A COMPARISON OF THE EFFECTS OF AN INVESTIGATIVE-BASED AND A TRADITIONAL LABORATORY PROGRAM ON STUDENTS' UNDERSTANDING OF THE PROCESS OF SCIENCE

by

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ABSTRACT

PURPOSE OF THE STUDY

The purpose of this study was to compare the effectiveness of two approaches to laboratory work in changing student understanding of the processes of science. An author-designed investigative-based laboratory approach was compared to a traditional laboratory method as outlined in conventional laboratory manual texts.

This investigation was undertaken to provide empirical data concerning the effectiveness of an approach used in teaching laboratory work during the past five years. The study was carried out in a senior high school in the B.C. Lower Mainland.

PROCEDURE

The sample consisted of 41 students enrolled in two blocks of the author's Biology 12 classes. One block was the control group, assigned to use the traditional laboratory approach and the other was the experimental group assigned to be exposed to the investigative-based laboratory approach. The experimental phase of this study took place over the first three months of the calender year 1983.

The students in both groups were pretested using the Welch Science Process Inventory (SPI) instrument during the first week of the study. Following exposure to treatment, the students were posttested using the same SPI instrument.

Data obtained from the instrument was analyzed using analysis of covariance with the posttest as the criterion variable. The F values obtained from this analysis were compared with the critical F values that were required for significance at the 0.05 level.

FINDINGS

From the analysis of data, it was found from the adjusted posttest means, that there was a significant difference between the laboratory groups with respect to an understanding of the process of science. Specifically, the investigative-based laboratory group was found to have a statistically significantly greater understanding of the process of science than the traditional laboratory group.

CONCLUSIONS

Although it was concluded that the experimental group possessed a significantly greater understanding of the process of science, caution was suggested in attempting to generalize the application of the results of this study outside the limiting confines of the study.

Recommendations for further research were proposed.

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CHAPTER I

INTRODUCTION

1.0 THE PROBLEM

The purpose of this study was to determine the relative effectiveness of two methods of teaching a senior high school laboratory biology program. Effectiveness was based on achievement of students' understandings of the process of science occurring during the course.

The treatment examined in this study was an 'investigative-based' format wherein students were provided with an opportunity to develop their own hypothesis to a research problem, design and carry out an experiment, and discuss the outcomes of the experiment after analysis of data. The treatment was compared with a "traditional" laboratory format in which the students performed assigned exercises using a conventional laboratory manual. Comparison between the treatment and control groups was undertaken using the S.P.I. (Science Process Inventory), an instrument designed by Wayne Welch and Milton O. Pella (1968) from the University of Wisconsin. This instrument purports to measure student understanding of the process of science which Welch and Pella (1968) derived from books by Beveridge, Conant, Kemeny, Lachman, Nash and Wilson (Welch, 1968, p.64). Elements of this derived process were presented to fourteen research scientists for validity judgment. The list was then revised on the basis of suggestions from the scientists.

Specifically, then, the problem may be stated as follows: is there any significant difference in student understanding of the process of science in biology twelve classes that can be attributed to the exposure of students to investigative-based laboratory procedures?

1.1 Importance of the Problem

The laboratory has long been a distinctive feature of science education. In 1970, the Commission of Professional Standards and Practices of the National Science Teacher's Association thought that the case for school science laboratories was too obvious to argue (Ramsey & Howe, 1969):

> That the experience possible for students in the laboratory situation should be an integral part of any science course has come to have a wide acceptance in science teaching. What the best kinds of experiences are, however, and how these may be blended with more conventional classwork, has not been objectively evaluated to the extent that clear direction based on research is available for teachers (p.75).

Less than ten years later, the case for the laboratory in science instruction was not as self-evident as it once seemed Science laboratory requirements are currently of special concern because there is now a trend to retreat from student-centered science activities, resulting in less time and experience in the science laboratory (Gardner, 1979).

Science educators continue to be disheartened by students' view of science as an absolute endeavor - as if it

yields the whole truth and nothing but. Yet a large part of the reason for such a misconception may be our failure to help students understand the process of science.

Merely to provide students with definitions of terms like "hypothesis" and "theory" will not help them understand the subtle and complex aspects of testing an hypothesis. Too few laboratory courses offer any sort of confrontation with the unknown. The student is expected to produce a verification of something he/she already knows. Instead of recording what actually occurs, he/she is trained to ask what a result is supposed to be. A student should be compelled to think through the bearing of his results on the possible conclusions. Such concerns may have prompted the following recommendation from the British Columbia Assessment contract team:

> That teachers of science at both the junior and senior secondary levels make a conscious effort to promote the development of skills such as designing experiments, and interpreting data, ... and an appreciation of the nature and methods of science (Hobbs, 1978, p.47).

Dissatisfaction with existing laboratory instruction has been expressed even by some who consider that time and money required for instructional laboratory work must be spent (Caplan & Fowler, 1968). "Cookbook" laboratory experiences, in which the student goes through the motions of experimental work without a concern for an understanding of the underlying principles, would not seem capable of providing meaningful

experiences for concept learning (Ausubel, 1964). Activities which simply confirm what the textbook or teacher has already said also seem to be unprofitable (Anderson & Weigard, 1967; Hurd, 1964). Laboratory activities of these sorts involve the student primarily in manipulation of apparatus and data and require only minimal consideration by the student of the rationale for these operations and certainly do not convey an impression of scientific research. Stake and Easley (1978) state the case rather poignantly by relating an anecdote from an actual classroom occurrence: "Seeing nothing but inky black in the beaker they asked, 'What's supposed to happen?' The girl at the next table said, 'Its supposed to go up and down,' so they all wrote, 'It went up and down,' in their lab reports" (p. 19:6).

Having become disillusioned with the traditional method of laboratory instruction as exemplified in laboratory texts issued to science students, the author has experimented with an "investigative-based" laboratory format in his classroom. Until the advent of this study, the opportunity has not arisen to empirically test the effectiveness of this alternate laboratory approach in terms of student understanding of the process of science.

At this juncture the 'process of science' will be expressed as this thesis demands that the process of science be measured to determine the effectiveness of experimental treatment.

Welch and Pella (1968) do not stipulate in detail what students must demonstrate to indicate knowledge of the process of science. The author considers that for knowledge of the process of science students must demonstrate the ability to:

1. make careful observations that lead to interpretations, explanations and predictions,
2. advance and formulate an hypothesis that is based on prior observations or research and attempts to predict some future event,
3. devise experiments that test hypotheses and that are adequately controlled,
4. report results in the form of organized quantitative data tables and/or qualitative observations,
5. analyse data either by graph or statistics,
6. draw inferences and discuss results from experimental data and analyses,
7. suggest further research or the creation of new hypotheses due to the insufficiency of data or sources of error.

1.2 Hypothesis

Because previous studies, in general together, do not provide definitive results regarding the differential effect of an investigative-based laboratory program to a traditional laboratory program the research hypothesis is stated in null form.

So comparing the traditional laboratory group and the investigative-based laboratory group:

There is no significant increase in student understanding of the process of science that can be attributed to the exposure of students to investigative-based laboratory procedures.

CHAPTER 2

REVIEW OF THE LITERATURE

2.0 Views on the Effectiveness of Traditional Laboratory Instruction

The role of science laboratory work has been a topic of much discussion and investigation since the latter part of the nineteenth century when individual laboratory work by the student became common.

The following survey will not attempt to provide a review of investigations that concern themselves with arguments for the inclusion of or elimination of laboratory work in science curricula. Instead what will be under review is the use of the laboratory in science education and the perceived effectiveness of various forms of laboratory instruction.

The first part of this survey will look at the variety of studies that have examined the so-called 'traditional' laboratory method as outlined in many science laboratory manuals and its effectiveness in providing the student with what the authors of the manuals perceive to be valuable laboratory experience. Following this will be an examination of studies that make comparisons between the traditional laboratory method and alternative forms of laboratory instruction.

The definition of 'traditional' laboratory instruction as used in this review and as used by researchers is as follows. The general feature of these traditional laboratory

experiments is that everything about the laboratory experiment is explained to the students before they proceed. They are given the theory underlying the experiment, the exact experimental procedure to be used and a detailed description of how the data are to be analyzed. An illustration of what the data should look like is often given. The main purpose of such an approach is to allow the students to verify that the experiment as presented does work. Education researchers often use such terms as "verification" laboratories or "conventional" laboratories when referring to traditional laboratory instruction.

Science educators have decried such emphasis on verification in the science laboratory. Rasmussen (1970), in an article in Bioscience criticized both college science teachers and teacher educators. He claimed that high school laboratory work is no better than it is because formal science school training is "... more often ... about science rather than in science..." (p.292), with very limited opportunities to really investigate ideas. Laboratory activities, according to Rasmussen, are largely illustrative, non-investigative, and not particularly exciting. Laboratory achievement is usually evaluated separately from the science content of the course. "Operationally, the student learns that the function of the laboratory should be certification of statements made by the teacher or by the textbook ..." (p.292). Rasmussen said that, in good science teaching, "the textbook supports the laboratory but in most present cases these roles are

reversed." He pointed out that the Biological Sciences Curriculum Study (B.S.C.S.) materials are not as successful as one might wish "... due in large part to teacher reluctance to change their mode of operation" (p.293).

In reviewing prevailing laboratory practices, Lee Nedelsky (1965) compared the conventional or traditional laboratory instruction as a kitchen where students follow a recipe; that is, the student is told precisely how to set up the apparatus, what readings to take, and what equations to apply to the data. Nedelsky felt that this represented a "sterile orderliness" where the instructor carefully watched the students to be sure they wasted no time nor gathered any unnecessary data. Conclusions for the experiment were written outside the laboratory period, away from the experimental set-up and phenomena observed.

By comparison Nedelsky describes the investigative laboratory as; leaving the student to his own devices to find out all he or she could about a phenomenon. In this less structured laboratory the student has more time to think and to exercise ingenuity, and is more motivated. This type of laboratory, however, costs more and is characterised by few clearly defined behavioural objectives. The instructor needs to be an expert in guiding the student toward the major objectives of the course. Nedelsky found that the higher cost of equipment and the higher cost of teaching personnel was the main reason for the comparative rarity of the unstructured laboratory. However, Nedelsky found that most teachers

familiar with the unstructured laboratory expressed that its advantages outweighed its disadvantages.

A recent article criticising the college science laboratory was published in The Chronicle of Higher Education (1980). Pickering identified two misconceptions about the use of the laboratory in college science. Misconception one was that laboratories should somehow "illustrate" lecture courses. This function is not possible in a simple, one-afternoon exercise, Pickering said, because "most scientifie theory is based on a large number of very sophisticated supporting experiments" (p. 80).

Misconception two is that laboratories exist to teach "finger skills". Pickering claimed that very few of the techniques students learn in their science laboratories will be directly usable in the careers they plan. Many of the skills students learn in the laboratories are obsolete. Few biologists do dissections and few chemists do titrations. Such skills are worth teaching only as tools to be mastered for basic scientific inquiry and as ends in themselves (p. 80).

Pickering distinguished between lecture and laboratory courses by contending that a good laboratory course should be an exercise in doing science while a good lecture course has the objective of teaching about science. He viewed good laboratory teaching as being essentially Socratic, involving the posing of carefully defined questions to be asked of nature. The intellectual processes students should use are

those of scientific research so they come to see how difficult it is to obtain meaningful data. Such a laboratory course could easily be defended as fitting into a liberal education, according to Pickering. Unfortunately most laboratory courses do not fit into this model.

Pickering sees other difficulties as well.

> Too few lab. courses offer any sort of confrontation with the unknown... The element of creative surprise is almost completely missing. The results of an experiment should be ambiguous enough so that a student is compelled to think through the bearing of his results on the possible conclusion (p.80).

Marshall D. Herron (1971) examined 41 Chem. Study laboratory exercises for their content and stated purposes. He grouped these 41 exercises into three major categories: (1) exercises through which the student was expected to "discover" certain specified principles or regularities in chemical phenomena; (2) exercises involving inference or problem-solving behaviour and having no pre-determined, unique solution; and (3) exercises said to "illustrate" or to "give the student the chance to observe, together with exercises intended to give the student practice in developing laboratory techniques" (p.196).

According to Herron, 24 of the 41 laboratory exercises (more than 50%) were of the illustrative - demonstrative variety. Six were of the open-ended problem-solving type, with four of the six occurring very late in the course. He concluded, "In the light of this analysis, it would appear that the 'discovery' rubric is misleading as applied to the laboratory portion of these materials" (p.198).

Herron, quoting from BSCS materials, identifies the goal of the text of the course as that of helping the student "obtain some understanding of the nature of science as a vigorous interaction of facts and ideas" (p.201). However, Herron maintains that laboratory work in the BSCS course lacks emphasis on the origin of scientific problems.

Lunetta and Tamir (1978) using an instrument called the Laboratory Structure and Task Analysis Inventory (LAI), examined laboratory activities from Project Physics and the Physical Science Study Committee (PSSC) materials, to check on Herron's contention that the materials did not always lend themselves to the goals the project developers advocated. They decided that the laboratory guides for the two courses were lacking in instructions and questions that might stimulate such inquiry activities as the formulation of hypotheses, the definition of problems, and the design of experiments.

They identified what they considered to be six important deficiencies where student involvement, or its lack were

concerned: (1) no student involvement in identifying and formulating problems or in formulating hypotheses, (2) relatively few opportunities to design observation and measurement procedures, (3) even fewer opportunities to design experiments and to work according to their own design, (4) lack of encouragement to discuss limitations and assumptions underlying the experiments, (5) lack of encouragement to share student efforts in laboratory activities when this is appropriate, and (6) lack of explicit provisions for post-laboratory discussions to facilitate consolidation of findings and understanding (p.10).

As indicated, scientists and science educators decry the use of cookbook-type, and verification laboratories and advocate laboratory activities that are designed to convey to pupils the nature of science, its methods, and the spirit of inquiry.

2.1 Alternative Forms of Laboratory Instruction as Compared to More Traditional Forms

In reviewing the empirical studies, it becomes apparent that many researchers have examined forms of laboratory instruction that differ from traditional methods of instruction. Many of these studies have arisen perhaps from frustration with traditional laboratory practices. Indeed, such frustration may have spawned new and innovative methods that the researchers wish to test empirically as to their

effectiveness in the cognitive, affective and psychomotor domains.

The studies presented here will be grouped according to the dependent variable(s) they measure. The following variables will be considered: academic achievement, student interest, cognitive ability, psychomotor skills, and student understanding of the nature and process of science.

2.1.1. Academic Achievement

Using a multivariate analysis of variance and trend analysis of adjusted means over ten quizzes, Egelston (1973) found that by using an 'inductive' method of laboratory instruction in comparison to the traditional method, superiority of achievement was obtained by the group involved with the inductive procedures.

Interestingly, over the span of the ten exercises, each followed by a quizz, the achievement of the experimental group using the inductive method, started out at a lower level but eventually surpassed that of the control group which used the traditional method. Egelston attributes this early poor performance to the novelty of the inductive method which hindered achievement initially.

Egelston's inductive method which she defines as an open-ended approach where the student develops and researches their own problem, is similar to that of James Bock's (1979) alternate laboratory method which he calls an "inquiry-investigative" program. Unlike Egelston, however, Bock found

no significant differences between the academic achievement of those students who undertook the traditional laboratory exercises as depicted in standard Biology texts and those who pursued the inquiry-investigative program.

Tanner (1969) also found no significant differences in measure of comprehension, lateral transfer and retention when comparisons were made of students engaged in an inductive or discovery method vs the traditional method which Tanner calls the "didactic" method.

Indeed, of the various studies that measured academic achievement after an exposure to an alternate laboratory method few studies indicated a strong trend toward increased retention and comprehension of knowledge.

2.1.2 Student Interest

Using an inquiry type of laboratory approach, Moll and Allen (1982) were interested in whether students would exhibit a better attitude towards their laboratory work. Using an analysis of variance of their data some significant differences were obtained in the positive direction. At least within the parameters of their study, Moll and Allen did find that students were more receptive to laboratory work which allows for more independent choice of problem, planning and conducting of experiment.

In contrast, Robert Allison's (1972) study did not show the marked improvement in students' positive attitude

towards laboratory work that Moll and Allen showed. Allison's study compared inquiry laboratory experience to conventional laboratory in a college chemistry course. He compared how the two methods effected changes in student attitudes towards science, critical thinking, laboratory skills and self-evaluation. He concludes that the inquiry approach is neither more nor less effective that in the conventional approach in improving attitudes toward science, critical thinking or laboratory skills.

A comparison of an auto-tutorial laboratory and students in a less independent laboratory in physical science was conducted by Harold Park and John Butzow (1975). Using examinations on independence of work-study habits and attitude toward the course, they found that independent study students achieved higher scores on independence of study, but found no significant difference in attitudes.

Studies on student attitude either indicate that attitude improves when students work with an inquiry laboratory format, or that attitude remains the same as that found in students working with a conventional format.

2.1.3 Critical Thinking and Reasoning Ability

A number of studies measured the cognitive abilities of students engaged in alternative laboratory activities. Particular among the cognitive measures were those of critical thinking and reasoning.

Unlike the categories of academic achievement and student interest, critical thinking and reasoning is, by indication of most studies, enhanced significantly by exposure of students to laboratory methods which differ from the traditional.

Pavelich and Abraham (1979) developed what they called a "guided-inquiry" format for freshman chemistry students. Similar to other methods previously discussed, the guided-inquiry format allows the student considerable freedom to investigate a problem of their choice, design an experiment and analyse the results. Using a Piagetian-type paper and pencil test developed by the Cognitive Analysis Project, Pavelich and Abraham were able to show that an exposure to an inquiry laboratory format allows the student to

> ... investigate chemistry at a level consistent with his/her level of intellectual development ... the more concrete student experiences chemistry solely at the concrete level; whereas the formal student has experiences which tax his/her abstract thinking abilities (p.103).

Rickert (1962) studied the development of the critical thinking ability of college freshmen and its relationship to the organisation of a physical science laboratory course. An experimental course, in which the students were given opportunities to analyse problems, collect and organise data, test hypotheses, and to draw conclusions from data, was introduced. This experimental group of students was compared with a control group which followed a traditional survey laboratory course format. A significant difference between

the groups' critical thinking ability, and the ACE Test of Critical Thinking, was found which favoured the experimental group. Rickert concluded that a physical science laboratory course can improve students' ability to think critically if the laboratory course provides them with opportunities to use critical thinking and problem solving methods.

Tamir and Glassman (1971) compared BSCS and non-BSCS students' performance on an inquiry-oriented performance laboratory test. They found that the BSCS students did significantly better, due mainly to superiority in reasoning and self reliance. The researchers concluded that BSCS students had a distinct advantage in solving open-ended problems using experimental procedures in the laboratory. Similar results were obtained two years earlier by Edgar (1969).

Campbell (1978) evaluated a Piagetian-based model for developing materials and instructing the laboratory portion of a beginning college physics course. Students (N=55) in two different states were involved. Although there were no significant improvements in learning physics content, there was a significant difference in the use of more formalistic reasoning abilities for the students. Campbell's "learning cycle" model involved three separate but interrelated activities: exploration, concept invention, and concept application with 10 "laboratory intervention periods".
The above studies do provide some support for the idea that

laboratory activities that differ from the traditional verification-type can be used to help students learn to think critically.

2.1.4 Understanding the Nature and Processes of Science

The majority of researchers who measured students' understanding of science and science processes used a discovery or inquiry laboratory approach as their experimental method. Researchers allowed students a fair degree of freedom in selecting a problem and in analysing their own research. In this way they believed that a student would gain a greater understanding of the science process as the students would be directly exposed to the frustrations and difficulties in developing his/her own experimental design.

Raghubir (1979) compared a "laboratory- investigative" approach to the traditional laboratory approach and found that the investigative approach provided students with the opportunity to develop the strategies and attitudes associated with scientific investigation. Raghubir concludes his study by stating emphatically that, "... conventionally taught science courses are, typically, instructor-centred, in the sense that they provide the student with very little opportunity for self-initiated and self-directed study" (p. 16).

Similarly, Boohar (1975) developed a laboratory program that allowed for student-directed activities. Boohar found that initially students were frustrated by the lack of

direction but that ultimately, having completed an inquiry-based activity, the students felt that they had an understanding of the processes of science. Boohar, unfortunately did not conduct an empirical study using any instrument described in the related literature. Instead, his conclusions are based on subjective findings and random verbalizations by students.

Stekel's (1970) work supports the findings of Raghubir (1979) and Boohar (1975). Stekel compared the effectiveness of two different laboratory programs in college physical science: a traditional program with a laboratory manual and a more flexible, open-ended program. In the open-ended approach students selected their own problems related to a general topic, designed their own procedures, and completed an experiment. Stekel found a significant difference ($p < .01$), favouring the open-ended group, on the understanding of actions and operations of scientists.

Serlin (1977) also talked about a discovery laboratory in college physics. In his terms, such a laboratory would emphasize hypothesizing, experimenting, and inferring rather than fact-gathering and principle verification. Serlin established three criteria for the discovery laboratory: (a) activities be matched to the developmental stage of the learner, (b) guidance be provided by the use of advance organisers, and (c) further guidance be provided by describing the nature of science as a discovery activity for the students. Two experimental groups and one control group were

involved. Students were provided practice in the process of science problem solving, and in setting up and providing standards of evaluation. With verbal SAT scores used as a covariate, Serlin found that the discovery laboratory was effective in increasing students' science process skills ($p = 0.05$).

A few studies indicated no significant difference between traditional and alternative laboratory forms on measures of student understanding of the nature and process of science. For example, Cannon (1975) in a study that is very similar to Stekel's (1970), used the Welch Process of Science Inventory to measure student understanding of the process of science. Unlike Stekel (who used the same instrument), Cannon found there was no difference between laboratory groups with respect to understanding the process of science.

In summary there are contrasting opinions as to whether student understanding of the nature and process of science can be enhanced by allowing that student a degree of freedom in directing their own work. Yet, of the nine studies found in the recent literature, seven indicated that the alternative laboratory method was superior when contrasted with the traditional method.

2.2 Measurement of Laboratory Research Study Outcomes

No matter what the desired outcomes of laboratory instruction are, increased achievement, more favourable attitude toward science, increase in critical thinking skills

or increase in the understanding of the nature and process of science, measures must be taken to verify whether the outcomes have been achieved.

Outcomes of laboratory instruction in science have been measured with paper and pencil tests, with laboratory skill examinations, with the use of checklists and rating scales, with classroom observational instruments focussing on verbal or non-verbal interaction, or some combination of these. If the goals are to be achieved the researcher needs to make certain that the measure used is sufficiently sensitive to detect any changes that occur between the beginning and end of the treatment.

In many studies, investigator-designed tests or other instruments are used. Frequently information about reliability and validity, as well as the methods used to obtain these measures, is sketchy. Even more frequently an explanation of the theoretical rationale underlying the instrument is not presented. These types of information are seldom found in the abstract of a doctoral dissertation; and frequently are not provided in journal articles based on the dissertation research.

Welch (1971) noted that 30 research reports concerning instructional procedures (including laboratory instruction) made no connection between the instructional procedure and the test chosen to measure the effect. This is important when considering Tamir's (1972) statement that the laboratory in

science education is not only a unique mode of instruction but also a unique mode of assessment. Therefore it is desirable to develop sensitive evaluation instruments that will provide information about what the student does in the laboratory and about his/her growth and ability to develop inquiry and other related laboratory skills.

The effects of science laboratory experiences on achievement have normally been measured by the use of an investigator-designed test or by the use of a well-known test such as the Nelson Biology test, to cite only one example. Science teaching traditionally has emphasized the learning of scientific 'information', concepts, principles, and facts, with little emphasis on the development of problem-solving skills, and this orientation is reflected in many of the test instruments that were used. Tests often emphasized student ability to identify or recall facts at relatively low taxonomic levels but seldom have assessed development of higher level skills that involve application, analysis, synthesis and evaluation (Bloom, 1956).

2.2.1 Watson-Glaser Critical Thinking Appraisal (WGTCA)

According to information in the Mental Measurements Yearbook (1959), the sub-tests of this instrument are designed to evaluate the ability to interpret data, to draw correct inferences, to draw appropriate deductions, to recognise assumptions, and to evaluate arguments. Such mental

operations can be accomplished in many context areas that are not unique to science. Indeed, the WGCTA (Watson & Glaser, 1961) has little to do with science teaching in general or with laboratory work in particular. The instrument was constructed and validated for use in the social sciences and is concerned with social and historical phenomena. While one can argue that transfer of learning is a desirable outcome of instruction, the difference between science laboratory experience and historical and social events is very large.

Seven investigators used the WGCTA test in their research related to the science laboratory. Three (Hoff, 1970; Rogers, 1972; Sorensen, 1966) reported that students involved in their treatment groups (an alternative laboratory approach) made significant gains in their critical thinking scores over and above those involved in the control groups who pursued a traditional laboratory approach. Four (Allison, 1973; Dawson, 1975; Mitchell, 1978; Sherman, 1969) reported no significant difference between the alternative laboratory groups and the traditional group on measure of reasoning ability.

2.2.2 Test on Understanding Science

A second, frequently used, instrument is the Test on Understanding Science (TOUS), developed by Cooley and Klopfer (1963). Form W of TOUS is a four-alternative sixty item multiple choice test. The items are categorized into three subscales:

Subscale I. Understanding about the scientific enterprise (18 items)

Subscale II. The scientist (18 items)

Subscale III. Methods and aims of science (24 items)

The TOUS was developed as a research tool. Its content validation rests upon an analysis of scientists at work and upon a diverse literature including the history and philosophy of science.

Criticisms of TOUS have emerged. Welch (1969) has suggested that form W might be improved through revision and stronger validity evidence. Wheeler (1968) has been more specific. He states that too many items embrace a negative viewpoint of science. Aikenhead (1973) suggests that some items evoke a response of attitude; i.e., students perceive the test as concerning their appreciation or lack of appreciation for science and scientists. Some items, Aikenhead reports, are answered according to a scientists' 'good guy' image.

In the four dissertation studies in which use of TOUS was reported, three researchers (Baxter, 1969; Sherman, 1969; Smith, 1971) reported no significant difference between groups involved in alternative laboratory work and those in the traditional groups. The fourth reported that the students in the experimental group (a revised general education laboratory course in physical science) exhibited significant gains in TOUS scores, even when differences in ability, scholastic achievement, background knowledge, or skill were covaried out

of the analysis, and concluded that the laboratory exercises had made an important contribution to student knowledge as tested by the TOUS instrument (Whitten, 1971).

2.2.3 Welch Science Process Inventory (SPI)

Wayne Welch and Milton O. Pella (1968) developed a valid, reliable and useable instrument to inventory the knowledge of the process of science. This instrument consists of 135 items pertaining to assumptions, activities, products and ethics of science. Validity was established by determining the instrument discriminating power between students, science teachers, and scientists. Reliability was measured by Kuder-Richardson formula 20. The authors concluded that the test measures the understanding of the process of science by high school students, their teachers, as well as professional scientists.

Douglas Magnus (1973) and Edward Lucy (1972) conducted experiments comparing the self-directed laboratory studies to the conventional laboratory. In both cases the SPI instrument was used to measure the understanding of the process of science. Lucy found a significant improvement in the independent laboratory students' understanding of the process of science. The Magnus study revealed no difference between the experimental and control groups in the understanding of the process of science.

Judith Damewood (1971) evaluated student competence in the process of science in a physical science course for

prospective elementary teachers. It was found that students who were free to choose their own laboratory exercise performed at a higher level on the SPI than the student using the prescribed, content-based laboratory exercises.

In a similar study, but with students of physics, Spears and Zollman (1977) focussed on the use of laboratories intended to provide students with experiences that would aid in understanding the process of science as well as the content of science. Students were placed in either a structured, traditional laboratory situation or in an unstructured, open-ended one. The SPI instrument was given both as a pre-test during the first week of the semester, and as a post-test, during the last week. Pre-test scores, laboratory grade, and lecture instructor were used as covariates in the data analysis. When scores were analysed, no differences were found for the components of the SPI: assumptions, nature of outcome, ethics and goals. Significant differences did occur in the fourth component, activities, with students in the structured laboratory scoring higher in this area. Spears and Zollman conclude by stating that, "Unstructured laboratories can provide useful experience for students having prior experience in scientific experimentation ... and training in the scientific process..." (p.37).

Finally, of the four dissertation studies in which use of the SPI instrument was reported, two (Cannon, 1975; Dawson, 1975) reported findings of no significant difference and two (Smith, 1972; Stekel, 1970) reported statistically significant

increases in the understanding of the process of science by the alternate laboratory group over the traditional laboratory group.

2.3 Summary

The review of literature indicates many studies dealing with comparisons between the traditional laboratory method and some alternative laboratory method. In the main, the traditional method may be described as involving students in verification laboratories that are quite structured, allowing students little opportunity to explore for themselves the complexities of the scientific process. The alternative laboratory methods examined in this review come under a variety of names given them by their researchers - 'inquiry-based' exercises, 'open-ended' laboratories, 'investigative' procedures, 'inductive' exercises, and the 'discovery' approach. All of these methods tend to emphasize student involvement in problem-creation, hypothesizing, experimental design and inferring rather than fact-gathering and principle verification.

As a means of encapsulating the variety of studies examined in this review, four tables have been compiled which reveal the essential characteristics of the studies. Each table is categorized according to the dependent variable measured by researchers.

These tables indicate that in all of the studies surveyed (except that done by Spears and Zollman (1977)) the

alternative laboratory method was found to be either superior to or the same as the traditional method of laboratory procedure on the various measures examined by the researchers. However the number of studies that showed no significant difference between the methods coupled with the researcher use of inappropriate instruments to measure variables, indicate the need for further research.

TABLE 1 - SUMMARY OF STUDIES COMPARING THE TRADITIONAL LABORATORY METHOD TO AN ALTERNATE LABORATORY METHOD ON MEASURES OF ACADEMIC ACHIEVEMENT

Researcher	Alternate Laboratory Type	Instrument Used	Results		
			No Significant Difference	Significant Gain in Scores on Alternate Lab. Type	Significant Gain in Scores on Traditional Lab. Type
Egelston	Inductive	Researcher-Constructed Tests		x	
Bock	Inquiry-Investigative	Knowledge and Application Subtests from BSCS	x		
Tanner	Inductive	Researcher-Constructed Test	x		
Pare &	Independent study	Nelson Biology Test		x	

TABLE 2 - SUMMARY OF STUDIES COMPARING THE TRADITIONAL LABORATORY METHOD TO AN ALTERNATE LABORATORY METHOD ON MEASURES OF ENHANCED STUDENT INTEREST IN LABORATORY COURSE OF STUDY

Researcher	Alternate Laboratory Type	Instrument Used	Results		
			No Significant Difference	Significant Gain in Scores on Alternate Lab. Type	Significant Gain in Scores on Traditional Lab. Type
Moll and Allen	Inquiry	Researcher Constructed Test		x	
Allison	Inquiry	Researcher Designed Questionnaire	x		
Pare and Butzow	Independent Study	Student Verbalizations	x		

TABLE 3 - SUMMARY OF STUDIES COMPARING THE TRADITIONAL LABORATORY METHOD TO AN ALTERNATE LABORATORY METHOD ON MEASURES OF CRITICAL THINKING AND REASONING ABILITIES

Researcher	Alternate Laboratory Type	Instrument Used	Results		
			No Significant Difference	Significant Gain in Scores on Alternate Lab. Type	Significant Gain in Scores on Traditional Lab. Type
Allison	Inquiry	WGCTA	x		
Pavelich and Abraham	G Inquiry	Piagetian-Type Paper and Pencil Test		x	
Rickert	Inquiry	ACE Test of Critical Thinking		x	
Tamir and Glassman	BSCS vs non-BSCS	BSCS Inquiry Test		x	
Campbell	'Learning-Cycle'Model	Researcher-Constructed Test	x		
Hoff	Inquiry	WGCTA		x	
Rogers	Discovery	WGCTA		x	
Sorensen	Open-ended	WGCTA		x	
Dawson	Discovery	WGCTA	x		
Mitchell	Discovery	WGCTA	x		
Sherman	Inquiry	WGCTA	x		

TABLE 4 - SUMMARY OF STUDIES COMPARING THE TRADITIONAL LABORATORY METHOD TO AN ALTERNATE LABORATORY METHOD ON MEASURE OF STUDENT UNDERSTANDING OF THE NATURE AND PROCESS OF SCIENCE

Researcher	Alternate Laboratory Type	Instrument Used	Results		
			No Significant Difference	Significant Gain in Scores on Alternate Lab. Type	Significant Gain in Scores on Traditional Lab. Type
Raghubir	Investigative	Subjective Student Responses		x	
Boohar	Student-Directed	Subjective Student Responses		x	
Stekel	Open-ended	SPI		x	
Serlin	Discovery	Subjective Student Responses		x	
Cannon	Discovery	SPI	x		
Dawson	Discovery	Subjective Student Responses	x		
Baxter	Investigative	TOUS	x		
Sherman	Student-Directed	TOUS	x		
Smith	Investigative	TOUS	x		

TABLE 4 - SUMMARY OF STUDIES COMPARING THE TRADITIONAL LABORATORY METHOD TO AN ALTERNATE LABORATORY METHOD ON MEASURE OF STUDENT UNDERSTANDING OF THE NATURE AND PROCESS OF SCIENCE

Continued

Researcher	Alternate Laboratory Type	Instrument Used	Results		
			No Significant Difference	Significant Gain in Scores on Alternate Lab. Type	Significant Gain in Scores on Traditional Lab. Type
Whitten	Researcher-Revised Lab. Course	TOUS		x	
Magnus	Self-Directed	SPI	x		
Lucy	Self-Directed	SPI		x	
Damewood	Self-Directed	SPI		x	
Spears and Zollman	Open-ended	SPI	x		x (4th comp. only)
Smith	Discovery	SPI		x	

CHAPTER 3

METHOD OF STUDY

3.0 INTRODUCTION

A nonequivalent control group design (Campbell and Stanley, 1963, pp. 47-50) was used to test the hypothesis of no difference between the means of the traditional laboratory method and the investigative-based laboratory method on the dependent variable considered. In what follows, the components of this design, including description of the subjects, selection of the subjects, teaching methods, design of the study, instrumentation, data presentation and analyses are described.

3.1 Population

3.1.1 Description

The subjects in this study were grade 12 students enrolled in Biology twelve at a Senior Secondary School, in District #38, Richmond during the 1982-83 school season.

The Senior Secondary School enrolls students in two grades, 11 and 12 and at the time of this study there were approximately 1,000 students enrolled. The school is located in the geographical centre of Richmond and the students come from middle class or lower middle class families.

Students of the Biology 12 course are generally considered "academic" in that a majority of the students have

aspirations to continue their education at a post-secondary level.

3.1.2 Selection of the Subjects

Two classes of Biology 12, taught by the author, took part in this study. One class, consisting of 21 subjects, were from the author's block B class and the other class, block C, consisted of 20 students. Block B became the control group as these students were exposed to the traditional method of laboratory procedures from laboratory texts issued for the course. Block C students were the experimental group that were required to be exposed to the author's investigative-based laboratory method.

Although a relatively small number of subjects took part in this study, the minimum requirement of 30 individuals laid down by Borg and Gall (1979, p.195) was exceeded.

Campbell and Stanley (1963) point out that the use of naturally formed classes in experiments is an acceptable procedure in the social sciences when random assignment of subjects to treatment is not possible. Such is the case in this study where students were allocated to specific blocks in a non-random fashion. One could not assume randomness as certain students were assigned to specific blocks by school counsellors in accordance with the students' particular program requests.

The characteristics of the two Biology 12 classes are outlined below:

TABLE 5

CHARACTERISTICS OF CLASSES

Class	Size	Male	Female
Block B (control)	21	7	14
Block C	20	8	12

The author who participated as the teacher for both classes had taught senior high school biology for six years prior to the study. Prior to this, he taught science in a junior high school for two years.

The author, at the time of this study, was 30 years of age.

3.2 Research Design

The research design used in this study was the nonequivalent control-group design (Campbell and Stanley, 1963, pp. 47-50) where an experimental and control group are both given a pretest and posttest, but in which the groups do not have pre-experimental equivalence. The design is represented by the following diagram:

$$- \frac{0}{0} - \frac{X}{} - \frac{0}{0} -$$

where 0 represents pretest or posttest measurement of the dependent variable, understanding of the process of science; and X represents the experimental treatment.

As a result of the fact that students were assigned by school counsellors to either the control or experimental groups, it may not be assumed that experimental subjects were randomly selected. Thus, this research design is quasi-experimental as opposed to true-experimental. The main difficulty with non-random assignment is that the experimental and control groups may differ in some characteristic, thus confounding the interpretation of the experiment. To lessen these initial differences between treatment groups, with respect to prior achievement, an analysis of covariance (ANCOVA) was used as a statistical technique.

In the nonequivalent control-group design, there is some threat to internal validity arising from interaction between such variables as selection and maturation, selection and history, or selection and testing. In the absence of

randomization, the possibility always exists that some critical difference, not reflected in the pretest, is operating to contaminate the posttest data. An analysis of covariance mathematically considers some of these possibilities and will indicate the importance of such interactions.

The nonequivalent control group design has some practical advantages over the true experimental control-group design. This is due, in part, to the fact that the former design deals with intact classes and does not disrupt the school's program.

3.3 Evaluation Instrument

The Welch Science Process Inventory (SPI) was used in this study to determine if there were changes in the students' understanding of the process of science. This instrument was developed by Wayne W. Welch (1968) and is available from the author for research purposes only.

The test consists of 135 statements concerning activities, assumptions, products and ethics of science. The student was asked to agree or disagree with each of the statements. The response of the students was scored using a key designed for the instrument.

The reliability of Form D, as measured by the Kuder-Richardson Formula 20, is 0.86 based on a sample of 171 students (mean score and standard deviation of 103.78 and 13.10 respectively). These students were drawn randomly from

a population of 2,500 senior high school students in 50 different high schools throughout the United States. The test's reliability was measured with respect to senior high students and it has been successfully used with undergraduate college students (Magnus, 1973) and by the test's author on college graduates (Welch and Walberg, 1968).

Content validity was established by 14 research scientists agreeing to the appropriateness of the items to sample the "universe of situations". The test consists only of those items where at least 75 percent of the scientists agreed with the keyed response to each item. The instruments' construct validity was determined by investigating the direction of discrimination among students, scientists, and science teachers. Nineteen scientists from Harvard University and Massachusetts Institute of Technology, 16 experienced science teachers, enrolled at the University of Wisconsin and 1,286 students were given the inventory. Through a one-way analysis of variance, it was found that the instrument discriminated by scoring the scientists the highest and students significantly lower.

The Welch Science Process Inventory was developed under the auspices of the Scientific Literacy Research Center at the University of Wisconsin.

3.4 Procedural Details

Students involved in this study were exposed to treatment during the period between January 4, 1983, and March 25, 1983.

Prior to this time, letters of consent were obtained for the 41 subjects of this study from the students' themselves and their parents (see Appendix A). Following receipt of consent, a random selection was made of the group to represent control and the group to represent the experimental. The activities of the control group (Block B) and the experimental group (Block C) will be considered in turn beginning first with the activities of the control group. (A chronological timetable of events that summarize when activities took place may be found in Appendix B.)

3.4.1 Control Group Activities

To establish base scores on the understanding of the process of science, the evaluation instrument, the SPI, was administered to the control group as a pretest during the first week of the study. The SPI was easily administered, requiring no special directions. Subjects were merely asked to express agreement or disagreement with each of the statements of the Inventory. Administration of the instrument took 45 minutes, and was thus completed during one class period.

Following the administration of the SPI instrument, the students in the control group followed a traditional laboratory program using assigned exercises from two laboratory manuals (Investigations of Cells and Organisms by P. Abramoff and R. Thomson, and A Student Laboratory Guide - Biological Science by W. Mayer. This program together with

laboratory manuals have been in use in the Biology 12 course for several years preceding this study. The students, working in groups of two, completed each exercise laboratory in one period. A description of these exercises may be found in Appendix C. These exercises were chosen by the instructor so as to correlate with theoretical lecture material being dealt with in class. Such lecture material was identical to that given to the experimental groups.

In the seven laboratory exercises undertaken by the control group, the experimental procedures, data format and analysis procedure are specified for the students in the laboratory manuals. Thus, the control group were subjected to a highly structured, convergent type of laboratory. The function of the instructor during this laboratory time was to facilitate the smooth operation of those procedures outlined in the laboratory manual. Strict observance of the manual procedures was followed so as not to prejudice student opinion by the offering of the instructor's viewpoints.

A posttest was administered on the last day of the study and the results of this examination were used to determine the change (if any) in students' understanding of the process of science.

3.4.2 Experimental Group Activities

Pre and posttesting using the SPI was accomplished in the same fashion and at the same time in the experimental group as in the control group.

Prior to student laboratory work, the students in the experimental group were instructed in the rudiments of the scientific method of investigation. During this instruction, the students were presented with an example of the application of the scientific method (see Appendix D). This example, together with a model of the process of scientific investigation, was used to bring out the following salient points concerning the experimental scientific approach:

(a) To observe is not just to look, but to notice. It requires a focussing of attention.

(b) Careful observations lead to interpretations, explanations and predictions.

(c) Qualitative observations are distinguished from quantitative observations. During quantitative observing, instruments are used to extend powers of observation.

(d) The statement of a problem must be precise and should not try to encompass too general a field.

(e) Hypotheses are based on prior observations or research.

(f) Any number of schemes for the testing of hypotheses may be devised.

(g) In an experiment, it is not only the hypothesis which is being questioned; the skill of the experimenter is also under test.

(h) A data table must be readily readable and depict all quantitative measures taken.

(i) Reporting results and discussing shortcomings of procedures leads to final reflections on the original hypothesis.

During the ensuing weeks following the pretest and discussion concerning the scientific method of experimentation, students in the experimental group became engaged in laboratory procedures following theoretical lectures on the process of scientific investigation. In the laboratory activities (outlined in Appendix E) students were allowed to be more flexible in the design of their experiments than in the control group. Before student experimentation, the students were presented with 'prior knowledge', which was not given in class lectures which could be used by the students to refine their hypotheses on problems which were clearly stated. The problems themselves were carefully chosen and worded so that a conclusion was not revealed or implied. In each case definitive "answers" were not readily obtainable by the students either from previous lectures on subject matter or literature research.

During student engagement in the process of investigation, the teacher acted as a general guide by asking probing questions and offering criticisms of the students' designs and analyses. The teacher, however, did not "tell" the student how to do the experiment or what experiment to do; these decisions were deemed the responsibility of the student.

At the end of each laboratory, the students in the experimental group were required to hand in a written report for evaluation. Each report included, (a) a title, (b) a statement of the problem, (c) formulation of the hypothesis, (d) an outline of experimental procedure, (e) collection of data, (f) analysis of data, (g) a discussion, and (h) an overall conclusion. The teacher gave the students this outline and provided minimal guidance, but the students were required to make all interpretations and evaluations.

3.5 Analysis Technique

Following the administration of the posttest of the SPI, raw scores of the 41 subjects were tabulated and the mean (δ), standard deviation (X) and range for pre and posttests of the control (T_2) and experimental (T_1) groups were calculated. Using this information, a graphical analysis was drawn up of scores as these scores deviated from the means.

Data from composite tables of changes in raw scores between pre and posttest were used to:

(a) present a graphical analysis comparing T_1 changes in score and T_2 changes in score.

(b) provide a data base for the analysis of covariance (ANCOVA).

An ANCOVA was performed so as to control for the effects of students' previous knowledge of the subject. All computations were performed at the University of British Columbia Research Computing Center using the BMD03R program -

Multiple Regression with Case Combinations - Nov. 1972, Health Sciences Computing Facility, UCLA.

Initially, an ANCOVA was performed using the following overall model:

$Y_{ij} = \beta_o + \beta_1 X_{ij1} + \beta 2\, X_{ij2} + \beta_3 X_{ij3} + \varepsilon_{ij}$; i = 1,2...N; j = 1,2

where Y_{ij} is posttest variable (criterion variable) (dependent variable)

independent variables: $\beta_1 X_{ij1}$ is a treatment vector (X_1)

$\beta_2 X_{ij2}$ is the pretest variable (X_2) or the covariate

$\beta_3 X_{ij3}$ is the interaction variable (X_3)= $X_1 X_2$

ε_{ij} is the residual difference $[Y_{ij} - E(\hat{Y}_{ik})]$

To determine the importance of the covariate interaction (X_3), the following test was carried out:

$$F = \frac{R^2_{Y.123} - R^2_{Y.12}/k_1 - k_2}{(1-R^2_{Y.123})\ /n-3-1}$$

where:

$R^2_{Y.123}$ = amount of variance in Y due to a linear combination of X_1, X_2 and X_3.

$R^2_{Y.12}$ = amount of variance in Y due to a linear combination of X_1, and X_2.

k_1, k_2 = n-k-1 degrees of freedom

n = total number of subjects in the two groups

The decision rule, if $F > .95F_{1,37}$, H_o may be rejected, was followed.

To test for treatment effects, the following statistical test was conducted to test the statistical hypothesis,

H_o: $\beta_1 = 0$ at the $\alpha = 0.05$ level:

$$F = \frac{R^2_{Y.12} - R^2_{Y.2}/1}{(1-R^2_{Y.12})/38}$$

Finally, using the adjusted posttest scores $(\hat{Y})_{adj}$ individual regression lines for each group were drawn and the difference discussed.

The validity and reliability of the results of this study are dependent, in part, upon the validity of the following assumptions:

1. The instrument employed in this study possesses adequate validity and reliability for the purposes for which they were employed.
2. The inherent assumptions of analysis of covariance such as homogeneity of regression were not seriously violated.

CHAPTER IV

ANALYSIS OF DATA AND RESEARCH FINDINGS

4.0 INTRODUCTION

The results of the analyses described in Chapter Three are presented in this chapter. These analyses evaluate the effectiveness of two methods of laboratory instruction in biological science - the highly structured traditional laboratory method and the more flexible investigative-based laboratory method.

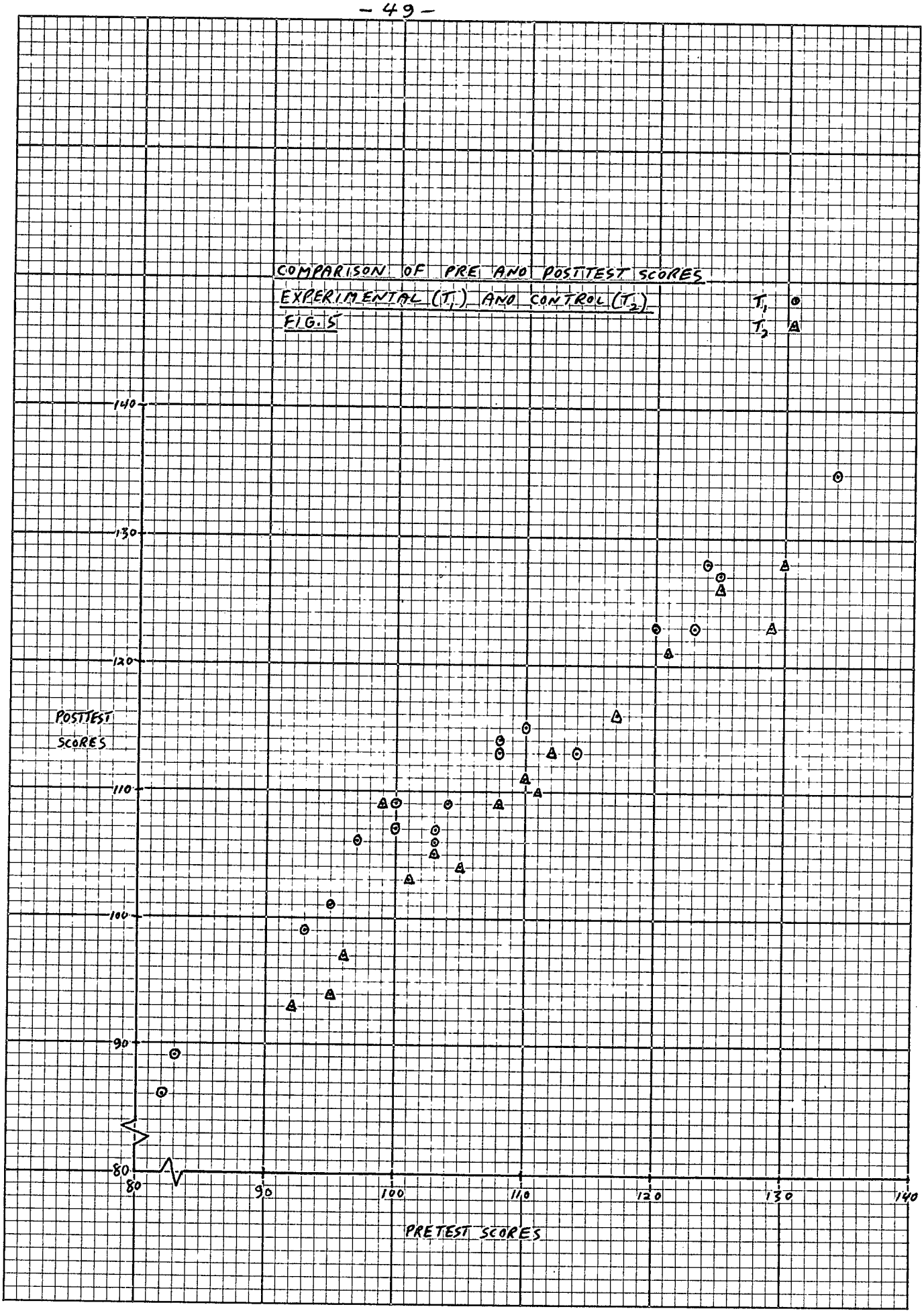
4.1 Description of Research Findings

Raw scores from the administration of the SPI instrument may be found in Appendix F. From the calculated mean values it is apparent that posttest scores generally varied little from pretest scores for the control group (a change of 0.19) whereas a change of 2.95 in the mean scores between pre and posttest was recorded for the experimental group. Whether this change is statistically significant was determined using the ANCOVA model.

A graphical analysis of deviations in score from the means may be found in Appendix G (figures 1, 2, 3 and 4).

The composite graph comparing changes from pre to posttest scores for the experimental (T_1) and control groups (T_2) is indicated (Fig. 5).

COMPARISON OF PRE AND POSTTEST SCORES
EXPERIMENTAL (T_1) AND CONTROL (T_2)
FIG. 5



The scattered points found on this graph were fitted by least-square regression lines later in this analysis. Of particular note are two data points (T_1 - 125/110 and T_2 - 112/100) that markedly deviate from the general linear tendency of data points. These points will be seen to have the highest residual error in the estimated regression lines (-15.481 and -11.556 respectively).

4.1.1 Analysis of Covariance (ANCOVA)

Raw data scores for Y of T_2 were given codes of 1 and -1 respectively, the data outlay of which may be seen on Table 6 (Appendix H). These scores were then used to estimate the overall regression model on which the ANCOVA was based.

From the analysis of the full model the following results were obtained:

(a) $R^2_{Y.123} = 0.89$

(b) e_{ij} are generally low (range 23.64)

Thus, extraneous variables are seen to have a very low effect on the dependent variable (Y). Indeed $\simeq$ 89% of the variance in Y was due to factors X_1, X_2 and X_3.

Using the test statistic indicated in Chapter Three we get the result:-

$$F = \frac{0.8903 - 0.8893/1}{(1-0.8903)\ /37}$$

$$F = 0.34$$

since $F > {}_{.95}F_{1,37}$ then H_o is tenable and the reduced model may be adopted. Thus, there is no difference in the performance on the criterion measure due to interaction between the treatment effects and the covariate.

4.1.2 F-Test Ratio

Treatment effects calculated below in Table 8 from the reduced model indicate that:

(a) covariate effect constitutes ≃ 87% of the total variation in Y scores.

(b) treatment effects constitute ≃ 2% of the total variation in Y scores.

(c) residual effects constitute ≃ 11% of the total variation in Y scores.

TABLE 8

TREATMENT EFFECTS

Source of Variation	Proportion of Variation	Degrees of Freedom
Covariate (X)	$R^2_{Y.1}$ = 0.87	1
Treatment Effect (X)	$R^2_{Y.12} - R^2_{Y.2}$ = 0.02	1
Residual	$(1-R^2_{Y.12})$ = 0.11	38
Total	1.00	

Using the F-test of significance statistic referred to in Chapter 3:

$$F = \frac{0.8893 - 0.8720}{(1-0.8893)\ /38}$$

$$F = 5.97$$

Since $F > {}_{.95}F_{1,38}$ then H_o may be rejected. Thus, there is a significant difference, at the .05 level, in the performance on the criterion measure due to the effects of the treatment variable.

4.1.3 Graphical Analysis

Regression lines of T_1 and T_2 data can be drawn using the overall estimated regression equation:-

$$Y_{ij} = b_o + b_1 X_{ij1} + b_2 X_{ij2}$$

TABLE 9

CALCULATIONS OF ESTIMATED POSTTEST SCORES

Treatment	X_1	Y_i
T	1	$(b_o + b_1) + b_2 X_2 =$ $19.5 + 1.5) + 0.8 X_2$
T	1	$(b - b_1) + b_2 X_2 =$ $(19.5 - 1.5) + 0.8 X_2$

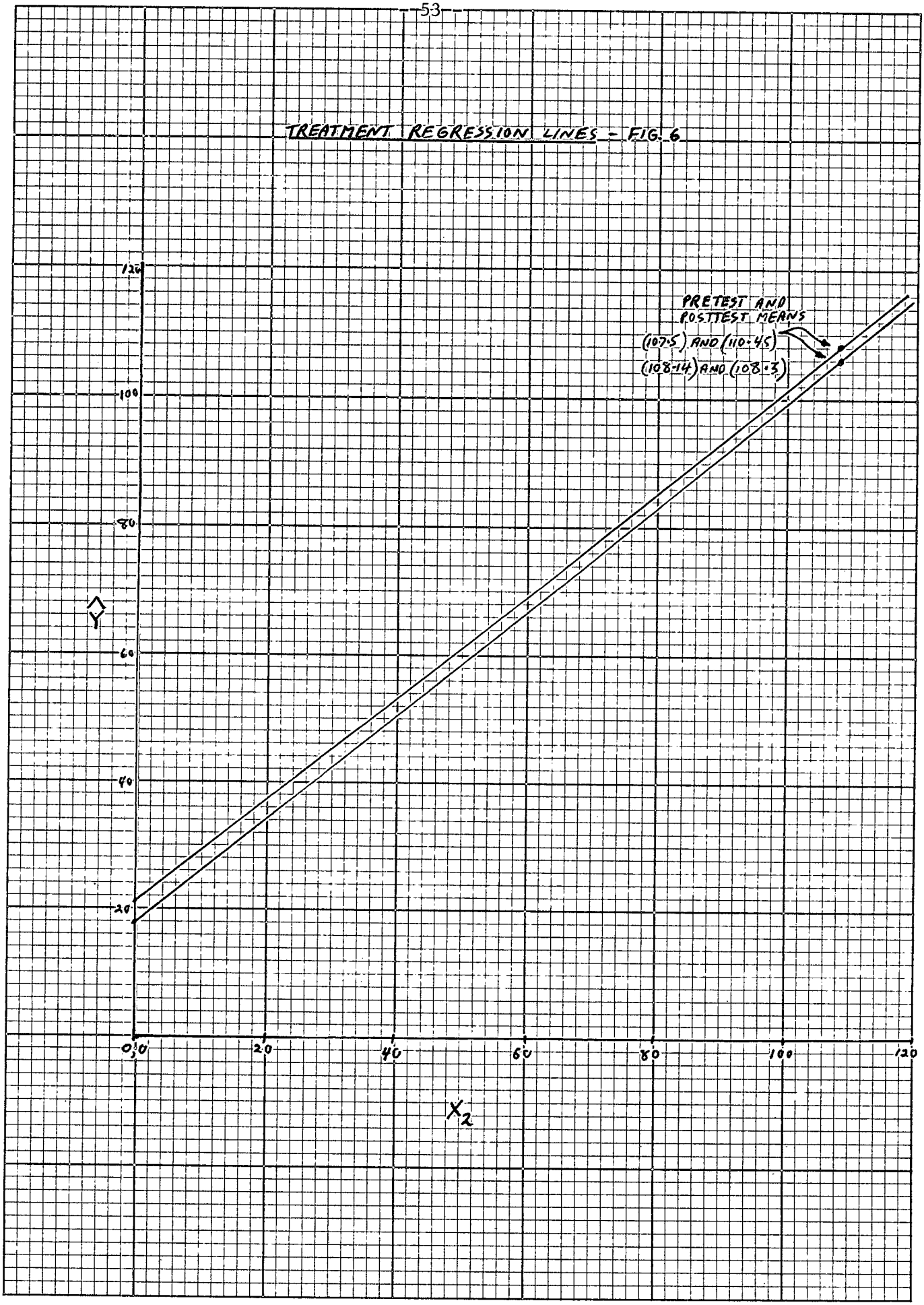
Equations for T_1 and T_2 linear variations are:

(T_1) $\hat{Y}_1 = 0.80X_2 + 21.0$

(T_2) $\hat{Y}_2 = 0.80X_2 + 18.0$

Thus, the slope of both regression lines is 0.8. The Y-intercept for T_1 = 21.0 and for T_2 = 18.0 (Fig. 6)

The difference between the Y-intercept of the two regression lines represents the effect of the treatment variable on the criterion variable. This difference was shown to be significant at the $\alpha < .05$ level.


TREATMENT REGRESSION LINES - FIG. 6
PRETEST AND POSTTEST MEANS
(107.5) AND (110.45)
(108.14) AND (108.3)
120
100
80
60
40
20
0
20
40
60
80
100
120
Ŷ
X2

CHAPTER V

CONCLUSIONS, LIMITATIONS AND RECOMMENDATIONS

5.0 Introduction

This study originated from the author's desire to test empirically the effects of an author-designed investigative-based laboratory program on student understanding of the process of science. In response to dissatisfaction with contemporary laboratory activities, there have been many innovative attempts to develop instructional laboratory activities which are more characteristic of the nature of science. However, at least in biology, the quantitative evaluation of the effectiveness of these innovations has been the exception rather than the rule. So there now exists an urgent need for both innovation of new laboratory activities and evaluation of their instructional effectiveness.

This study deals with the evaluation of the relative effectiveness of a traditional laboratory program and a more flexible, investigative-based laboratory program. These laboratory activities were part of a biology 12 secondary school program at a Senior Secondary School during three months of the school year 1982/83. One group, the control group, followed a traditional laboratory program using exercises from a conventional laboratory manual. The other group followed a more flexible program which emphasized student involvement in hypothesising, experimental designing

and the discussing of research findings. Intact classes were used since the registration procedure precluded assignment of students to specific classes; thus, random selection was not presumed in the study.

A quasi-experimental nonequivalent control group design was used with the Welch Science Process Inventory used to measure student understanding of the process of science. Statistical analysis performed by an analysis of covariance computer program was used to minimize any bias due to prior knowledge about the science process.

5.1 Conclusions

Based upon the results from the analysis of data it may be concluded that the null hypothesis stipulated in Chapter One may be rejected. That is, students involved in a laboratory program that emphasized more involvement in student-directed investigations achieved a significantly better understanding of the actions and operations of scientists than students in a traditional laboratory program.

However, it should also be noted that only 2% of the variance in Y was accounted for by the treatment effects.

Other, more subjective conclusions that are borne out of this study come from the author's ethnographic observations, and, although not based on an analysis of quantitative data, are considered salient points to be expressed. These conclusions are:

1. Most of the students in the investigative-based program enjoyed these activities more than their prior experiences with traditional laboratory programs. (The degree to which in-class discussions contributed to this apparent increase in level of motivation remains unknown.)
2. The length of time required to complete laboratory activities for the experimental group exceeded that for the control group.
3. Although the length of time required to complete laboratory activities was greater for the experimental group, with an increase in time it was found that a great deal more was accomplished in the class time given for experimentation.
4. The amount of apparatus required for the experimental group was greater and of a more diverse nature than that required for the control group. This necessitated greater preparation time for the instructor.
5. Evaluation of laboratory reports from the experimental group was found to be more difficult and time consuming for the instructor. Such reports, which included a detailed descriptions by the students of procedural methods and, often, lengthy discussions of results, were often difficult to assess as to their merits. Control group reports

tended to be more cursory, simply offering answers to stated questions from the prescribed laboratory manuals.

6. During laboratory classes there were often as many as six or seven quite different procedures taking place at once in the experimental group. This made it difficult for the instructor to monitor all of the students' experimental designs.

5.2 Limitations

Measuring understanding of the process of science is a matter of assigning quantitative scores to subjective responses. These responses are sensitive to external influences. The identification of these influences and the effect they have on experimental results is a continuing problem in affective research.

This study was limited to grade 12 students and was carried out over a relatively short period of three months. What effect the investigative-based laboratory method has on students' understanding of the process of science when this method is used over longer time periods or with other grades has not been investigated. The results of this study must therefore be used with caution when attempting to generalize outside the population studied.

The involvement of the investigator as the teacher in this study introduced a possible error as the investigator

possesses a bias towards the investigative-based method of laboratory teaching. It has been shown (Rosenthal and Fode, p.163) that if the researcher has a strong expectancy that his innovation is superior to conventional practice, his experiment might yield this finding. The use of a reliable and non-instructor designed instrument together with an analysis of covariance, and researcher avoidance of the suggestion to subjects that one experimental treatment was better than another; may have minimized, to some degree, this experimenter bias effect.

The lack of random assignment of subjects limits the internal validity of this study. However, this random assignment is not recognized as a major problem the more similar the experimental and control groups are in their recruitment, as reflected in the similarity in pretest means:

> In particular it should be recognized that the addition of even an unmatched or nonequivalent control group reduces greatly the equivocality of interpretation over what is obtained in Design 2, the One-group Pretest-Posttest Design. [True experimental design] (Campbell and Stanley, 1963, p.47)

5.3 Recommendations

1. Innovation, development and evaluation of new laboratory programs should be continued.
2. Incorporation of increased student involvement in the process of scientific investigation should be considered for at least some laboratory experiences in secondary schools. These laboratory experiences

do possess some unique advantages.

3. This study should be replicated with more heterogenous populations and at other institutions.
4. A study needs to be conducted, involving several instructors, both partial and impartial, to determine the instructor's interest as a motivating factor in building student understanding of science processes in the laboratory. Or, a replication of this study may be made with removed biases.
5. A similar study needs to be conducted, over a longer period of time, to determine if retention of understanding is increased in laboratory work.
6. The effect of the investigative-based laboratory method on other areas of science: areas such as chemistry, physics and earth science, needs to be investigated.

5.4 Epilogue

It was hoped that by exposing science students to an investigative laboratory program they would emerge from the laboratory with some understanding of the problems and operations of a scientist. It was hoped that they would begin to feel their dependence on a framework that establishes, designs and directs experiementation, that they would learn the limits of both their perceptual senses and thinking abilities and see the usefulness of various instruments that

could help them solve the problem. It was hoped that they would develop an experiment to generate data that could be used to decide the validity of their hypotheses and then to tentatively accept, restate in a modified form or discard what was chosen to be the best hypothesis.

Within the limited confines of this study, these aspirations seem to have been accomplished.

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APPENDIX A

Sample letters of Consent

Richmond Sr. Sec. School Letterhead

Dear Parent/Guardian,

In addition to being your son/daughter's biology teacher, I am also a part-time graduate student at U.B.C. (Science Education Department). I have given your son/daughter a consent form for a study I wish to conduct to determine the effectiveness of a new laboratory method I have designed. Such a method will allow students more participation in the design of their biology experiments and allow them to discuss their results in a manner that I hope will result in a better understanding of the processes of science.

The students will be separated into a control and experimental group with the control group simply following traditional lab methods from the prescribed lab text and the experimental group following my lab design. Your son/daughter will be in the _____ group.

Participation in my field of study is strictly on a volunteer basis and will take place between January 4 and March 31, 1983. Refusal to participate or withdraw from the study will not jeopardize class standing of the subjects. Students who do not participate in the study will complete the class activities as scheduled but will not write the pre/post test. As parent/guardian, if you consent to your son/daughter's participation in my study please indicate by signing the portion below and returning it to Mr. McCarthy by mail. (Richmond Sr. Sec. School, 7171 Foster Road).

I, _____ consent to have my son/daughter participate in Mr. McCarthy's study as described above.

Richmond Sr. Sec. School Letterhead

Dear Student:

As you are aware by now, I am a graduate student at the University of British Columbia (Science Education Department), as well as your biology teacher! To complete my thesis requirements, I have designed a field experiment that requires volunteers. That is where you come in!

For one of my biology 12 blocks, I will be using an alternate laboratory method to the one you normally use (i.e. the one from your lab text) for the months of January, February and March. This lab method will require students to design their own experiments, hypothesize and discuss their results. As a control, I will have the other biology 12 block continue as we have done this year - using the traditional method of lab instruction from the lab text.

At the beginning and end of the study, a test questionnaire will be administered that will measure students' understanding of the processes of science.

Refusal to participate or withdraw from the study will not jeopardize your class standing.

If you do consent, please indicate by signing the section below and returning it to me as soon as possible.

I, _____ consent to participating in Mr. McCarthy's study as described above.

APPENDIX B

Overall Timetable of Events

	DATE	J 4-7		J 10-14			J 17-21			J 24-28		
	Class Period	1	2	1	2	3	1	2	3	1	2	3
	Control	1	A_1	(1)	2	3	(2)	4	5	6	7	8
Activity	Exp	1	A_1	(P+1)	(1)	2	3	(2)	(2)	4	5	6

	DATE	J 31-4F			F 7-11			F 14-18			F 21-25		
	Per.	1	2	3	1	2	3	1	2	3	1	2	3
	C	(3)	19	10	11	12	(4)	13	14	15	(5)	16	17
Activity	E	7	8	(3)	(3)	9	10	11	12	(4)	13	14	15

	DATE	F 28-4 M			M 7-11			M 14-18			M 21-25		
	Per.	1	2	3	1	2	3	1	2	3	1	2	3
	C	18	(6)	19	20	21	(7)	22	23	24	25	(8)	A_2
Activity	E	(5)	16	17	18	(6)	(6)	19	20	21	(7)	22	A_2

In A Chronologically Ordered Sequence
- Circled Numbers = Lab Activities
- Uncircled Numbers = Lectures, Mic. Examination Work, Guest Speakers, Tests
- A_1 = SPI pretest
- A_2 = SPI posttest

Chronological Sequence of Events during treatment period Jan. 4 to March 25.

APPENDIX C

Activities in the Control Group's Traditional Laboratory program.

INQUIRY

5-1

AN ENZYME IN PLANT AND ANIMAL TISSUES

In Inquiry 4–1 you found that certain reactions were speeded up by the action of the enzyme diastase. In this inquiry you will investigate the enzyme catalase (CAT·a·lace) in various tissues. One of the questions you will attempt to answer is whether catalase is present in all the tissues with which you will work.

MATERIALS

2 test tubes
A variety of animal and plant tissues: fresh beef, pork, or lamb liver and kidney; worm tissues; frog blood; potato; apple; etc.
3 percent hydrogen peroxide (H_2O_2) solution
Graduated cylinder, 25–50 ml
Thermometer, 0°–100° C
Vial 95 mm long × 25 mm external diameter
One-holed stopper, No. 4 size
Forceps
Paper toweling
Bunsen burner or other heat source

EXPERIMENTAL DESIGN

On a demonstration table are slices of various plant and animal tissues, with labels for easy identification. Do not touch the samples at any time with your fingers, for you do not want to introduce substances from your own skin tissue. Use the forceps to take a piece of each of the tissues and place it on a piece of paper toweling. Keep each piece apart from the others on the towel, and label the towel for their identification.

On a second piece of paper toweling take identical tissues which have been boiled. Again handle the tissues with your forceps.

Take two clean test tubes and pour 5 ml of fresh 3 percent hydrogen peroxide solution into each tube. (CAUTION: *Hydrogen peroxide, if spilled on clothing, will produce discolorations.*) Select an untreated and a boiled tissue sample of the same tissue, and with the forceps place one of them in each tube. ► Observe and record the results [1]. Empty the tubes, rinse them, and again pour 5 ml of fresh 3 percent hydrogen peroxide solution into each tube. Proceed as before with another tissue pair. Continue in this manner until you have tested all tissue pairs and have added the results to your record for the first pair.

Catalase is an enzyme that breaks down hydrogen peroxide, forming oxygen and water. ► How does each sample tissue you tested indicate the presence or absence of catalase in the tissue [2]? Prepare a list of the tissues beginning with the one showing the greatest catalase activity and continuing in order of decreasing catalase activity. ► Which of the tissues are most active in catalase activity [3]? ► least active [4]? ► What, if anything, do the

tissues at opposite ends of the list have in common [5]? ► What do your data indicate about catalase activity in boiled and untreated tissues [6]?

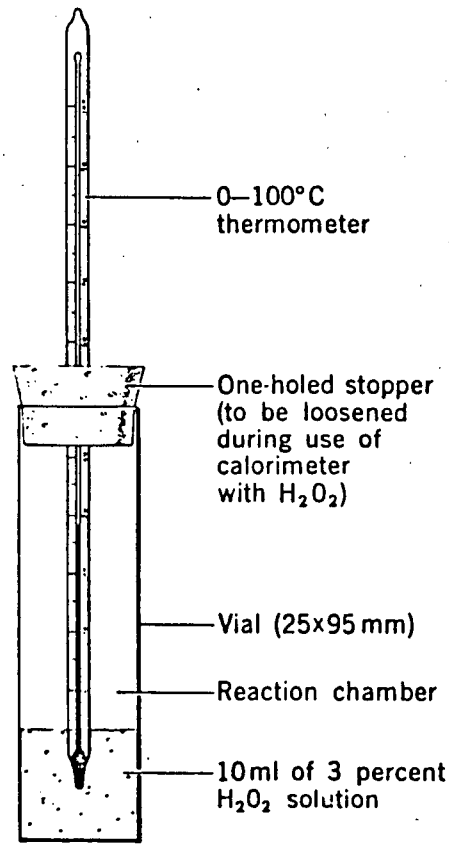
Hydrogen peroxide is frequently used as an antiseptic. When poured on an open wound, it begins to bubble. ► What does this indicate to you about human tissues [7]?

If you held the test tubes with your fingers during the preceding reactions, were you able to notice changes other than the production of bubbles? In many chemical reactions both in the laboratory and in living organisms, some of the energy is given off as heat. We measure heat in units called **calories** and **kilocalories** (1000 calories). One calorie is the amount of heat required to raise the temperature of 1 g of water 1° C.* A device frequently used to measure this heat is a **calorimeter** (cal·o·RIM·e·ter). Figure 15 shows the type of calorimeter you will construct for this investigation.

Set up the calorimeter and place 10 ml of hydrogen peroxide in the reaction chamber. Moisten the thermometer, pass it through the hole in the rubber stopper, lower it into the hydrogen peroxide, and record the initial temperature. Note that the definition of a calorie is in terms of water, not of hydrogen peroxide. ► What assumptions does this suggest you are going to have to make about the use of hydrogen peroxide in this inquiry [8]? ► Why should you be concerned with the basic assumptions for this or any other scientific inquiry [9]?

Before proceeding further, read the remainder of the experimental design and set up your controls for this inquiry.

After you have measured the initial temperature of the hydrogen peroxide in the reaction chamber, introduce two drops of liver extract (which your teacher will supply to you) into the chamber with the 10 ml of hydrogen peroxide. Insert the cork into the vial loosely to allow any gas generated to escape. Record the temperature change in the reaction chamber every 30 seconds for a period of at least 5 minutes. Repeat this procedure at least two more times with fresh hydrogen peroxide and liver extract. ► Why [10]? Take the average of your three temperature measurements for each time interval of 30 seconds. Record the results of each time trial and the trial averages in a data table, and then graph this data. ► By reference to your data and graph, what is the total temperature change that occurred in the reaction chamber [11]? ► How many calories of heat does this temperature change represent [12]? ► If your graph reaches a



15 A glass-vial calorimeter

* This definition of calorie is the true one, not the "calorie" used by nutritionists in discussing food values. The latter actually is the kilocalorie.

plateau, what might this indicate about the rate of reaction [13]? ► If the graph indicates that the temperature is decreasing after an initial increase, what should this indicate about the reaction [14]? ► What is the source of the heat measured in this inquiry [15]?

Consider the data further. The reaction of catalase with hydrogen peroxide takes place in the human body as well as in other animals and plants. ► Does all energy resulting from biochemical reactions appear as heat? Explain [16].

The temperature of the liver of the mammal from which the liver extract was taken was probably about 38° C. What would happen to the activity of catalase if the liver temperature were increased briefly (for 3 to 5 minutes) to 50° C? 55° C? 60° C? Design and carry out an experiment that will give you answers to this question.

INQUIRY
6-5

REACTIONS OF CELLS IN CHANGING ENVIRONMENTS

In Inquiry 6–4 you discovered some principles of diffusion in a model of a cell. How do the principles apply to a living cell? How is a cell's internal environment affected when change in and around it occurs constantly?

MATERIALS

Part A
5 ml suspension of yeast cells (freshly prepared) for each group of 2 to 4 students
Congo red solution
Microscope slide
Cover glass
2 test tubes
Test tube rack
Compound microscope
Bunsen burner
Test tube holder
Beaker

Part B
Sprig of elodea
5 percent sodium chloride (NaCl) solution
Compound microscope
Microscope slide
Cover glass
Paper toweling or filter paper
Medicine dropper (pipette)
Glass of water
Glass for NaCl solution

EXPERIMENTAL DESIGN

Part A. Diffusion in a Uniform Environment

Place 1 ml of yeast suspension in each of two test tubes. Add 3 drops of Congo red solution to each test tube. Heat the contents of one test tube to the boiling point in a beaker of boiling water, then extinguish the burner.

Prepare wet mounts of both yeast suspensions and examine under low and high power. ► Describe the differences you observe in the two suspensions [1]. ► How do you account for these differences in terms of the way the yeast cells were treated [2]? ► What hypothesis can you offer about cell membranes and diffusion on the basis of this inquiry [3]?

Part B. Diffusion in a Changing Environment

The closely regulated environment inside an elodea cell contains a concentration of approximately 0.9 percent sodium chloride (table salt). If the cells are in water that is also near this concentration of salts, no special problems occur. ► But what do you think will happen if you place a higher concentration of salt solution around the outside of the cells [4]?

Place a leaf from a growing tip of elodea in a drop of tap water on a clean slide. Add a cover glass and study it under low power and high power. Now place a small bit of paper

toweling or filter paper at one edge of the cover glass to draw the water off the leaf. Add a drop of salt solution on the opposite side of the cover glass. It will be drawn under the cover glass as the water already there is drawn off by the paper towel or filter paper. Observe the effect on the cells as the salt water moves over the leaf. ► Describe what you see taking place within the cells [5].

What will happen to the cells if the leaf is washed and again placed in plain water? Remove the leaf and place it in a glass of water. Study it again under the microscope after a period of 5 minutes. ► Record any changes you observe [6].

Will the plant die if allowed to remain in an unbalanced salt environment for 10 to 15 minutes? Test this question by placing the leaf in a glass of 5 percent NaCl solution. Remove after 15 minutes and observe under the microscope in a drop of the 5 percent NaCl solution. ► What are the results [7]? ► How can you tell if the cell is dead [8]?

► What have you observed in Parts A and B of this inquiry about cell membrane activity [9]? ► Why do you think the membrane in one instance inhibits the passage of a substance and in another instance does not [10]? ► What conclusions can you draw regarding the sizes of molecules of Congo red and of water [11]?

► On the basis of your study of Part B, formulate a statement about the ability of a cell to maintain its internal stability in a changing environment [12].

INQUIRY 7-1

MITOSIS AND GENETIC CONTINUITY

"Like tends to beget like." This phrase has a meaning so self-evident, we hardly pause to give it a second thought. Oak trees give rise to oak trees; rabbits reproduce more rabbits. Somehow the reproductive cells of an oak or a rabbit receive—and pass on—hereditary materials that give them and their descendants specific characteristics of oaks or rabbits and not of some other organism.

How have these hereditary potentialities been passed on from one cell to the next in such a precise way that *all of them*, both in *quantity* and *quality*, can be transmitted to the reproductive cells?

To answer this question we must investigate the changes that occur in the nucleus of a cell before cell division occurs. These nuclear events are called **mitosis.**

The process of mitosis is not easy to see in living cells because the nucleus and all the structures within it are nearly transparent in the living condition. We learned in Inquiry 1–4 about a special kind of microscope—the phase-contrast microscope—that makes it possible to see cell structure without killing cells, and that makes it possible to observe transparent structures. We could use such a microscope to observe mitosis in living cells.

EXERCISE 20

HOW DOES LIGHT INTENSITY
AFFECT THE RATE OF PHOTOSYNTHESIS?

The intensity of sunlight striking the surface of the Earth varies from hour to hour as well as from one season to another. Since oxygen is a by-product of photosynthesis, oxygen production may be used in designing an experiment to measure the effect of variations in light intensity on photosynthesis. The production of oxygen may be demonstrated by placing a plant under water and then measuring the escape of oxygen bubbles. In this exercise, changes in the photosynthetic rate under different light intensities will be measured.

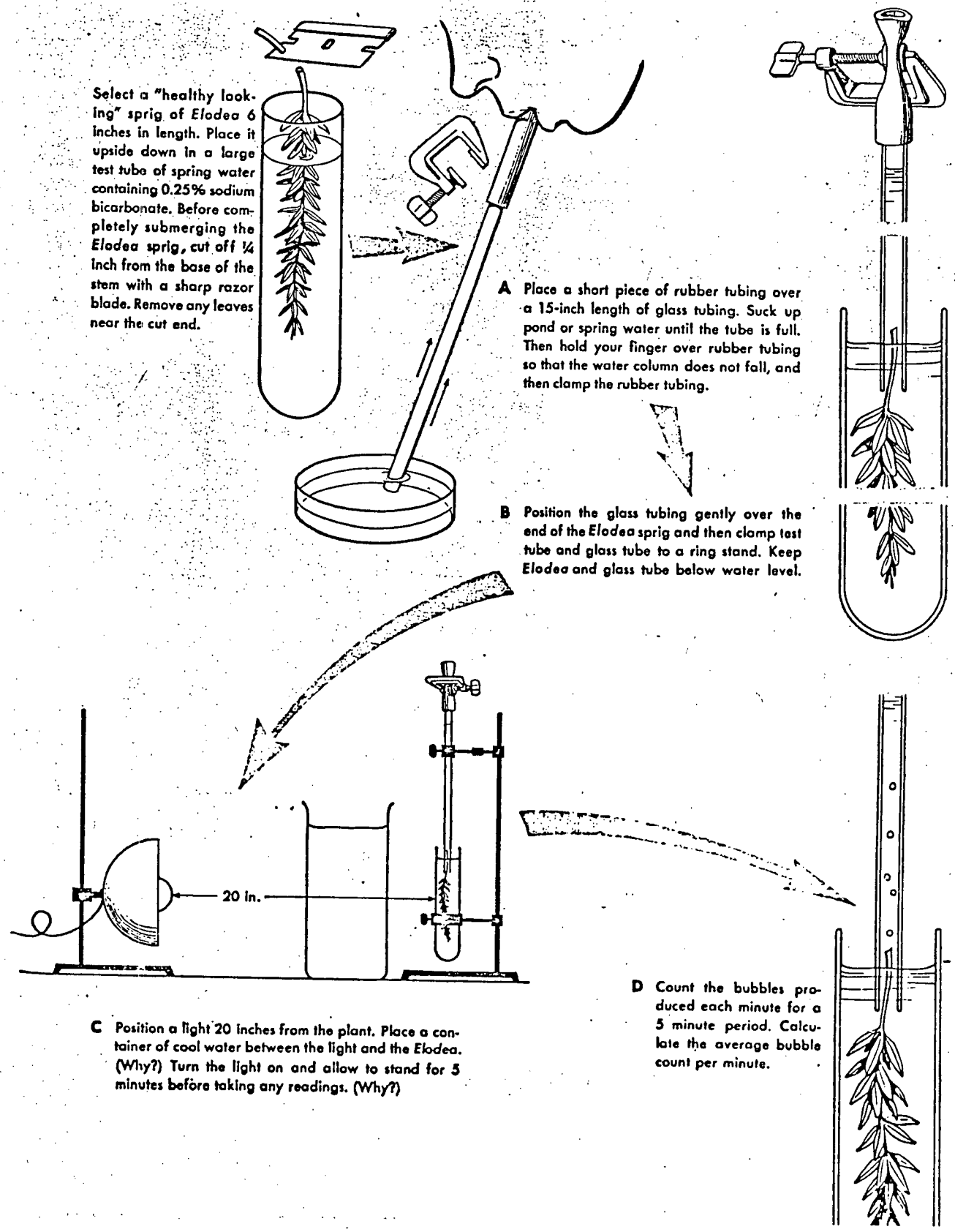
PROCEDURE

Following the method shown in Fig. 5.2, calculate the average number of bubbles produced per minute with the lamp 20 inches from the Elodea. 20-A Record your data in the table on page 279. Move the lamp to a distance of 10 inches from the Elodea. Allow the set-up to stand for five minutes. 20-B Why? Determine the average bubble count at this distance (10 inches) and record your data. Repeat this experiment with the light source five inches from the Elodea and record your data in the table. 20-C Graph your results on page 279.

FOR THOUGHT, DISCUSSION, AND FURTHER STUDY

1 How can you prove that the bubbles given off during photosynthesis are composed of oxygen?
2 How has the intensity of the light been varied in the experiment conducted in this exercise?
3 What is the relationship between the amount of oxygen produced (as bubbles) and light intensity?
4 If you were able to increase the intensity of light indefinitely, would you expect the production of oxygen to continue to increase at the same rate? Explain.

FIG. 5.2 PROCEDURE FOR DETERMINING THE EFFECT OF LIGHT INTENSITY ON PHOTOSYNTHESIS



EXERCISE 21

HOW CAN YOU DETERMINE IF CARBON DIOXIDE IS NECESSARY FOR PHOTOSYNTHESIS?

The atmosphere is composed predominantly of nitrogen (approximately 78 per cent) and oxygen (approximately 21 per cent). In addition, it contains variable amounts of water vapor and small quantities of other gases. Carbon dioxide (CO_2) constitutes about 0.04 per cent by volume of the atmosphere.

PROCEDURE

Your instructor will provide you with several geranium plants that have been kept in the dark for 36 to 48 hours. Select a leaf from one of the plants and test it for the presence of starch (Figs. 5.3A,B). Return the plants to the dark during the time you are testing the leaves. 21-A Why?

If a strong, positive starch test occurs, select another plant and test the leaves until a negative or very weak starch test occurs. 21-B Why is this step necessary?

Set up the experiment as shown in Figs. 5.3C,D. This is accomplished by placing a geranium leaf in an atmosphere lacking CO_2. Potassium or sodium hydroxide (KOH or NaOH) effectively remove CO_2 from the air. 21-C What "control" should be set up so that meaningful conclusions can be made?

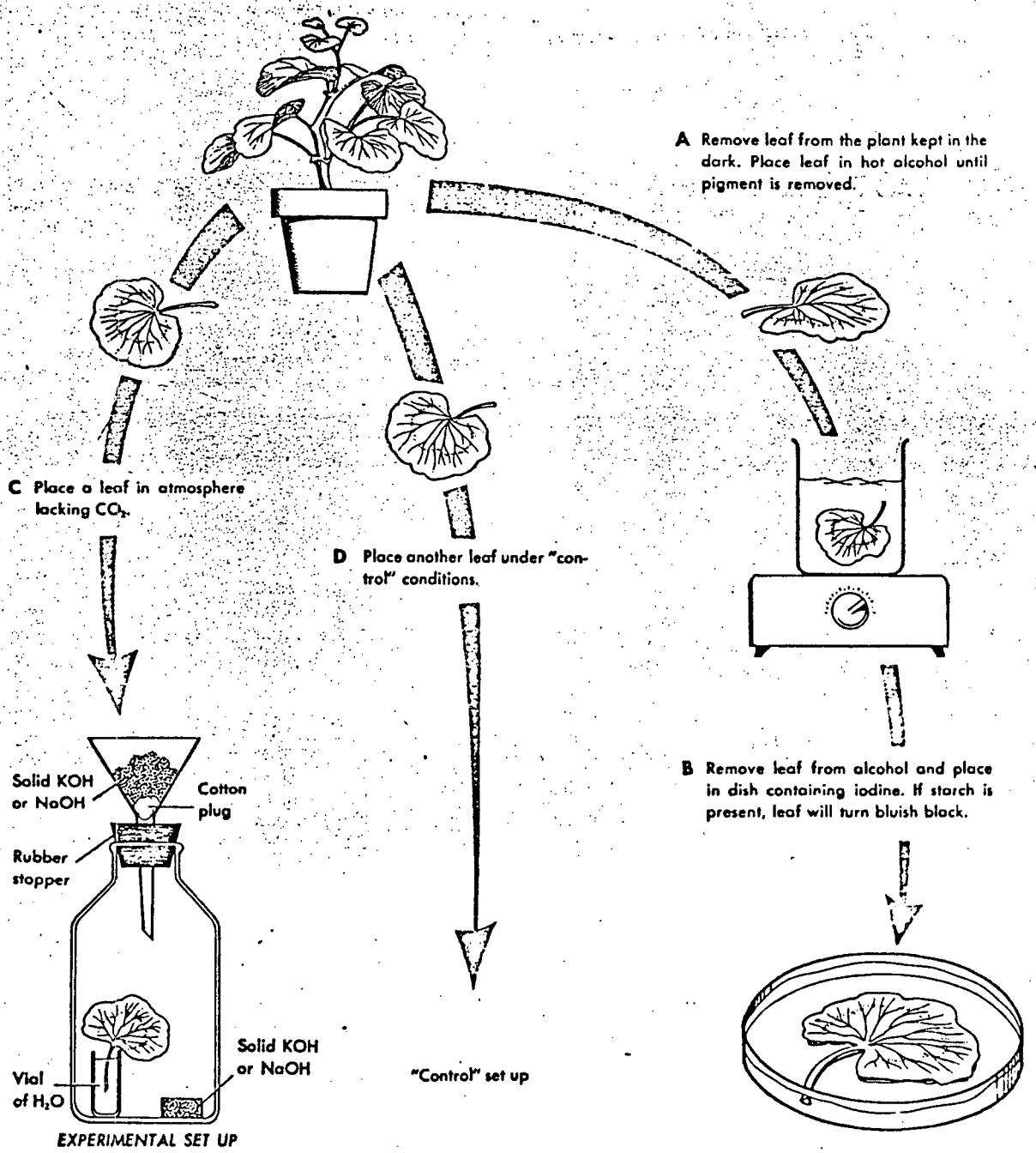
Set up this "control" along with the experimental set-up and place the "control" under bright lights for 24 hours. Test for photosynthetic activity by testing the leaves for starch.

CAUTION: KOH or NaOH is extremely hazardous to use. Do not touch with your hands. Use tongs or a plastic spoon to transfer this chemical from its container.

FOR THOUGHT, DISCUSSION, AND FURTHER STUDY

1 In Fig. 5.3, why is potassium hydroxide (or sodium hydroxide) placed within the jar as well as in the funnel?
2 Based on the results of the experiment, what conclusions can be made about the necessity of carbon dioxide for photosynthesis?
3 Suppose you were to put a sprig of Elodea into a test tube completely filled with boiled (and cooled) water. You then seal the tube with a rubber stopper and place it under bright light. Would you expect photosynthesis to occur? Explain.
4 A solution of phenol red is orangish-red in the presence of carbon dioxide. The solution becomes yellowish in the absence of carbon dioxide. Devise an experiment to show that Elodea plants use CO_2 when photosynthesizing.

FIG. 5.3 PROCEDURE FOR DETERMINING IF CO_2 IS NECESSARY FOR PHOTOSYNTHESIS



Place "experimental" and "control" set ups under bright lights for 24 hours. Then test for starch as shown in steps A and B.

EXERCISE 31

WHAT IS THE EFFECT OF VARIOUS ENVIRONMENTAL FACTORS ON TRANSPIRATION?

Most land plants obtain water from the soil. However, only a small amount of the water absorbed by the roots is used in growth and photosynthesis. The rest is lost through **transpiration,** a process in which water is lost (as water vapor) from the surface of leaves, or in some cases, from other aerial parts of plants.

In this exercise you will use an apparatus called a **potometer** to determine the effects of various environmental factors on the rate of transpiration.

PROCEDURE

▶ Completely cover the potometer flask (except for the openings) with aluminum foil.

▶ Using a 2-inch piece of rubber tubing, attach a 15-inch length of capillary tubing to the potometer flask. Support the capillary tubing in an *elevated position,* using a clamp and ring stand as shown in Fig. 8.1A. Attach a millimeter ruler to the back of the tubing with tape.

NOTE: The rubber tubing must fit tightly on the capillary tubing to prevent air leaks.

▶ Fill the flask to the brim with water provided by your instructor. Pour the water in slowly to avoid the formation of bubbles.

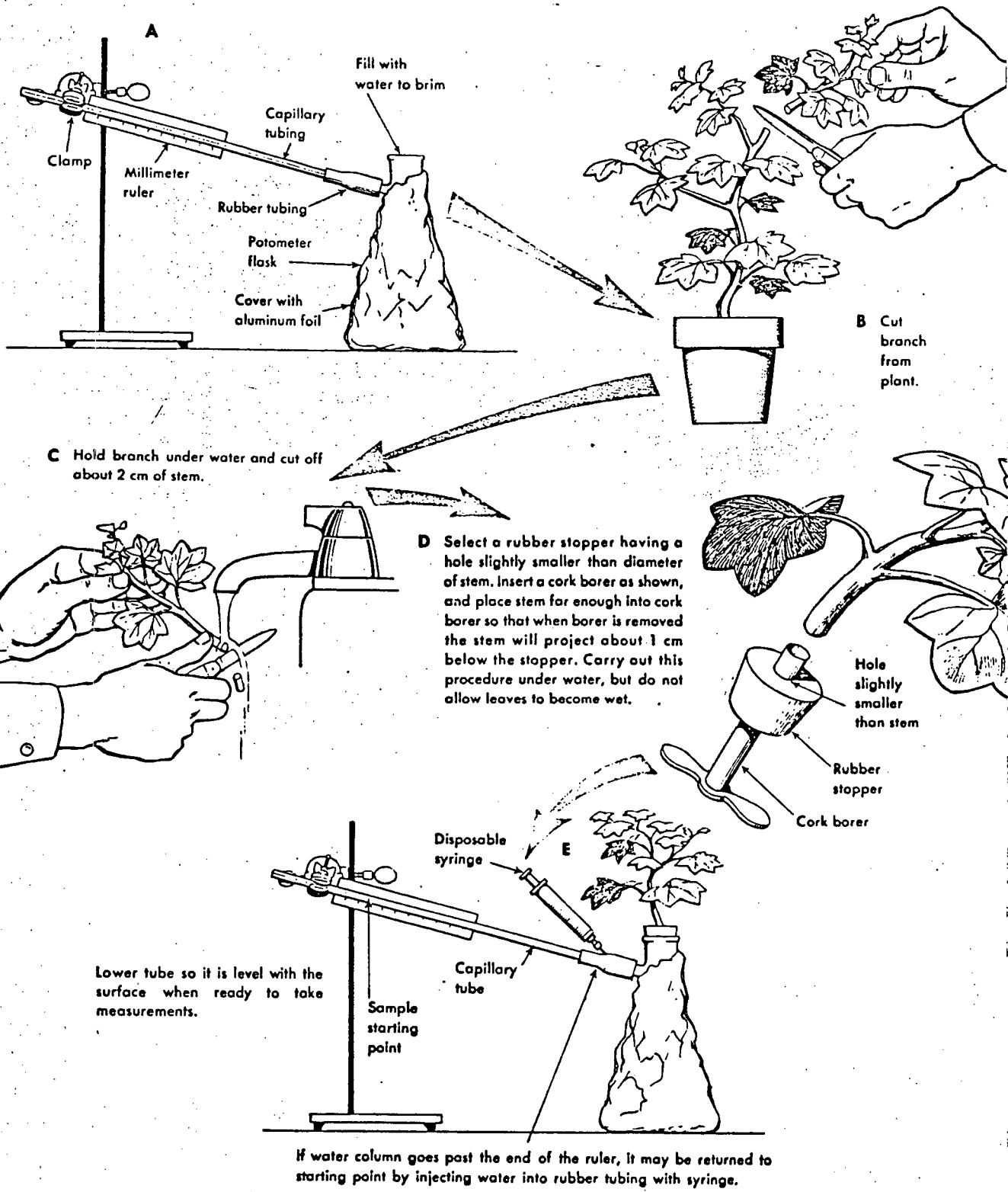
▶ Following the procedure shown in Figs. 8.1B,C,D, cut a branch from a geranium plant and insert it into a rubber stopper. *Keep the cut end moist, but avoid wetting the leaves.*

NOTE: After cutting the branch off, hold the cut end under a running faucet (avoid wetting the leaves!) and cut another inch off. The cut surfaces must be kept moist to prevent breaking the column of water in the vascular tissues of the branch.

▶ Slowly insert the rubber stopper and branch into the flask to avoid creating bubbles. (If this is done properly, water will be forced out of the end of the capillary tubing. When the pressure on the stopper is released, the fluid in the capillary tubing will tend to move back toward the flask. If this should occur, fill a syringe with water and insert the needle into the rubber tubing at the place where the capillary tubing and the flask join. *Slowly* inject water until it comes back out of the end of the capillary tubing.)

▶ Loosen the clamp on the ring stand and lower the capillary tubing so that it is level with the surface of your table or desk (Fig. 8.1E). If the apparatus has been properly set up, the water column in the tube will begin to recede toward the flask. 31-A What is responsible for this movement of water? The rate at which the water moves is a measure of the rate of water uptake by the branch and may be used as a measure of the rate of transpiration.

FIG. 8.1 PROCEDURE FOR DETERMINING THE RATE OF TRANSPIRATION



NOTE: If the water column goes past the end of the ruler nearest the flask, it may be returned to your starting position by injecting water into the rubber tubing connecting the capillary tubing to the flask.

▶ Determine the transpiration rate by recording the distance the water column moves each minute for a period of 10 minutes (be prepared to change to shorter or longer intervals of time depending on the rate of water movement in the column). 31-B Record your results in the table on page 301. 31-C Graph your data on page 302.

FOR THOUGHT, DISCUSSION, AND FURTHER STUDY

1 Under what conditions in nature would you expect a plant to have a high or low rate of transpiration?
2 Did you have a "control" for this experiment? If not, suggest one.
3 How do you think a scientist would proceed to measure the actual force of the transpirational pull in this experiment?
4 How is the movement of water and dissolved substances in a plant related to transpiration?
5 In this experiment, what parts of the apparatus represented the missing (cut off) parts of the whole plant?
6 In order for plants growing in a desert to survive, what are some of the adaptations of the leaves or other organs that you would expect to find?
7 If you used the procedure in this experiment, what would be the effect of the following on the rate of transpiration—light intensity, air movement, humidity, others? Enter your results in the table on page 301 and graph your data in Fig. 31-C.
8 Devise a method for estimating the volume of water lost in transpiration per unit area of leaf surface in a given time (using the apparatus of this experiment).
9 Of what value is this control of water loss to the plant?

EXERCISE 49

HOW DO GIBBERELLINS AFFECT PLANT GROWTH?

Gibberellins are plant growth substances that were first isolated in Japan from a fungus that caused a disease called "foolish seedling disease." The Japanese scientists who studied this disease found that the fungus was producing chemical substances that were strongly affecting the normal growth and development of rice plants. Gibberellins are also produced by the higher plants, beans, for example.

In this exercise you will attempt to determine what aspect of plant growth is affected by this plant growth substance.

PROCEDURE

▶ Working in teams of three, obtain 40 bean seeds that have been soaking in water for several hours.

▶ Plant 20 seeds (about ½ inch deep) in moist vermiculite in a tray. Label the tray "Gibberellin treated" (Fig. 11.4B).

▶ Plant the remaining 20 seeds in a second tray labeled "Control" (Fig. 11.4B).

▶ Watch the trays for the next seven to 10 days. When the plants are several centimeters tall (about three inches), select 10 plants in each tray that are about the same size. Label each individual plant with a number (1, 2, 3,...) along with the date. Cut the remaining plants at the ground level and discard the parts you have cut off (Fig. 11.4C).

▶ Measure the height of each plant (in millimeters) from the soil to the tip of the shoot apex. 49-A Record the individual measurements in the table (page 341) under the column headed "Day 0."

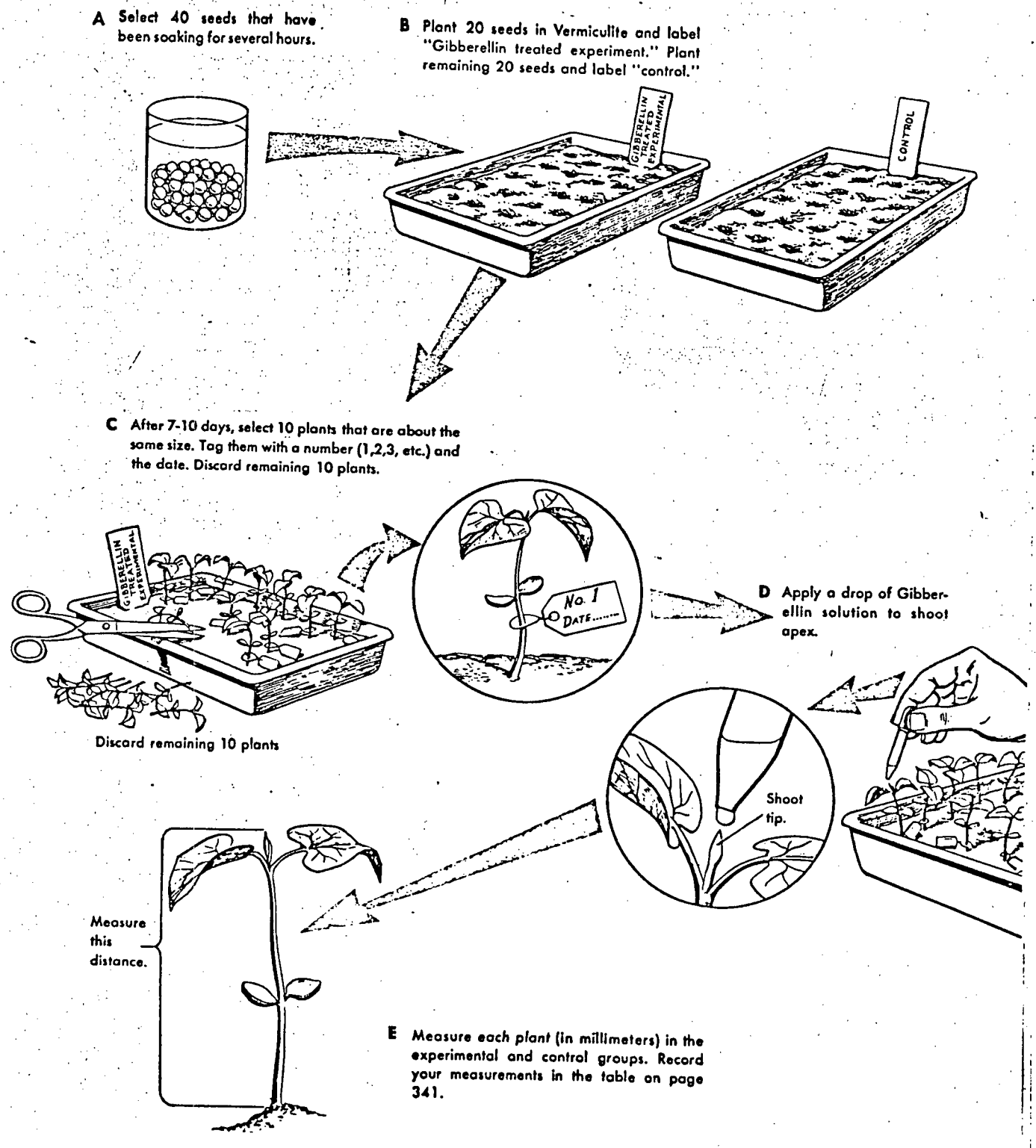
▶ Apply a drop of gibberellin to the shoot apex of each plant in the "G-A" tray (Fig. 11.4D). 49-B What will you apply to the "control" plants? (This procedure should be repeated in three to four days.)

NOTE: This procedure may be modified if a weekend falls during the first 5 measurements.

▶ Measure the height of each plant in the "experimental" and "control" groups on each of five days following the initial measurement (Day 0) and on the eighth day (Fig. 11.4E). Record the measurements in the table (49-A). 49-C Do the control plants respond to gibberellin in the same way as the experimental plants? If not, how do they differ?

▶ Using the data in the table (49-A), calculate the *per cent* increase in length for each group on the first, second, third, fourth, fifth, and eighth day by using the following formula:

FIG. 11. 4 PROCEDURE FOR DETERMINING EFFECT OF GIBBERELLIN ON PLANT GROWTH



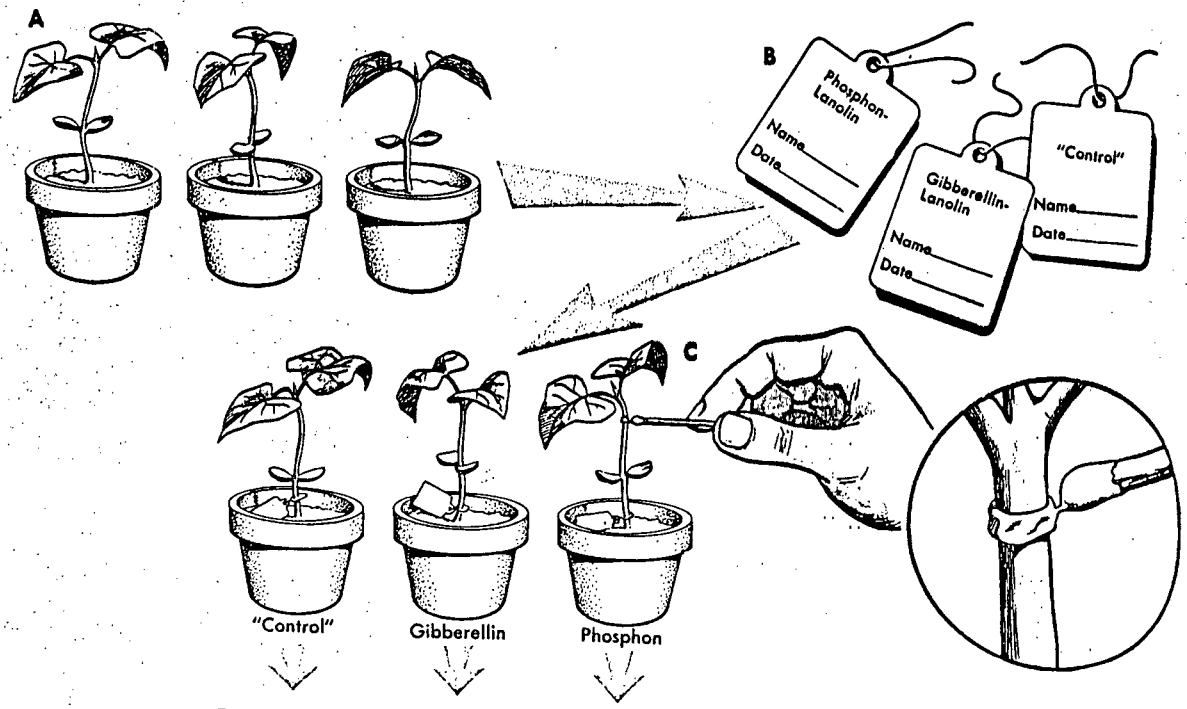
$$\frac{\text{Average length (day 1, 2, 3, etc.)} - \text{Average Initial Length}}{\text{Average Initial Length}} \times 100 = \% \text{ Increase in Length}$$

Plot these data in 49-D. Use a different colored pencil for the experimental and control group.

FOR THOUGHT, DISCUSSION, AND FURTHER STUDY

1 Based on the results of this experiment, what do you think the rice plants that have "foolish seedling disease" look like?
2 The peas used in this exercise are a dwarf variety whose dwarfness is controlled by a single gene. Suggest a possible way this gene might produce dwarf plants.
3 How would you go about determining where gibberellins are produced in the plant?

FIG. 11.5 EFFECT OF GROWTH INHIBITORS ON PLANT DEVELOPMENT

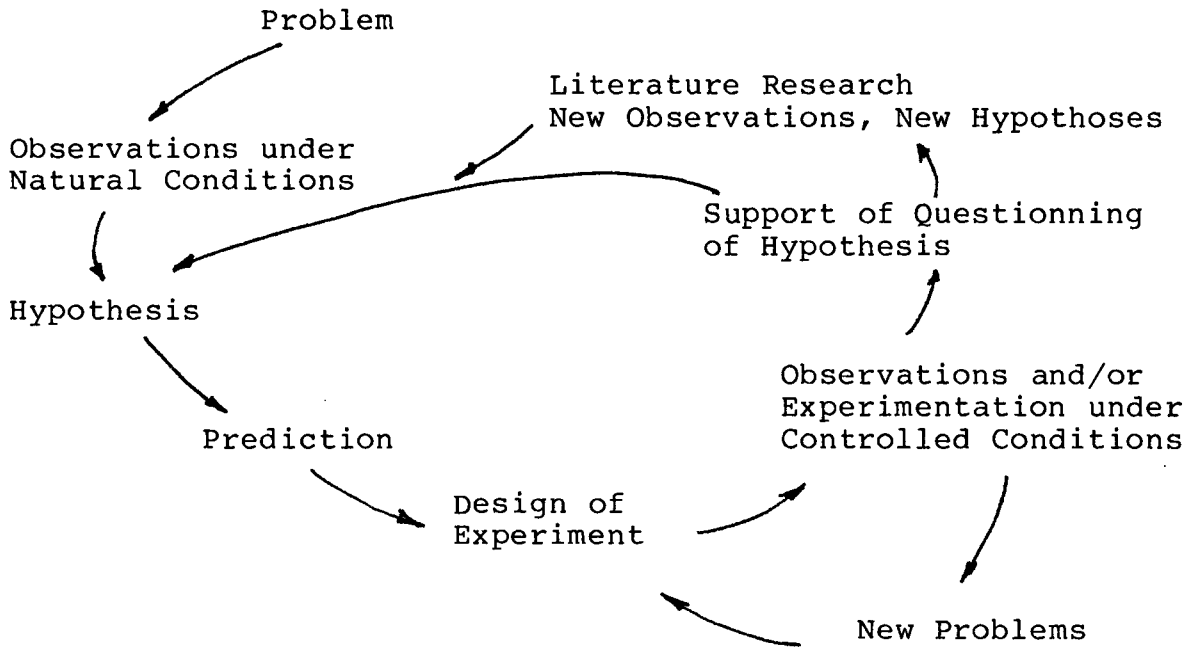


D Examine the plants every 2 to 3 days for the next 3 weeks. Record your observations in the table (on page 343) and by a drawing (on page 344).

APPENDIX D

An Example of the Process of Scientific Investigation

AUTHOR'S MODEL OF THE PROCESS
OF SCIENTIFIC INVESTIGATION



- as used in preliminary lesson (P) of experimental group

AN EXAMPLE OF THE APPLICATION OF THE SCIENTIFIC METHOD

PROBLEM

What internal factor causes the male piranah's belly to turn bright red in the presence of an estrus female piranah?

OBSERVATIONS

(1) When an estrus female piranah is placed near a male piranah, the piranah's belly turns red.

(2) If the female is not in estrus then the male belly does not turn red. (All other conditions controlled)

RESEARCH

(1) When an estrus female of almost any higher vertibrate comes near the male of the species, the levels of testosterone in the blood stream of the male rises.

(2) From experiment, it has been shown that the levels of testosterone in the blood stream of the male piranah rise when an estrus female is present.

HYPOTHESIS

Perhaps testosterone is the internal factor responsible for the red belly of the male piranah.

EXPERIMENTAL PROCEDURES AND DATA COLLECTION

(1) Castrate a male, put with female - red belly? (Tabulate several trials.) Answer - not. Control - non-castrated male under the same condition.

(2) Inject a castrated male with testosterone, place with estrus female - red? (Tabulate several trials.) Control - castrated male. Answer - yes.

ANALYSIS

Any graphs accumulated from data.

DISCUSSION

Problems with the practical aspects of the experiment. Any unexpected (i.e., off the topic) results? Sources of error?

CONCLUSION

The testosterone seems to produce the red belly. Additional examination required, e.g., histological data, metabolic date. Maybe testosterone is a precursor for something else.

APPENDIX E

Activities in the Experimental Group's Investigative-based Laboratory Program

CATALASE ACTIVITY OF VARIOUS TISSUES - LAB 1

A. PRIOR KNOWLEDGE

1. $H_2 O_2 \xrightarrow[\text{(ENZYME)}]{\text{CATALASE}} H_2 + 1/2\ O_2 + \text{Energy}$

   PEROXIDE
   (A METABOLIC POISON)

2. Catalase is found in living tissues in various concentrations depending on the amount of peroxide present.
3. Peroxide is sometimes used as an antiseptic.
4. 1 calorie is the amount of heat required to raise the temperature of 1 gram of water 1°C.
5. A calorimeter is a device used to measure the amount of heat released or used by a reaction.

B. STATEMENT OF THE PROBLEM

What are the relative amounts of catalase found in various kinds of tissue?

C. HYPOTHESIS (THEORY)

Make a statement with regard to the following tissues - cooked and uncooked minced - apple, potato, kidney and liver. Substantiate your statements.

D. EXPERIMENTAL PROCEDURES

Be sure your procedures are well organized such that the experiment may be repeated by another investigator. The design must include controls*, the number of trials to be run, the length of each trial, etc. Some equipment will be laid out for you - ask for anything in addition that you think you might need.

E. DATA

Gather and tabulate data - be sure data tables depict quantitative results (numbers, symbols). Organize your observations.

F. ANALYSIS

To adequately analyze data, figures may be graphed so as to see trends.

G. DISCUSSION

What relationships may be seen between the analysis of the data and the original hypothesis? Use your intuition, imagination and reasoning to interpret and speculate from your analysis of data. Any sources of error?

*"It has been conclusively demonstrated by hundreds of experimentors that the beating of drums will restore the sun after an eclipse".

Sir R.A. Gregory

H. CONCLUSIONS

What conclusions (if any) can be made about the original hypothesis? What further problems are suggested by the outcomes of the research?

FINAL WRITE-UP

1. Title
2. Statement of the problem
3. Formulation of the hypothesis
4. Experimental procedures
5. Collection of data
6. Analysis of data
7. Discussion
8. Conclusion.

Catalase Activity- Teacher's Notes - LAB # I

A) Apparatus supplied- cooked and uncooked, minced potatoe and liver (20% solution)
- long TT, thermometers, stoppers (ie. crude calorimeters)
- 3% peroxide solution
- graduated cylinders, balances
- tweezers, tubing, volumetric tubes, ring stands.

B) Hypothesis- be sure to watch that students comment on both the relative amounts of catalase in cooked vs uncooked material and liver vs potatoe. Justification must be provided for hypothesis based on prior knowledge.

C) Experimental Procedures- any procedures that attempt to measure the amount of either oxygen or energy released from the breakdown of peroxide is satisfactory.
Before actual experimentation begins students will have to establish the amount of tissue to be used- too much will result in excessive oxygen.

D) Data and Analysis- students will hopefully categorize their data in a readable fashion. A graphical analysis of temp. vs time clarifies data if the energy component is measured.

E) Discussion- full and complete discussion of all experimental results are looked for including any sources of error that may have affected the results- eg. poorly insulated calorimeter, pressure build up in the stoppered test-tube.

Laboratory 2

Reaction of Cells in Changing Environments

A) Prior Knowledge

1) The closely regulated environment inside an elodea cell contains a concentration of approx. 0.9% NaCl.
2) The natural environment of elodea is pond water of approx. 100% H_2O.
3) Reveiw all of the theoretical principles of osmosis and diffusion before continuing.

B) Statement of the Problem

What is the response of an elodea leaf cell to an environment that contains a higher concentration of NaCl than its natural environment?

C) Hypothesis
D) Experimental Procedures
E) Data and Observations
F) Analysis
G) Discussion

- follow general guidelines from previous lab.

Reaction of Cells in Changing Environments- LAB 1
Teacher's Notes

A) Apparatus supplied- sprigs of elodea
- 5% NaCl solution
- microscope slides and coverslipes
- eye droppers

B) Hypothesis- be sure the reasons for the hypothesis are clearly stated and supportable by theoretical notions.

C) Experimental Procedures- adequate control of procedures is most necessary - light, temperature and water content are critical. It is better to use the same leaf cell as control (100% water) and experimental (5% water)- this will allow student to view the evidence continuously.

D) Data and Analysis- be sure that only measured values are recorded on the data table- all qualitative results are observations and should be included under that title.

E) Discussion- the major sources of error are- maintenance of controlled conditions, improper and inadequate evidence for stating assuredely that the environments are as claimed.

Laboratory 3
Light Intensity and the Rate of Photosynthesis

A) Prior Knowledge

1) Light intensity varies from hour to hour as well as season to season on the earth.
2) Light intensity is a measure of the quantity of light and may therefore be measured in watts.
3) The rate of photosynthesis refers to the amount of photosynthetic activity taking place in the plant leaf over time.
4) Elodea, a water plant, will be used as the experimental subject. For information concerning elodea and its natural environment, see lab 2.

B) Statement of the Problem

How does light intensity affect the rate of photosynthesis in elodea leaf cells?

C) Hypothesis
D) Experimental Procedures
E) Data and Observations
F) Analysis
G) Discussion

- follow general guidelines from previous labs.

Light Intensity and the Rate of Photosynthesis-Lab 3

Teacher's Notes

A) Apparatus supplied- sprigs of elodea
- test tubes, clamps, ring stands
- various wattages of light bulbs
- pond water

B) Hypothesis- most students will make a general statement concerning light intensity and the rate of photosynthesis. Indeed, lecture knowledge up to this point is insufficient to warrant any detailed hypothesis such as; a 100 watt increase will result in a two-fold increase in photosynthetic activity. A more general hypothesis such as; as the intensity increases one will find that photosynthetic activity will also increase is sufficient.

C) Experimental Procedures- some students will attempt to use the amount of sugar produced by photosynthesis as an indication of photosynthetic rate. This is difficult to measure over time. More adequate is measure of oxygen emission which may be readily determined by counting bubbles emerging from the elodea leaves.

D) Data and Analysis- it is important for the student to understand that to measure the RATE of photosynthetic acitivity, one must measure the amount of photosynthetic product produced over time.

E) Discussion- for the discussion to be adequate, a clear relationship must be presented from data analysis. Some students may not have used enough time to establish the levelling off in photosynthetic activity that should have occurred after continuous intensity exposure.

Laboratory 4

Varying Quantities of Carbon Dioxide Exposure and Photosynthetic Activity.

A) Prior Knowledge

1) In this case the amount of exposure of a plant to varying quantities of carbon dioxide are related to the rate of photosynthesis.
2) Although the atmosphere is predominately composed of nitrogen (approximately 78%); and oxygen (approximately 21%); carbon dioxide constitutes about 0.04 per cent by volume of the atmosphere.
3) Quantities of carbon dioxide do vary globally. Higher concentrations are found in industrialized areas where the bi-products of fossil fuel combustion are emitted into the air.
4) Potassium or sodium hydroxide solids will effectively remove CO_2 from the air.

B) Statement of the Problem

What is the relationship between photosynthetic activity in a geranium leaf and varying quantities of carbon dioxide exposure to that leaf?

Varying Quantities of Carbon Dioxide Exposure and Photosynthetic Activity- Lab 4

Teacher's Notes

A) Apparatus Supplied- Geranium plants
- beakers, petri dishes, funnels
- KOH, NaOH solids
- lamps, cotton, hot plates
- alcohol, iodine solution

B) Hypothesis- most students will suggest a direct variation relationship between the amount of CO_2 and photosynthetic activity. However, a more refined and definitive statement may be forwarded as a result of the experience gained from the last lab where photosynthesis rates were measured.

C) Experimental Procedures- this time a geranium plant is provided, not elodea. Because geraniums are not hydrophytes as are elodea plants, oxygen emission is not as viable a measure of photosynthetic activity. The alcohol bath method of extracting chlorophyll may be demonstrated if desired. Iodine may then be used to indicate the presence of starch.

D) Data and Analysis- accumulated data should naturally lead to a graphical and possibly mathematical correlation between photosynthetic activity and carbon dioxide concentration.

E) Discussion- controlling such variable factors as the quality and quantity of light, quantity of water and the soil composition must be fully discussed.

Laboratory 5 - Determination of the Quantity of Gibberllic Acid in a Bean Seedling

A) Prior Knowledge

1) Gibberllic acid is a plant growth hormone that causes stem elongation in bean seedlings.
2) The quantity of gibberllic acid in most dicotyledonous plants is extremely small. (<0.01 g/plant)
3) A gibberllic solution, using water as the solvent, is often applied to the apical meristematic region by horticulturalists when cell elongation is required in the stem.

B) Statement of the Problem

What is the precise quantity of gibberllic acid in the plant body of the common castor bean (Ricinus communis)?

Determination of the Quantity of Gibberllic Acid
In a Bean Seedling - Lab 5 - Teacher's notes

A) Apparatus supplied - 200 pre-soaked castor bean seeds
- plant trays
- vermiculite, potting soil
- labels, eye droppers, toothpicks
- solutions of gibberllic acid (0.0001 g, 0.0005 g, 0.001 g, 0.005 g, 0.01 g in 10 ml water)

B) Hypothesis - a specific statement is requested here yet students really do not have sufficient experience to stipulate anything but a general range. A little research concerning gibberllic concentrations and dicotyledon plants should bring a figure of within 0.0005 and 0.01 g per 10 ml water.

C) Experimental Procedure - using known concentrations of gibberllic acid the student should design a controlled experiment using several plants exposed to the hormone concentrations. The quantity of gibberllic acid is estimated by comparison to the ability of known concentrations of the hormone to stimulate stem elongation.

D) Data and Analysis - data must include the control measure of plant stem growth (p.0 g of gibberllic acid) and stem growth of all other plants. All plants initially are the same size so as to allow comparisons after final growth. (termination - 8 days)
Analysis of height (y-axis) and hormone concentratin (x-axis) should result in a linear relationship $y=mx+b$. The slop of the

growth (m) depicts the rate of growth. Calculating for a y equal to the average height of the control plants, a comparison may be made to the experimental plants which were under varying conentrations of gibberllic acid.

E) Discussion - due to the fact that such minute concentrations of hormone are used it is critical that solutions are made up careful. The degree of error should be indicated as potential sources of error.
Stem elongation may be discussed with particular reference to apical meristem histology.

Laboratory 6 - The Rate of Transporation and Humidity

A) Prior Knowledge

1) As strictly defined, transporation refers to the process whereby water vapor is lost to the atmosphere from plant leaves.
2) For the purposes of this lab, the amount of water absorbed by the roots that is used in growth and photosynthesis is insignificant compared to the amount of water that is absorbed and then lost through transpiration.
3) Cobalt chloride paper (supplied) is sensitive to moisture. In the presence of moisture, this blue paper turns pink.
4) Relative humidity is a measure of the quantity of moisture in the air compared to the same air when saturated. Relative humidity is measured as a %, ie. 100% is saturation; 60% would mean the air is 60% saturated with moisture. Humidity is measured using a sling paychrometer.

B) Statement of the Problem

How does a change in relative humidity affet the rate of transpiration from a geranium plant?

The Rate of Transpiration and Humidity
Lab 6 - Teacher's Notes

A) Apparatus Supplied - Geranium plants
- Ring stands, clamps
- glass tubing (2mm diameter)
- rubber tubing
- razor blade
- 100 and 250 ml beakers

B) Hypothesis - saturated air (R.H.=100%) provides reverse pressure on leaf transpiration in view of the fact that saturated air can no longer hold water that is bein g transpired. Most students will use this as an indication that dryer air will allow for more rapid transpiration and that saturated air will reduce the transpiration rate close to zero.

C) Experimental Procedure - two difficulties will emerge when students set out to design their procedure -

1) How to control relative, ambient humidity.
2) How is measure the rate of transpiration.

This first problem may be overcome by taking measurements over a period of several days, as R.H. varies considerably from day to day depending on meteorological conditions.
The second problem will be solved in a variety of ways the best of which incorporate the use of an instrument that measures the uptake of water by the plant's roots as an indication of transpiration rate.

D) Data and Analysis - graphical analyses readily indicate the relationship between humidity and rate of transpiration. As humidity is the independent variable it is displayed on the x-axis.

E) Discussion - controlling variables is difficult in this experiment, particularly if the procedures take several days for completion. Temperature must be controlled as must quality, quantity and duration of light.
Many students will make mention of the many and varied practical problems with their apparatus.

Laboratory 7 - The Rate of Transpiration and Temperature

A) Prior Knowledge

1) This is a continuation of the previous lab in the sense that you will be measuring the rate of transpiration again.
2) In this case you will relate ambient temperature to the rate of transpiration. Temperature is measured in °C and will be measured using a standard laboratory thermometer - + 0.02°C. (degree of error)
3) In view of the discrepancies obtained using your previous apparatus, this lab provides an opportunity to 'upgrade' your technique, therby increasing your experimental validity.

B) Statement of the Problem

How does a change in ambient temperature affect the rate of transpiration from a geranium plant?

The Rate of Transpiration and Temperature - Lab 7

The same apparatus is supplied for this lab us that for the last lab as this experiment is essentially a continuation of lab 6.

It is hoped that by continuing an investigation of the same phenomena (that of transpiration) that tudents will learn from past errors and use either a modification of previous technique or a wholly new technique depending on degree of previous error.

The variable factor of temperature is more easily varied than humidity so the students should find that obtaining results occurs in a shorter period of time.

By using prior experience from a previous piece of work (lab 6) it is hoped that students will not only work faster but increase the validity of their results.

APPENDIX F

Raw Scores for T_1 and T_2

SPI RAW SCORES - PRE TEST

BLOCK B - CONTROL

	Student Number	Score (x)	$x=x-\bar{x}$	x^2
	1	110	1.86	3.46
	2	121	12.86	165.38
	3	111	2.86	8.18
	4	112	3.86	14.9
	5	99	9.14	83.54
	6	103	5.14	26.42
	7	117	8.86	78.5
Female	8	125	16.86	284.26
	9	95	13.14	172.66
	10	108	0.14	0.02
	11	104	4.14	17.14
	12	92	16.14	260.5
	13	129	20.86	435.14
	14	110	1.86	3.46
	15	130	21.86	477.86
Male	16	96	12.14	147.38
	17	112	3.86	14.9
	18	111	2.86	8.18
	19	101	7.14	51.0
	20	80	28.14	791.9
	21	105	3.14	9.9

$21 \overline{)2270.98}$ $\quad$ $21 \overline{)3054.68}$

$\delta = 108.14$ $\quad$ $\Sigma x^2 = 145.46$

$\bar{x} = \sqrt{145.46} = 12.06$

(Mean) δ = 108.14

(Std. Dev.)$\bar{x}$ = 12.06

Range = 80 - 130

SPI RAW SCORES - POST TEST

BLOCK B - CONTROL

Student Number		Score (x)	$x=x-\bar{x}$	x^2
	1	111	2.67	7.13
	2	121	12.67	160.53
	3	110	1.67	2.79
	4	100	8.33	69.39
	5	109	0.33	0.11
Female	6	105	3.33	11.09
	7	117	8.67	75.17
	8	126	17.67	312.23
	9	94	14.33	205.35
	10	109	0.67	0.45
	11	109	0.67	0.45
	12	93	15.33	235.01
	13	123	14.67	215.21
	14	111	2.67	7.13
	15	128	19.67	386.91
	16	97	11.33	128.37
	17	113	4.67	21.81
Male	18	110	1.67	2.79
	19	103	5.33	28.41
	20	82	26.33	693.27
	21	104	4.33	18.75

$21\overline{)2275}$

$\delta = 108.33$

$21\overline{)2662.54}$

$\Sigma x^2 = 126.79$

$\bar{x} = \sqrt{126.79} = 11.26$

(Mean) δ = 108.33

(Std. Dev.) $\bar{x}$ = 11.26

Range = 82 - 128

SPI RAW SCORES - PRE TEST

BLOCK C - EXPERIMENTAL

Student Number		Score (x)	$x=x-\bar{x}$	x^2
	1	97	10.5	110.25
	2	110	2.5	6.25
	3	123	15.5	240.25
	4	83	24.5	600.25
Female	5	134	26.5	702.25
	6	93	14.5	210.25
	7	125	17.5	306.25
	8	95	12.5	156.25
	9	104	3.5	12.25
	10	103	4.5	20.25
	11	125	17.5	306.25
	12	108	0.5	0.25
	13	82	25.5	650.25
	14	103	4.5	20.25
	15	120	12.5	156.25
Male	16	100	7.5	56.25
	17	114	6.5	42.25
	18	125	16.5	272.25
	19	100	7.5	56.25
	20	108	0.5	0.25

$20\overline{)2150}$

$\delta = 107.5$

$20\overline{)3925.0}$

$\Sigma x^2 = 196.25$

$\bar{x} = \sqrt{196.25} = 14.01$

(Mean) δ = 107.5

(Std. Dev.)$\bar{x}$ = 14.01

Range = 82 - 134

SPI RAW SCORES - POST TEST

BLOCK C - EXPERIMENTAL

Student Number		Score (x)	$x=x-\bar{x}$	x^2
	1	105	5.45	29.7
	2	115	4.55	20.7
	3	123	12.555	157.5
	4	89	21.45	460.1
Female	5	135	24.55	602.7
	6	99	11.45	131.1
	7	127	16.55	273.9
	8	101	9.45	89.3
	9	109	1.45	2.1
	10	107	3.45	11.9
	11	110	0.45	0.2
	12	114	3.55	12.6
	13	86	24.45	597.8
	14	106	4.45	19.8
	15	123	12.55	157.5
	16	109	1.45	2.1
Male	17	113	2.55	6.5
	18	128	17.55	308.0
	19	106	4.45	19.8
	20	113	2.55	6.5

$20 \overline{)\ 2209}$

$\delta = 110.45$

$20 \overline{)\ 2909.8}$

$\Sigma x^2 = 145.49$

$\bar{x} = \sqrt{145.49} = 12.06$

(Mean) δ = 110.45

(Std. Dev.)$_{\bar{x}}$ = 12.06

Range = 86 - 135

RAW SCORES - EXPERIMENTAL GROUP (BLOCK C)

	Student Number	x (pre score)	y (post score)
	1	97	105
	2	110	115
	3	123	123
	4	83	89
	5	134	135
Female	6	93	99
	7	125	127
	8	95	101
	9	104	109
	10	103	107
	11	125	110
	12	108	114
	13	82	86
	14	103	106
	15	120	123
Male	16	100	109
	17	114	113
	18	124	128
	19	100	106
	20	108	113

TABLE T_1

RAW SCORES - EXPERIMENTAL GROUP (BLOCK C)

	Student Number	x (pre score)	y (post score)
	1	110	111
	2	121	121
	3	111	110
	4	112	100
	5	99	109
Female	6	103	105
	7	117	117
	8	125	126
	9	95	94
	10	108	109
	11	104	109
	12	92	93
	13	129	123
	14	110	111
	15	130	128
	16	96	97
	17	112	113
Male	18	111	110
	19	101	103
	20	80	82
	21	105	104

TABLE T_2

APPENDIX G

Standard Deviation Graphs for T_1 and T_2

FIG. 1 - ANALYSIS OF PRETEST SCORES - CONTROL GROUP

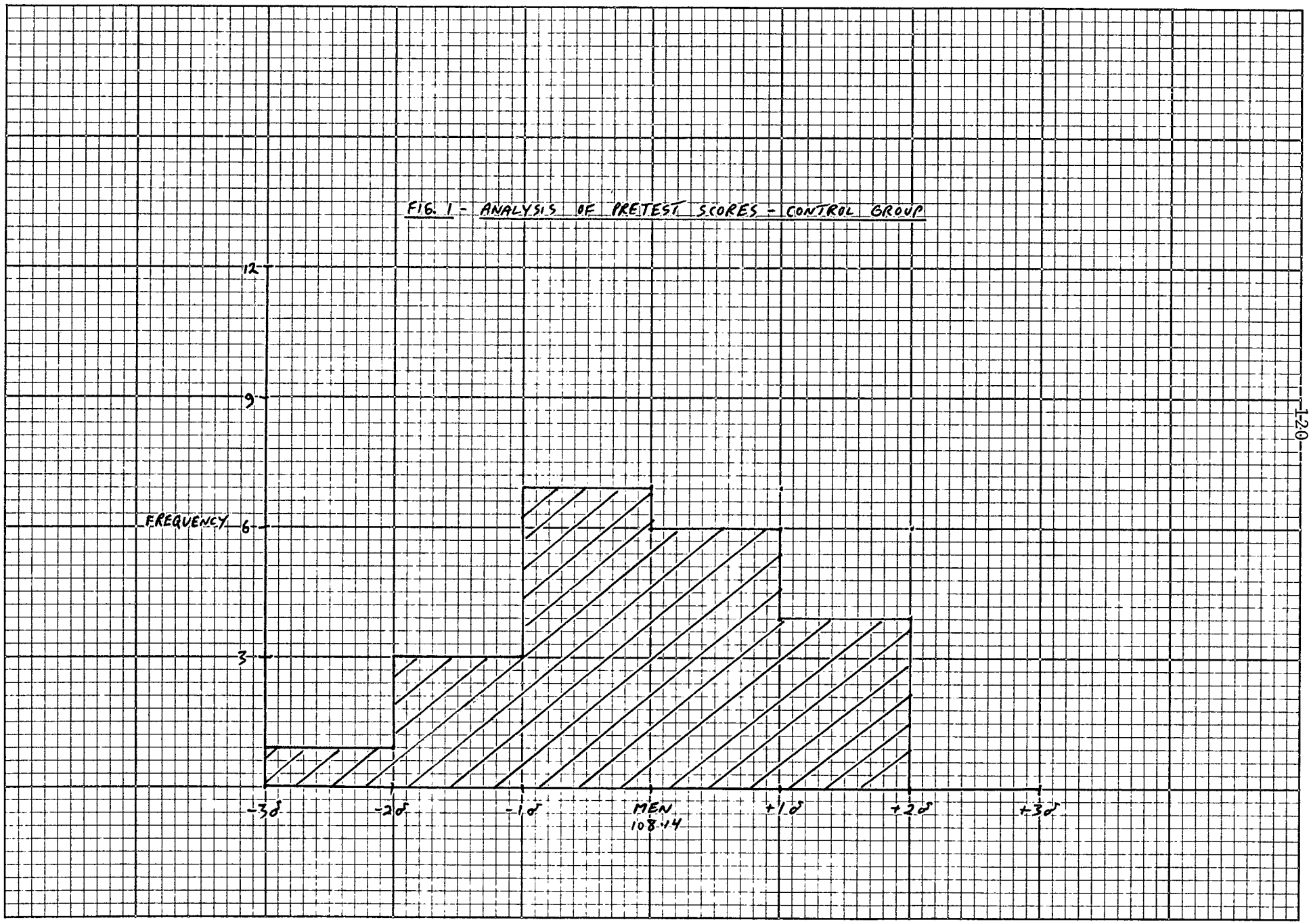


FIG 2 - ANALYSIS OF POSTTEST SCORES - CONTROL GROUP

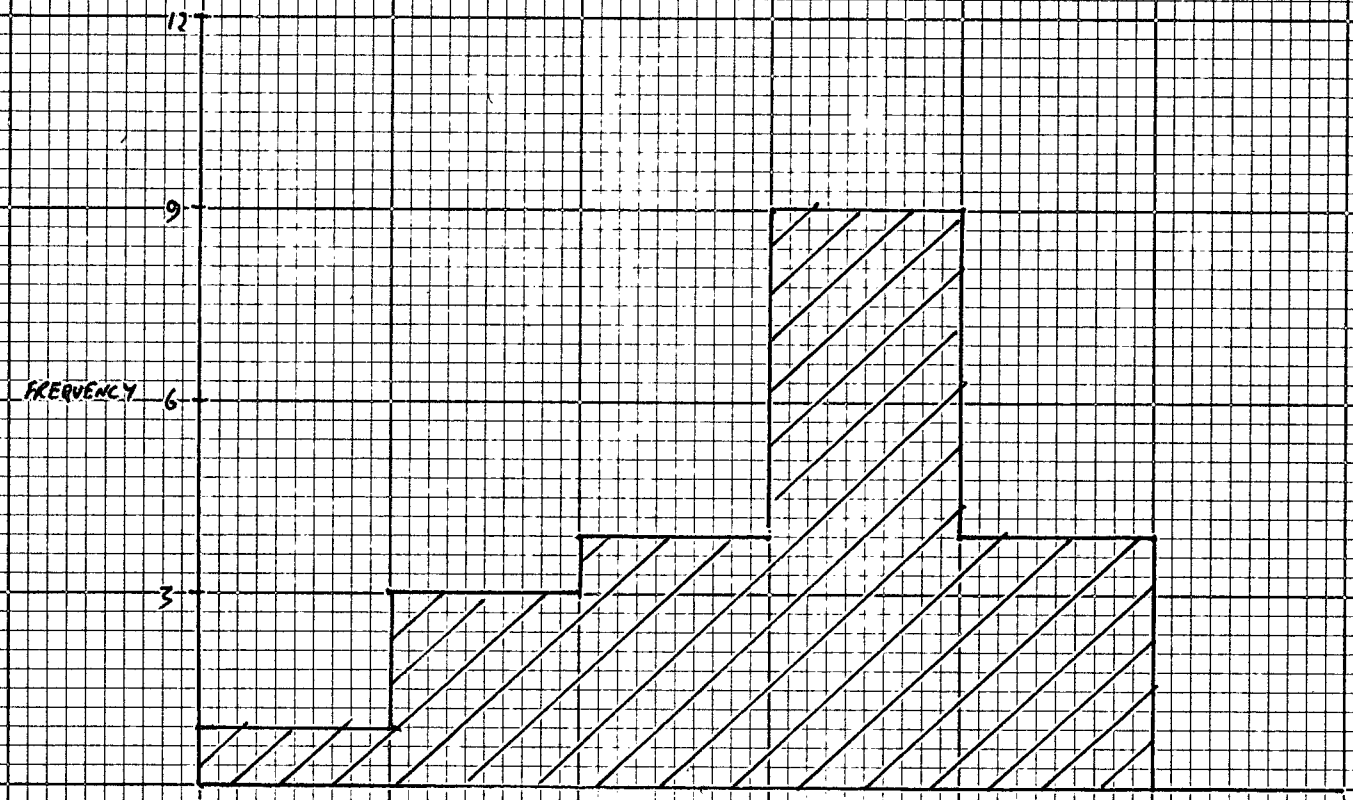


FIG. 3 - ANALYSIS OF PRETEST SCORES - EXPERIMENTAL GROUP

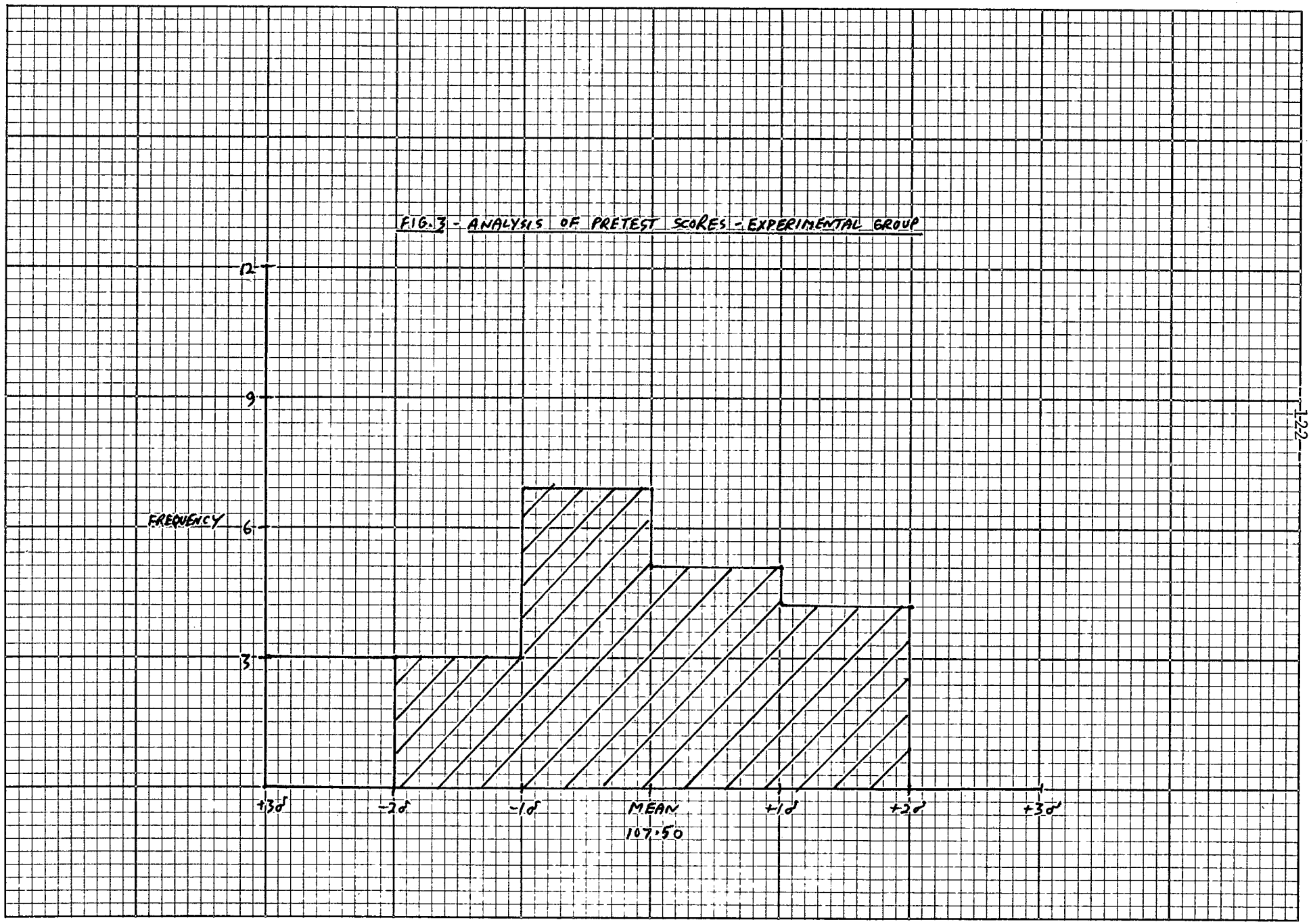
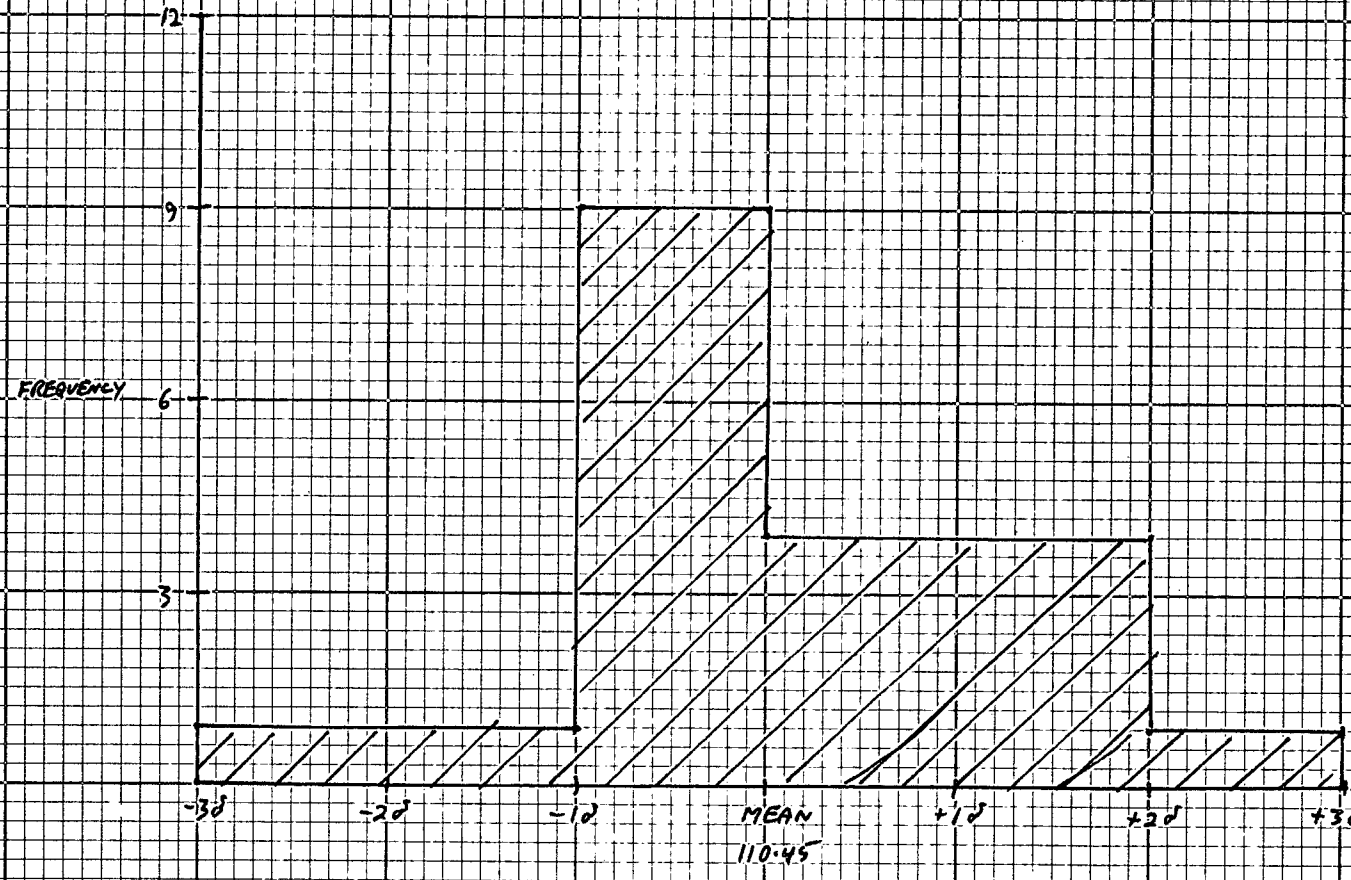


FIG. 4 - ANALYSIS OF POSTTEST SCORES - EXPERIMENTAL GROUP



APPENDIX H

Data Outlay for the Analysis of Covariance

Table 6 - Data Outlay - T_1

Student Number	Y	X_1	X_2	X_3
1	105	1	97	97
2	115	1	110	110
3	123	1	123	123
4	89	1	83	83
5	135	1	134	134
6	99	1	93	93
7	127	1	125	125
8	101	1	95	95
9	109	1	104	104
10	107	1	103	103
11	110	1	125	125
12	114	1	108	108
13	86	1	82	82
14	106	1	103	103
15	123	1	120	120
16	109	1	100	100
17	113	1	114	114
18	128	1	124	124
19	106	1	100	100
20	113	1	108	108

Table 7 - Data Outlay - T_2

Student Number	Y	X_1	x_2	x_3
1	111	-1	110	-110
2	121	-1	121	-121
3	110	-1	111	-111
4	100	-1	112	-112
5	109	-1	99	- 99
6	105	-1	103	-103
7	117	-1	117	-117
8	126	-1	125	-125
9	94	-1	95	- 95
10	109		108	108
11	109	-1	104	-104
12	93	-1	92	- 92
13	123	-1	129	-129
14	111	-1	110	-110
15	128	-1	130	-130
16	97	-1	96	- 96
17	113	-1	112	-112
18	110	-1	111	-111
19	103	-1	101	-101
20	82	-1	80	- 80
21	104	-1	105	-105