates a positive correlation. Therefore, the FOAT can be used to measure the students cognitive level. Since the FOAT is easier and faster to evaluate a group of students, there would be an advantage in using the FOAT.

There is evidence to support the claim that the change in the cognitive level of students in different programmes of study is not equal. That is to say, students taking one programme of studies improve in their cognitive level of thought more than those students in a different programme.

In Table 4, the average ranking and change in the FOAT score for each group is presented. Groups 1, 2, and 3 consist of students who are taking one or more science courses at the 00-level. Groups 4, 5, and 6 consist of students who are taking one or more science courses at the 01-level.

At either the 00- or 01-level, students who take more science courses demonstrate a greater change in their formal-operational reasoning. Group 7 consisted of students at both the 00- and 01-level, but they were not taking any science courses. This group demonstrated the least change in formal-operational reasoning.

As a point of interest to other researchers in this area, the average change in the FOAT score is presented in Table 5 rather than the ranking as in Table 4. The average change in the FOAT score for groups 6 and 7 are 0.81 and 0.74 with standard deviations of 2.18 and 2.08 respectively. These results indicate that many students in these two groups not only showed no change in the FOAT score, but that they even had a negative change in their FOAT score.

Table 4

The Average Change in the FOAT Score by Ranking

Group	Number of Students in each Group	Average Ranking of the Change in the FOAT Score	Standard Deviation of the Average
(1) Physics + another 00-level science course	52	133.27	59.63
(2) Physics + no other science course	10	122.75	48.37
(3) No Physics + another 00-level science course	41	108.90	58.52
(4) Physical Science-01 + Biology-01	9	118.11	61.23
(5) Physical Science-01 + no other science	20	104.38	57.85
(6) No Physical Science + Biology-01	58	80.33	54.86
(7) No Science	19	79.63	52.40

Table 5

The Average Change in the FOAT Score

Group	Number of Students in each Group	Average Change in the Foat Score	Standard Deviation of the Average
(1) Physics + another 00-level science course	52	2.88	2.43
(2) Physics + no other science course	10	2.40	1.58
(3) No Physics + another 00-level science course	41	2.02	2.35
(4) Physical Science-01 + Biology-01	9	2.44	2.40
(5) Physical Science-01 + no other science	20	1.85	1.98
(6) No Physical Science + Biology-01	58	0.81	2.18
(7) No Science	19	0.74	2.08

CHAPTER V

DISCUSSION AND CONCLUSIONS

Discussion

This study focused on a group of students who were transitional between concrete and formal operational stages of thought as measured by FOAT, and were taking a variety of programmes at the grade 11 level. The underlying thesis of this study was that students who are exposed to a curriculum which would stimulate a variety of cognitive activities, would show a greater change in cognition.

This study has shown, as many other studies have (Herron, 1975; Lawson & Renner, 1975), that students in the same grade level are operating at quite a different level of formal-operational thought, and that the students are not fully formal by the ages of 15 or 16-years. A basic idea underlying this study was that it is not the stages that are important, but rather what happens in the transition.

Lawson, Karplus, and Adi (1978) argued that the gradual but steady increase in older students' ability to use proportional, probabilistic, and correlational reasoning are not acquired as a result of any direct and/or short-term teaching programmes. They argued that support was obtained for a developmental perspective in which these reasoning abilities are acquired as a consequence of the gradual process of equilibration. This would imply that curricula designed to promote the acquisition of these reasoning abilities should provide opportunities for equilibration to take place. Lawson and Wollman (1976) found that this process was facilitated by providing students with problems from a wide variety of contexts. This suggests that interdisciplinary programmes teaching the various aspects of formal reasoning from widely differing content areas would be an effective means for provoking students to equilibrate with respect to the various patterns under consideration. Science courses which engage students in data gathering activities while capitalizing on the opportunity to apply the appropriate quantitative relations is what is needed.

One of the major objectives of the physics programme was to combine data gathering activities with the application of the appropriate quantitative relations. For this reason, it should be expected that the physics students' FOAT score would show a large upward change.

The data from Tables 4 and 5 do indeed indicate that the FOAT scores of the physics students do improve, but they are not alone. Within the two groups of students, the 00- and 01-level, those students who took more science and science which uses mathematics demonstrated a larger change in the FOAT score.

This result would indicate that students in both the 00- and 01-level programme would benefit from an interdisciplinary programme which combines the activities of science and math.

In the review of literature, it was suggested that each hemisphere of the brain has a specialized cognitive style. The left hemisphere is specialized for analytical, verbal, logical, linear, and sequential tasks which are abstract and time related. The right hemisphere is specialized for synthetic, visual, spatial, and holistic tasks. The left being the centre for verbal and mathematical tasks, while the right being the centre for the processing of nonverbal information and visual imagery.

If a task had visuo-spatial components during the stimulus period, right hemispheric activity during that period would be elicited. If a task had verbal or logical components during the response period, then left hemispheric activity tended to be elicited. Children who are identified as gifted, and who demonstrate formal operational thought, tend to use either hemisphere depending upon the question or activity. This sorting does not appear to occur with students who are at the concrete operational stage. The concrete operational student uses the left hemisphere predominately and the formal operational student shows a greater proportion of right hemispheric activity. Kraft (1976) has suggested that these results and Piaget's tasks are behavioural components of interhemispheric communication and of maturing neural fibres which facilitate these processes.

Students engaged in problems from a wide variety of contexts will be required to use those parts of the brains which specialize in the corresponding activity. Glial cells are a source of nerve growth factor (NGF) which stimulate axonal outgrowth and attract nerve fibres to their targets. It has been observed in the brains of mice and rats which have been raised in an "enriched environment", that the number of glial cells can be increased, and this would indicate a continual regulation of the number of terminal branches of adrenergic nerve fibres. These studies also show that long-lasting changes in the development of dendrites and synapses occur.

In the review of literature, it has also been pointed out that while some neurons are inherently predisposed in their development, other neurons require appropriate stimulation for development.

In curriculum guides such as the pilot programme guide for physics in Manitoba (1982), educators have concluded that the curriculum should be aimed at the cognitive level of the students. While this would have the result of moving more of the high school curricula towards the concrete-level, it does not address the question of *how do the schools encourage the development of formal-operational thought*? Cantu and Herron (1978) found that it did not matter whether concrete or formal concepts were being taught, and that using different teaching strategies would not eliminate the differences in achievement observed between concrete- and formal-operational students.

While researchers conclude that there is no teaching strategy which will eliminate the difference between the concrete- and the formal-operational students, there is evidence in this study to support the claim that the change in the cognitive level of students in different programmes of study is not the same. That is to say, students taking one programme of studies improve in their cognitive level of thought more than those students in a different programme. The combination of courses might make a difference in the cognitive growth of students.

Keeping in mind what the literature has to say about the function of the left and right hemispheres, a detailed examination was performed on courses which the grade 11 students would take. A course which would combine mathematics, data calculating relationships, the building of theories using both positive and negative experimental results, and the testing of ideas and theories, would help to promote the use of both hemispheres. While most courses do not have the students working on tasks which would elicit right-brain activity, or to promote a combination of both hemispheres, the P.S.S.C. physics 200 programme has expectations of the students working through these activities. The main topic in the P.S.S.C. physics 200 programme in Manitoba was "Light". The students were to answer the question "What is light?" by formulating hypotheses, defining operationally, controlling variables, experimenting, and formulating models and interpreting data.

It was expected by this author that those students who were taking the physics 200 course would show the greatest improvement in their FOAT score. While these results were realized, other important trends have become apparent.

The results of this study indicate that students at both the 00- and 01-level will benefit most by a greater exposure to a *variety* of science, especially physics or physical science. With respect to what has been said in the review of literature, this is not surprising. It is in physics and physical science where we get a blend of mathematics, reading, and problem solving, with the combination of model building and testing. Not even in mathematics 200 with geometry and algebra do we get as great a combination of the activities for both hemispheres.

The process skills in science are divided into two parts: Basic Skills and Intermediate Skills. With the *Basic Skills* the student learns to (1) observe, (2) communicate ideas, (3) classify, (4) measure, (5) use numbers, (6) use spatial and temporal relations, (7) make inferences, and (8) predict. The *Integrated Skills* make use of the basic skills in the development of more sophisticated processes of (1) formulating hypotheses, (2) defining operationally, (3) controlling variables, (4) experimenting, and (5) formulating models and interpreting data.

It is the opinion of this author that it is the students, who were exposed to the above through a variety of disciplines, who showed the greatest change in cognitive operation. Further, it is the opinion of this author that this change in formal operational thought is not limited to the curricula of the sciences. Other disciplines, if the process and cognitive skills are developed, should encourage the development of formal operational thought. A study, which categorizes students other than by the sciences, should be done in the near future.

Rather than allowing students to specialize, students should be encouraged to study many disciplines. Students should be faced with problems from a wide variety of contexts; they should be in an interdisciplinary programme which teaches the various aspects of formal reasoning.

This author could not locate any studies in the literature which compared students within existing courses. Studies which pulled the students out of courses or which had the students do extra activities, were usually for only a few weeks and did not have a regular classroom setting.

To the degree which the Piagetian stages are a measure of brain development, and in accordance with the need to detect any true changes in these stages, the study must be longer than a few weeks. It was for this reason that this study was done using students in a non-semestered school year.

Two of the groups of students, group 2 and group 4, were of small sample size. This is unfortunate, but until the entire grade 11 population in a specific school was tested, the sample sizes for each group of transitional students could not be estimated. Since it was important to have the students at the same cognitive level, and to have groups of students in fundamentally different curricula, none of these groups could be either eliminated nor combined. With the limited resources of manpower and finances available at the time of this study, there appeared to be no way around this problem. To get a large enough sample size for each group, five or more large high schools would have to be included in the study.

CONCLUSIONS

The combination of courses in the curriculum which a student takes does appear to have an effect upon the cognitive growth of the student. The same trends appear in both the 00- and the 01- level of courses if the combination of subjects is equivalent. This would indicate that students should be involved with a greater variety of interdisciplinary programmes, and that teachers should combine data gathering activities with the application of quantitative relations to build models. It is also imperative that the students work with both positive and negative results in model building. These activities do not need to be limited to the science curricula. If courses such as history and geography are promoting the above activities, then results corresponding to this study should also be realized.

These results also indicate that when curricula are being designed, the cognitive function of the hemispheres should be kept in mind. The key to cognitive development might be interhemispheric communication across the corpus callosum. Different tasks will elicit either right or left hemispheric activity. If these tasks vary greatly and frequently, then both hemispheres will be active a great deal of the time and promote development of both sides of the brain.

IMPLICATIONS AND COMMENTS

The general concern and topic for this study was spawned by the recommendation from the Physics 200-300 Committee for the Manitoba Department of Education. These concerns have been discussed in chapter 1 of this study.

The new curriculum for physics 200 was to contain materials which were found in the 300 programme. There was to be less of an opportunity to work with model building and testing of hypotheses using both positive and negative results. Before changing the curriculum, this author wanted to try and identify any positive or negative aspects of this "old" physics programme.

As the results of this study have shown, it is important that the students get a variety of materials. With both the recommendations of the Physics Committee in mind and the results of this study, a proposal for a "Spiral Approach" to teaching the physics course was formulated. This proposal was approved by both the Department of Education and the River East School Division. The first year for piloting this spiral approach to the physics 200 programme has just been completed.

The objectives of this new physics 200 programme are:

1. To increase student's basic knowledge of what physics is and the role it plays in their everyday life.
2. To enable students to develop and apply the skills of science.
3. To enable students to develop their cognitive abilities.

Every student who enters this physics 200 programme will not necessarily continue with the 300-level programme. Therefore, if the first objective is to be realized, then more than just a few selected topics must be presented. An overview of several areas must be presented.

All students in the physics 200 course will be functioning at different cognitive levels. Therefore, if each student is to have an opportunity to improve, then the programme must be flexible enough to allow both the concrete- and formal-operational students to develop further.

The spiral programme will initially move rapidly through most of the topics for both the 200- and 300-level programme. The text which is being used is written in a straight forward manner and at a level which is easy for students who are functioning at the concrete level. Because the text and the concepts are easier than the PSSC programme, a greater variety of topics can be covered. This allows those students who will not continue in physics to get a broader view of what is physics, and it allows those students who are not formal-operational thinkers to develop a "good" feeling about the subject.

For those students who are operating at the formal-cognitive level, they will have challenging concepts from the PSSC and other sources presented to them. These students will not have to wait for the others to catch up because the other students will not be exposed to these topics in grade 11.

In grade 12, the spiral continues with the regular students now being exposed to most of the same topics of the 200-level, but at a more abstract and difficult level. The more advanced students, who did this in grade 11, will be working at more advanced topics still. The programme has a built in mechanism which seems to create a desire in the more advanced students to want to achieve, while their final marks cannot be threatened by taking on a greater challenge.

The results at the end of the first year have been very promising. While the number of available students for the physics 200 programme next year has decreased, the number of requests from students to take the course has increased (from four classes to five). Three top 200-level students participated in the Canadian Association of Physicists prize examination, and finished in the top 20 out of 235 students for Manitoba (scoring higher than most of the grade 12 students).

It would appear that the spiral approach might be able to address the individual cognitive needs of students while also allowing them to become more familiar with the variety of topics within a disipline which affects society and individuals every day.

We must continue our efforts to develop procedures which can be used to enhance the intellectual development of students. This paper has addressed a few of the issues, but further studies must be done.

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APPENDIX A

NAME ____ GRADE______
first name   last name

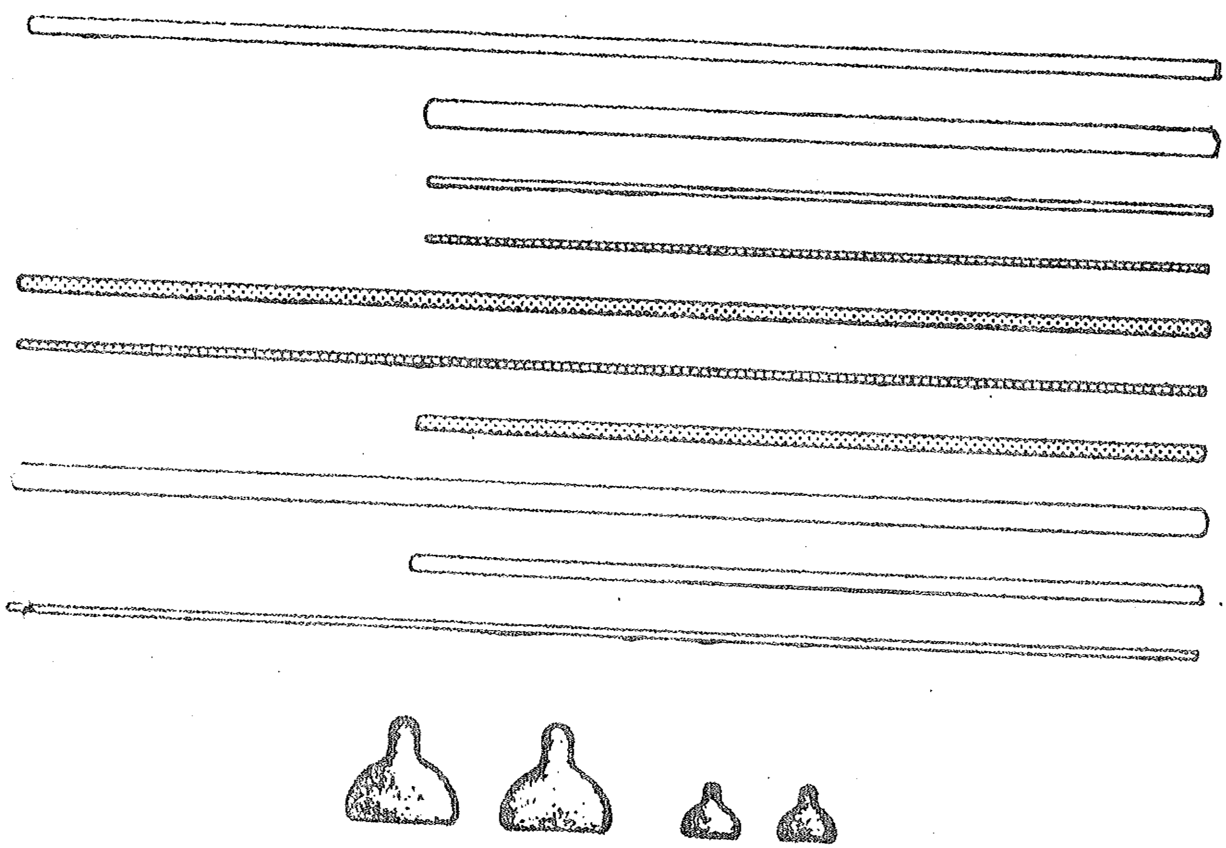
This is a problem dealing with rods and why they bend.

The rods and weights used in the problem are shown below.

Rods marked like this ░░░░░░ are all the same kind of metal.

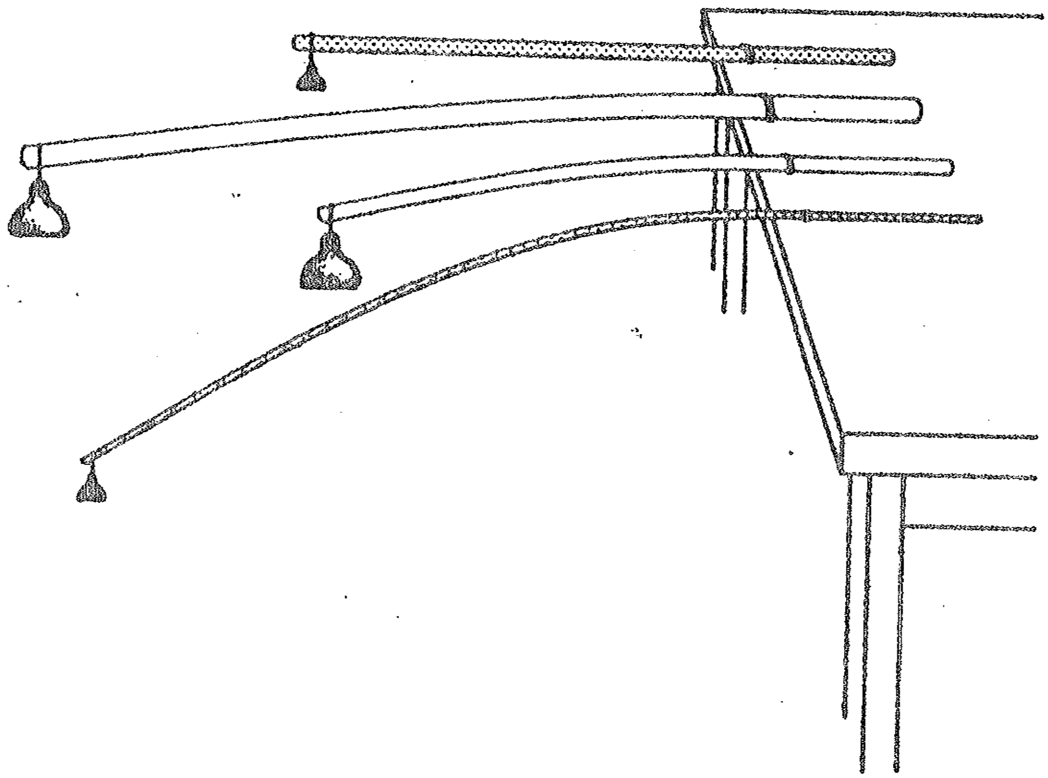
Rods without markings are all the same kind of wood.

All the rods are round.



The picture below shows how the rods bend when weights are placed on the ends.

All of the pictures show exactly what happens using real rods and weights.



QUESTION 1 Bending probably depends on several things because the rods bend different amounts.

Make a list of the things which may influence bending.

(You do NOT need to write sentences. Just make a LIST.)

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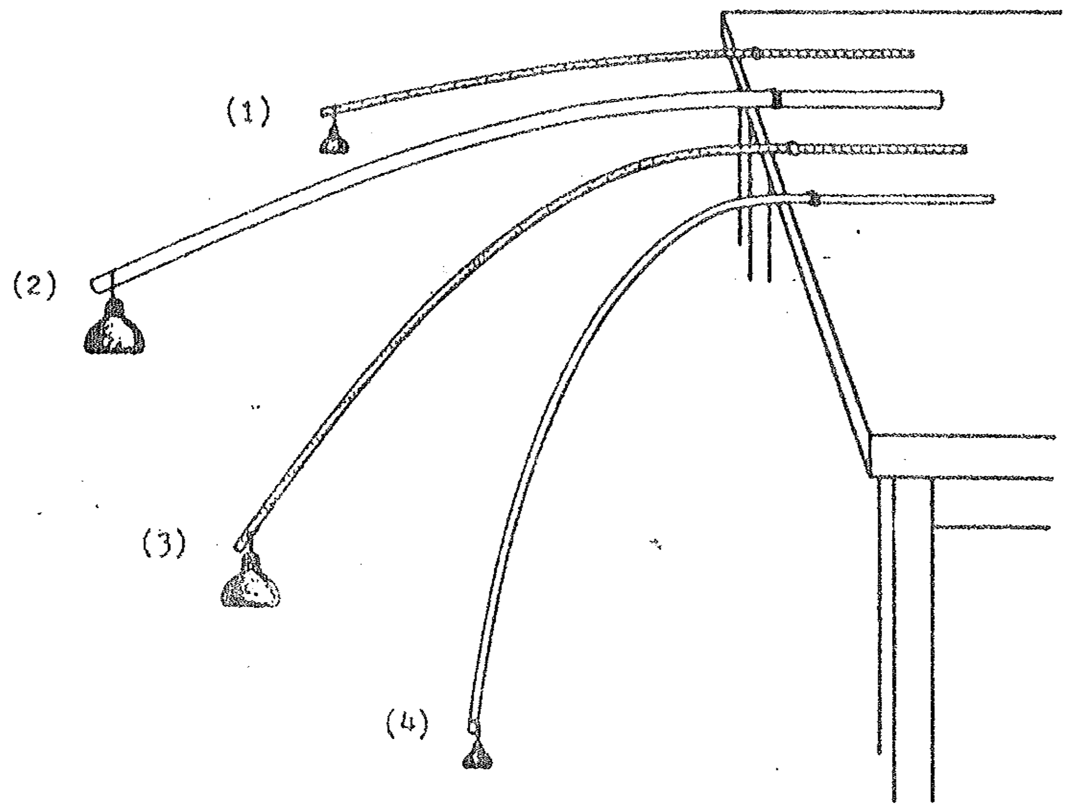


QUESTION 2 Probably (3) bent more than (2) because

____

____

QUESTION 3 Probably (4) bent more than (1) because

____

____

QUESTION 4 Probably (3) bent more than (1) because

____

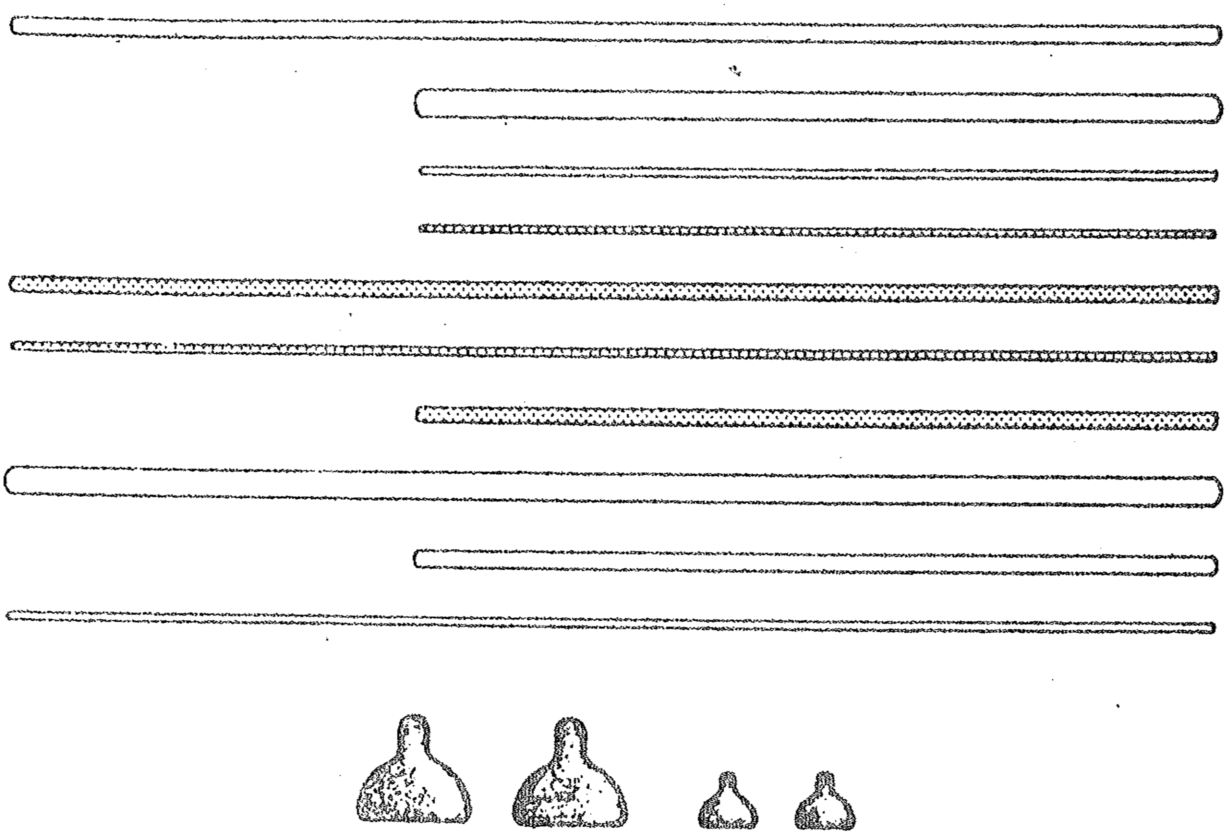
____

QUESTION 5 Suppose you think that a difference in material (that is, metal or wood) might cause one rod to bend more than another.

Mark X's on the two rods you would use to prove that bending depends on the kind of material.

Mark X's under the two weights you would use.

(You should use four X's, two for rods and two for weights.)

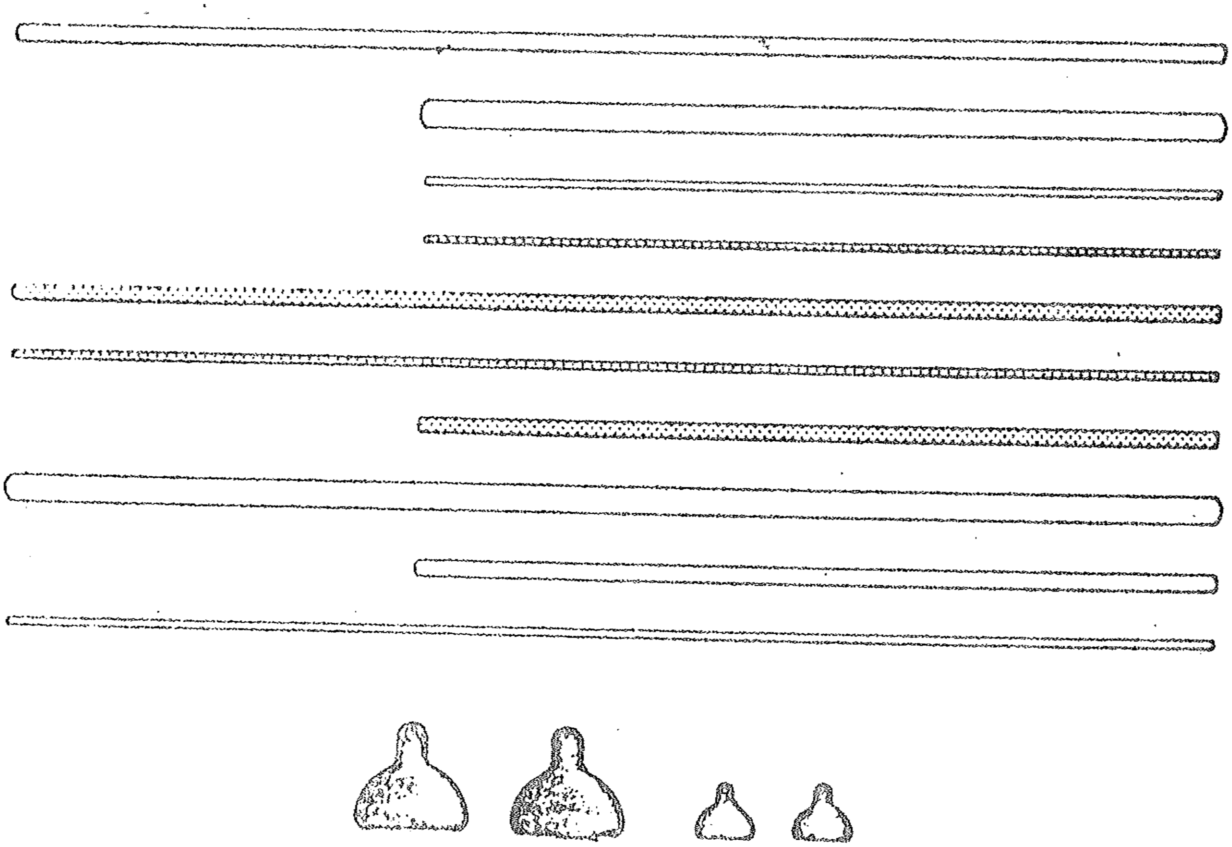


QUESTION 6 Suppose you think that a difference in length might cause one rod to bend more than another.

Mark X's on the two rods you would use to prove that bending depends on length.

Mark X's below the two weights you would use.

(Use four X's, two for rods and two for weights.)

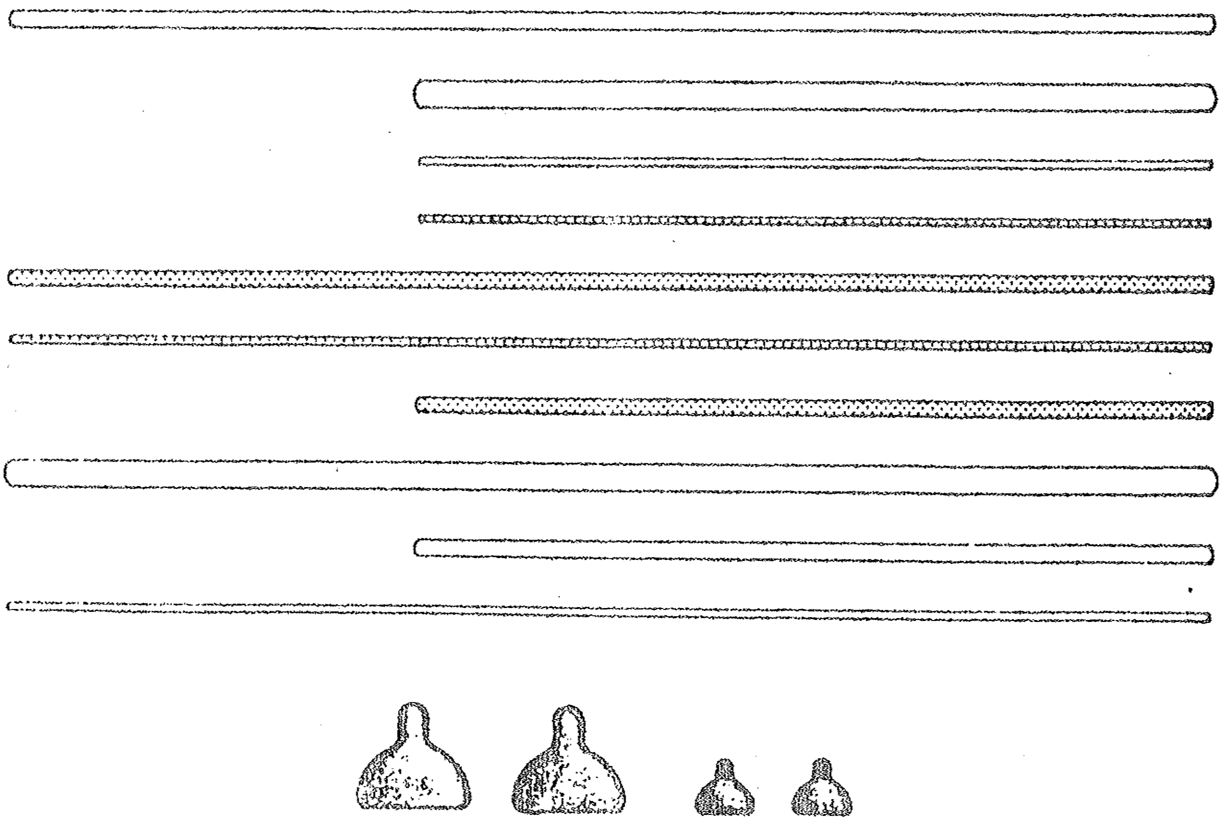


QUESTION 7 Suppose you think that a difference in thickness might cause one rod to bend more than another.

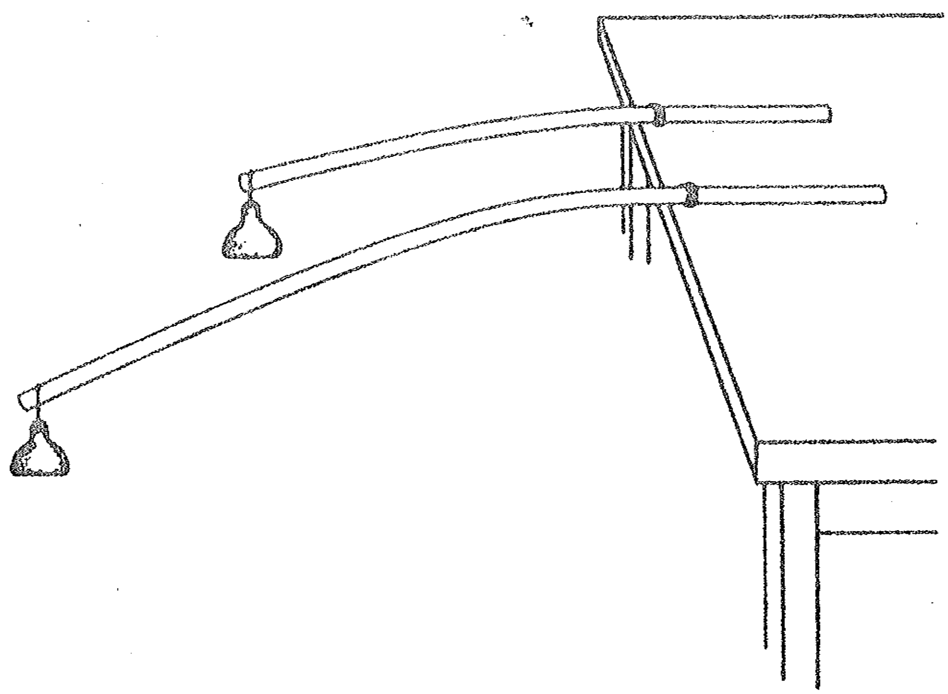
Mark X's on the two rods you would use to prove that bending depends on thickness.

Mark X's below the two weights you would use.

(You should use four X's, two for rods and two for weights.



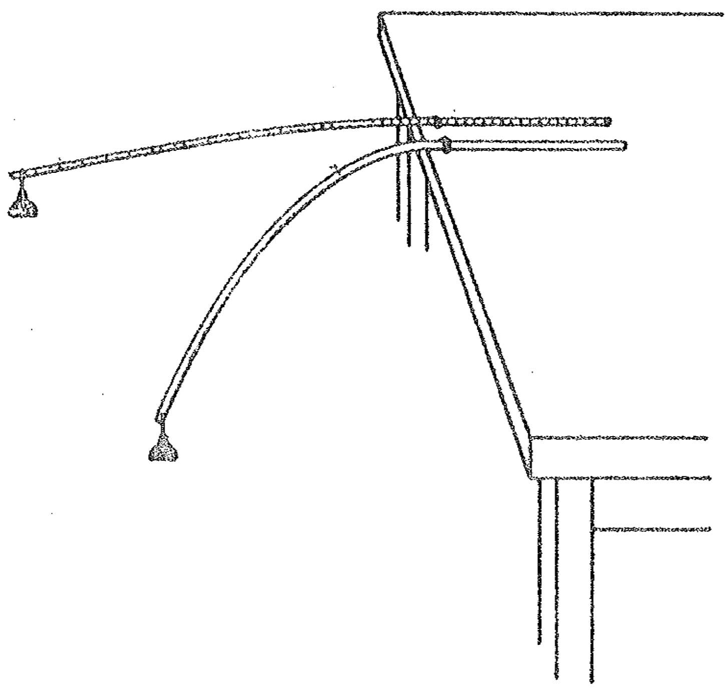
QUESTION 8 What does the demonstration pictured below prove?



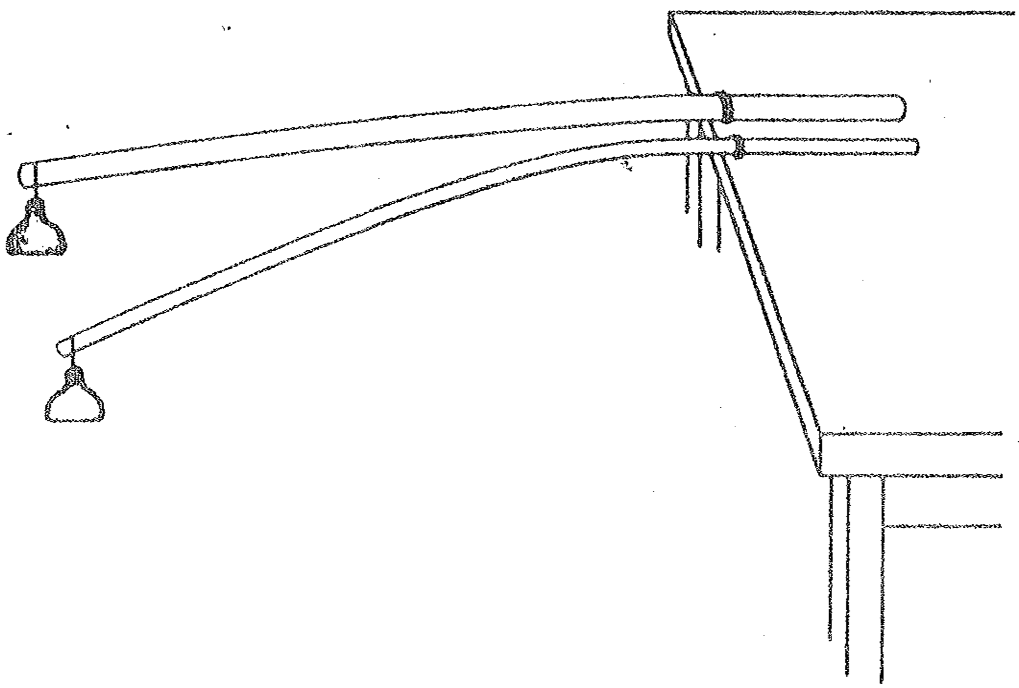
QUESTION 9 What does the demonstration pictured below prove?

____

____



QUESTION 10 What does the demonstration pictured below prove?



QUESTION 11 Both of the rods pictured below bend exactly the same amount.

Explain carefully why one rod bends the same amount as the other.

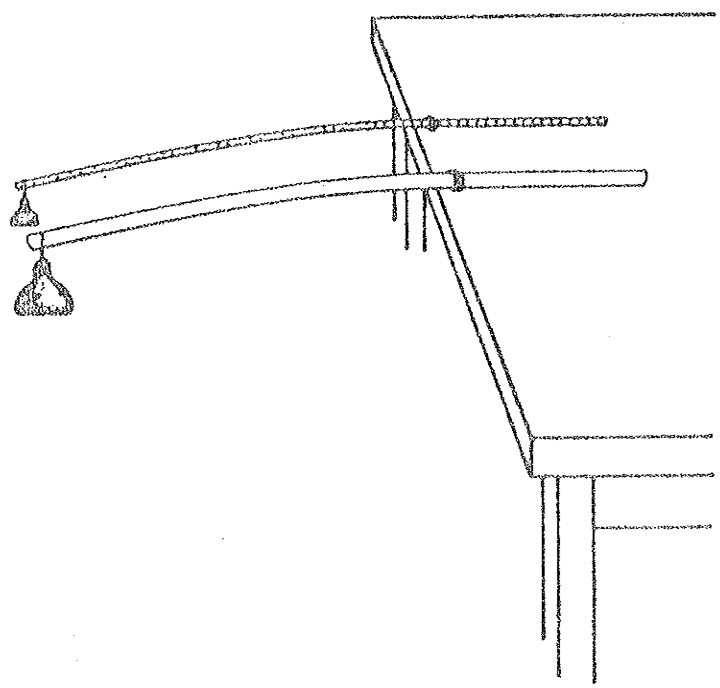
____

____

____

____

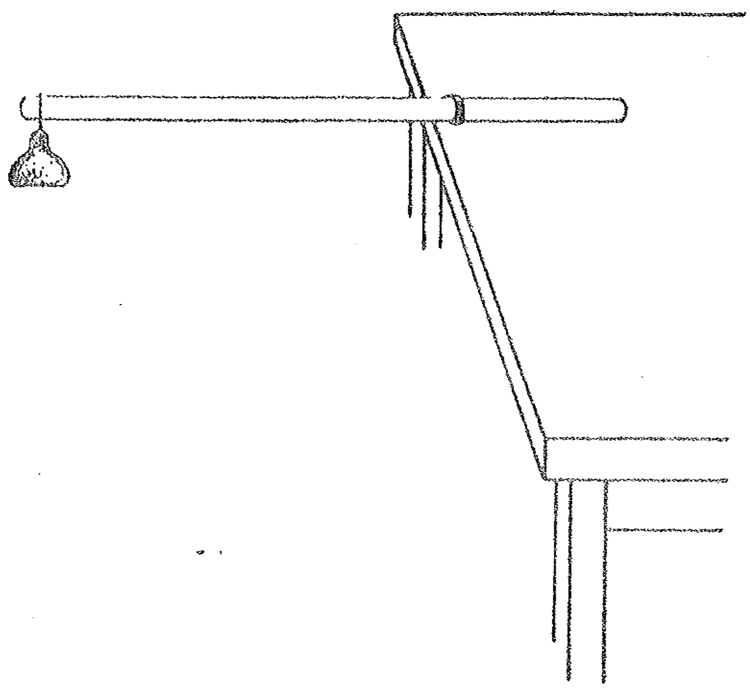
____



QUESTION 12 The rod shown below is not bending.

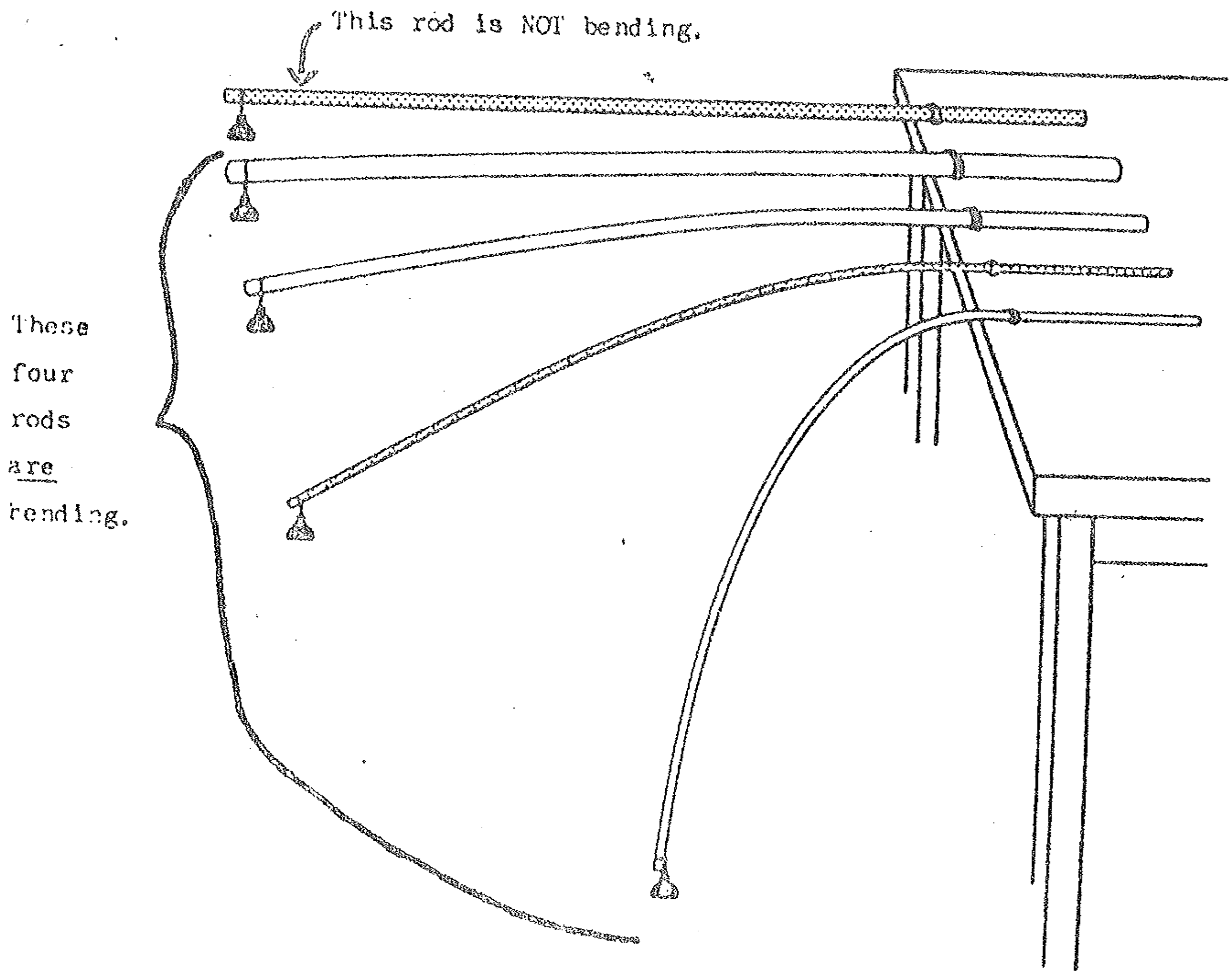
What could be done to make the rod bend?

Try to give several different suggestions.



QUESTION 13. What are two kinds of long rods which bend?

(Use as few words as possible in your answer.)



APPENDIX B

SCORING CRITERIA FOR RODS

General Instructions

1. The scoring is related to the variables named in the response.

2. Ignore irrelevant terms in the answer as long as the correct variable is also included in the answer.

   Irrelevant terms include: lightness, heaviness, size, weaker, bigger, smaller, softer.

3. For all questions width, diameter, thickness, radius, circumference are considered as synonymous terms.

		SCORE
#1	weight of weights (weights, size of weights) width length (where the weight is placed) material rod is made of (type of rod, whether the rod is metal or wood)	
	response includes all four variables listed above	5
	response includes all four variables, but breaks them into attributes, for example "Whether the rod is thin or thick" or response includes irrelevant terms such as gravity, flexibility, air pressure	4
	response includes three variables listed above	3
	response includes one or two variables listed above	2
	no response or one which includes only irrelevant terms	1

SCORE

#2 difference in material
difference in thickness

---

response includes the two differences given above	3
response includes only one of the differences	2
any other answer	1

===

#3 difference in material
difference in length

---

response includes both differences given above	3
response includes only one of the differences	2
any other answer	1

===

#4 difference in length
difference in weights used

---

response includes both differences given above	3
response includes only one of the differences	2
any other answer	1

===

#5 four X's are used -- the rods marked must have the same **width** and the same **length**
one X must be on a wooden rod
one X must be on a metal rod
two X's on the weights -- both small OR both large weights must be marked.

---

scoring is done by counting the number of variables correctly marked; width, length, material, weight. All four X's are correctly placed.	5
three variables are correctly marked	4
two variables are correctly marked	3
one variable is correctly marked	2
no response or the X's are placed ambiguously	1

===

		SCORE
#6	rods marked have the same width, and are made of the same material (both metal OR both wooden) two X's on the same sized weights (either both small OR both large) one long and one short rod MUST be used	
	count the number of variables correctly identified (width, length, material, weight) all four X's are correctly marked	5
	three variables are correctly marked	4
	two variables are correctly marked	3
	one variable is correctly marked	2
	no response or X's placed ambiguously	1
#7	rods marked have the same length and are both wooden OR both metal two X's on the same sized weights (either both small OR both large) rods must be of different thickness	
	count the number of variables correctly identified (width, length, material, weight) all four X's are correctly marked	5
	three variables are correctly marked	4
	two variables are correctly marked	3
	one variable is correctly marked	2
	no response or X's placed ambiguously	1
#8	a long rod bends more than a short rod	
	if answer includes an indication that length has an influence on bending	3
	if answer refers to one rod being different than another, or says one rod is heavier than the other	2
	no response or incorrect (e.g. weights are different)	1

SCORE

#9 a wooden rod bends more than a metal rod	
if answer includes an indication that the difference in material incluences bending	3
if answer refers to one rod being different than another, or says METAL bends more than WOOD	2
no response or incorrect (e.g. one rod is thicker)	1

#10 a thin rod bends more than a thick rod	
if answer includes an indication that the difference in width influences bending	3
if answer refers to one rod being different than another, or lighter or heavier	2
no response or incorrect (e.g. a heavier weight)	1

#11 the thicker wooden rod has a heavier weight on it compared to the thinner metal rod which has a lighter weight on it

Some allowances must be made here for the difficulty subjects have in wording their answers. The more sophisticated answer would include the concept of compensation (ie. for the thicker rod by the heavier weight), but subjects are unlikely to answer in this way.

response mentions differences in thickness, material, and weights used	5
response mentions differences in only two of the above variables	4
response refers to the variables in general terms and does not indicate that a relationship between thickness and heavier weight has been observed	3
response mentions differences in only one of the above variables	2
no response or incorrect response	1

		SCORE
#12	use a heavier weight use a thinner rod make the rod longer (pull the rod out from the table) loosen the clamp soak the wood in water use a different material (NOT METAL)	
	response includes four of the above	5
	response includes three of the above	4
	response includes two of the above	3
	response includes one of the above	2
	no response or incorrect	1
	Note: changing the rod to metal will not make it bend. Moving the weight UP, shortening the rod, or making it thicker will not increase bending. If response includes any one of these deduct 1 point from the scoring.	
#13	wooden rods and thin (ner) (est) rods	
	responses match the above	5
	responses accurately describes the rods which bend (e.g. the wooden rods and the thin metal rods)	3
	incomplete or inadequate description of the rods which bend (e.g. metal rods and wooden rods)	2
	no response or completely irrelevant (e.g. fishing rods)	1

Response Patterns for Identification of Substages on Rods

==

Formal Substages

IIIB	#1	Formal (4 or 5)
	#5, #6, #7	Formal (all 5)
	#11, #12, #13	Formal (all 4 or 5)
	No responses scored 1 or 2	
IIIA	#1	scored 3, 4, or 5
	#5, #6, #7	Formal (all 5)
	#11, #12, #13	at least two scored 4 or 5
	No responses scored 1	

Transitional

IIB-IIIA	Identify last. Inconsistent pattern which does not fit any other category

Concrete Substages

IIB	No responses scored 4 or 5 (Ignore one formal if in #5, #6, or #7 -- possible by chance.)
IIA	No responses scored 4 or 5 Seven or more responses scored 1

==

APPENDIX C

Form _____

Name____________________

Grade____________________

Date of Birth_____/______/_____
(day) (month) (year)

List your courses for this year.

Instructions: There are 15 questions. Read each question carefully and answer it the best you can. Do not hesitate to clearify or discuss your answer.

Time Limit: 40 minutes

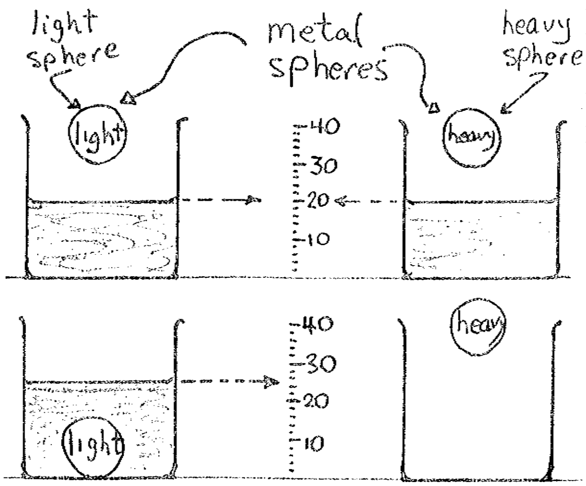
1. Two balls of clay are identical in size, shape, and weight. The clay balls are placed at opposite ends of a balance beam. The balance beam is balanced which shows that the two balls of clay weigh the same. One of the balls is flattened into a "pancake" shape. How do the weights of the two pieces of clay compare?

____

____

2. In the diagram to the right, are two solid metal spheres. These spheres are of the same size but of different weight. The two containers are the same and they have the same amount of water in each.

The light metal sphere is placed into one of the containers of water and the water rises as shown.



If the heavy metal sphere is placed into the other container, predict the level of the water. (If you wish to draw the predicted level in the above diagram, draw it carefully).

____

____

3. Two plastic cylindrical containers have the same height but the diameters are different (one is skinny and the other is fat). A given quantity of water rises 4 units in the wide container and 6 units when poured into the narrow container.

A given quantity of water rises 6 units in the wide container. If this water is now poured into the narrow container, to what level will it rise?

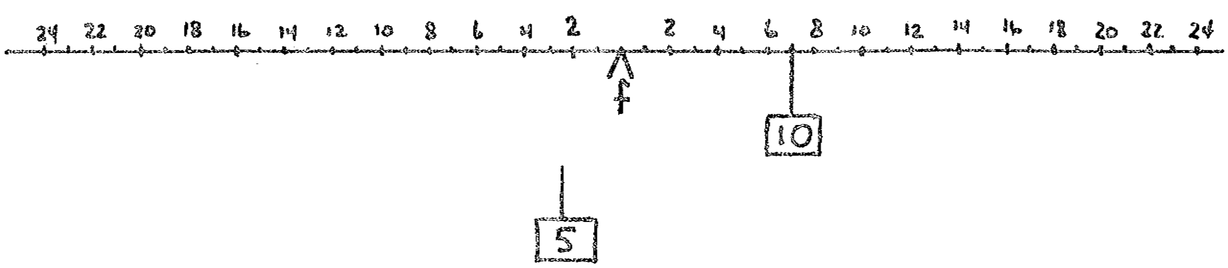
____

4. The same plastic containers from question #3 are used.

11 units of water are poured into the narrow container. If this water is now poured into the wide container, how high will the water rise?

____

5.

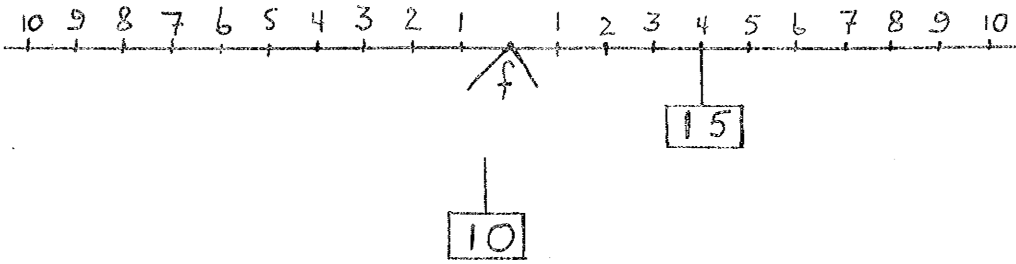


The above is a balance. The long arm is marked off in equal units from point " f ". Point " f " is the fulcrum. The balance arm is supported at the pivot or fulcrum " f ".

A 10-unit weight is hung 7-units of length from the fulcrum.

Where must a 5-unit weight be hung to balance the 10-unit weight? (Carefully draw the 5-unit weight in the correct position).

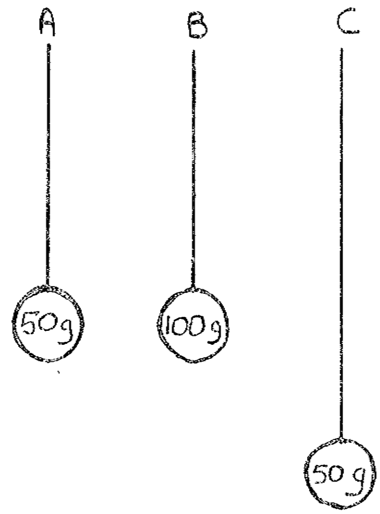
6.



On the above balance beam, a 15-unit weight is hung 4-units of length from the fulcrum.

Where must a 10-unit weight be hung to balance the 15-unit weight? (Draw the 10-unit weight in the correct position).

7. We have three pendulums as shown. Two have the same length but one is 50 g. while the other is 100 g. The third pendulum, which is 50 g., is longer.



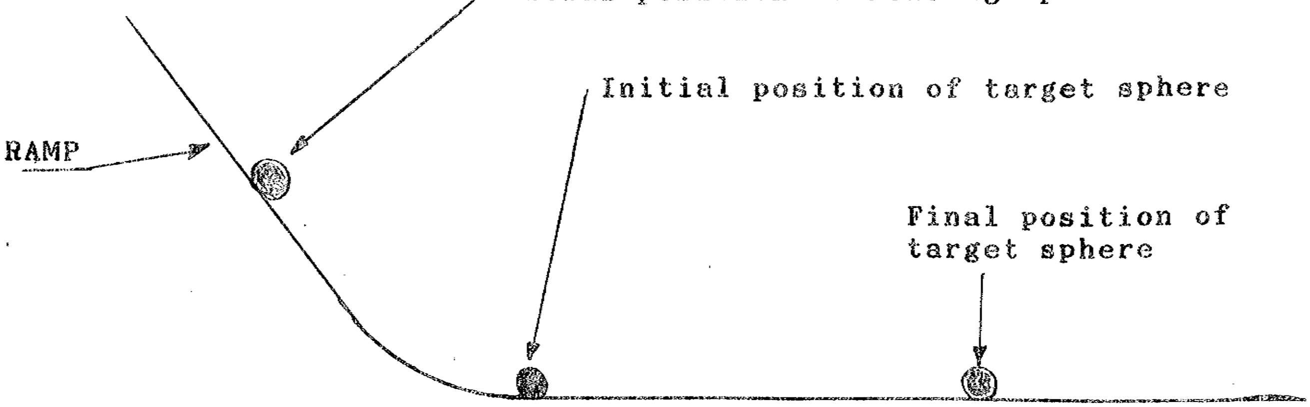
Select which pendulums should be used in an experiment to find out if the variable of length affects the period of the pendulum. The period is the time it takes the pendulum to swing back and forth.

____

8. Using the same three pendulums from question #7, select which pendulums should be used in an experiment to find out if the weight of the bobs affects the period of the pendulum.

____

9.



In the diagram above, we have a sphere on a ramp. The sphere is allowed to roll down and hit a target sphere. The target sphere then moves a distance as marked in the diagram.

Which type of sphere would you select (LIGHT, HEAVY, or the SAME) to release from a high position to find out if the variable of release position affects how far the target sphere will travel after it has been struck?

____

10. Two metal spheres (A and B) roll down the ramp from the same starting position and strike two different target spheres. The target hit by sphere A travels further than the target hit by sphere B.

Does this experiment prove that metal A can displace a target further than metal B?

____

Briefly explain. ______________________________

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____

____

____

____

11. You have a metal box with four colour-coded switches and a light. The switches are red (R), yellow (Y), green (G), and blue (B). By flipping a certain combination of the switches, the light will turn on.

List all the possible combinations of the four switches that you would have to try to discover which combination or combinations will turn the light on.

12. There are four stores: a barber shop (B), a discount store (D), a grocery store (G), and a coffee shop (C). These stores are going to be arranged side-by-side on the ground floor of a new shopping centre.

List all the possible ways in which the stores could be arranged side-by-side.

13. Three yellow wooden squares and three red wooden squares are placed into a sack.

What are the chances of drawing out a red square on the first draw?

____

14. Three red squares, four yellow squares, and five blue squares are placed into a sack. Four red diamond-shaped pieces, two yellow diamond-shaped pieces, and three blue diamond-shaped pieces are also placed into the sack.

What are the chances of drawing out a red piece on the first draw?

____

15. Using the objects from question 14, what are the chances of drawing a red <u>or</u> blue diamond-shaped piece on the first draw?

____