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DISSERTATION

Presented in Partial Fulfillment of the Requirements for
the Degree Doctor of Philosophy in the Graduate
School of The Ohio State University

By
William R. Hughes, B.S., M.A.

The Ohio State University
1973

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CHAPTER I

INTRODUCTION

Introduction and Need for the Study

In today's rapidly expanding technological world, where it has been suggested that approximately 90% of all human knowledge has been discovered in the last two decades, it is imperative that educational institutions commit themselves to improving both their facilities and curriculum. In order to provide a broader and more comprehensive education for our children, schools must make efficient use of some of today's modern tools. Jerome Bruner (1962:1) stated that:

More than ever before, we are concerned with the nature of the educational process, with the goals of education, with the impact of change and with the techniques and devices that can be used in improving the educational enterprise. Indeed, to the outside observer it must seem as if we were preparing to embark upon a permanent revolution in education.

One of the most important devices to be developed and gain widespread usage in our society is the computer. Patrick Suppes (1968:420) observes that:

Current applications of computers and related information-processing techniques run the gamut in our society from the automatic control of factories to the scrutiny of tax returns. Every kind of complex experiment is beginning to be subject to computer assistance, either in terms of the actual experimentation or in terms of extensive computations integral to the analysis of the experiment. These applications range from the bubble-chamber data on particles to the crystallography of protein molecules.

As yet, the use of computer technology in administration and management on the one hand, and scientific and engineering
applications on the other, far exceed direct application in education. However, if potentials are properly realized, the character and nature of education during the course of our lifetimes will be radically changed.

The computer's potential for educational use lies in its capability of doing calculations quickly and retrieving stored information almost instantaneously. The approach to education can change. Students can spend time analyzing problems and developing solutions - not in the tedious task of performing the arithmetic required to arrive at an answer. The computer will do the arithmetic for them. The instant retrieval of information may alleviate the difficult task of remembering large amounts of information. Education may be directed toward application and other higher order skills. A combination of information retrieval and speed of calculation or decision making makes the computer useful as an individualized teaching device. Because of the versatility, computer systems may prove to be teaching devices that will revolutionize education.

Computer capabilities can be effectively used in science classroom and laboratory situations. One of the primary functions of science teaching is that of aiding students in their development of skills in the processes of science, such as recognizing and identifying problems, stating hypotheses, understanding assumptions, designing experiments, observing carefully, collecting, interpreting, and evaluating data, and drawing proper conclusions. To achieve that end, the computer can be used to analyze laboratory data quickly and efficiently. Laboratory problems involving mathematical calculations can be programmed and solved quickly. Consequently, students can focus their
attention on the attainment of process skills.

Students are often prevented from being as process oriented as they might be because of a number of extraneous variables. When students actually perform experiments, time, availability of equipment, complexity of equipment, and physical restrictions such as friction and air resistance prevent them from collecting sufficient data or data that would permit appropriate conclusions to be drawn. Most physical situations encountered in a high school laboratory can be described by a few mathematical equations. Using the computer's ability to retrieve information and perform calculations quickly, laboratory situations can be simulated. Computer simulations may permit a greater number of experimental trials, a better selection of input data, and a better pattern of output data. If such results can be realized, the computer will become an indispensable laboratory instrument.

The computer has been used as an instructional tool in a variety of ways, four of which will be discussed here. Computers have been used as a direct means of instruction. This use of the computer is often referred to as Computer Assisted Instruction (CAI). In this application, instructional programs are stored in the computer and the student interacts with these programs by means of electronic interface devices. In its simplest mode of operation, the student sits at something like an electric typewriter. Messages are typed out by the computer and the student types his responses on the typewriter keyboard. The instructional programs may include a broad range of subject matter content.
The simplest CAI application is a drill-and-practice system. A lesson is taught by a teacher in a traditional way. The computer is then used to provide review and practice on the basic concepts and skills.

A higher level CAI application is a tutorial system. The responsibility for presenting concepts is assumed by the computer program. The computer is programmed to converse with the student and become his tutor.

The highest level CAI application is a dialogue system. In this application, the student would carry on a free response dialogue with the computer. Because of the difficulties involved, at present the dialogue systems are only at a conceptual level.

A major obstacle to the widespread utilization of computer systems as a CAI device is their cost and consequent availability. During the 1972-1973 school year, the local Battelle Memorial Institute computer facilities cost $300 per month per terminal. The teletypes rent for about $60 per month. The telephone coupling devices cost about $15 per month. The total cost of a computer terminal is about $400 per month. Showalter (1970) suggests that other commercial computer terminals can be obtained for about $550 per month.

CAI involves students, "on-line", interacting with the computer through a teletype terminal. An estimate of $3.20 per student hour is calculated using the $400 per month terminal cost, six hours per school day, and 21 days per month. Hansen (1968), using a 64 terminal system at Florida State University, reported a cost of $5.85 per instructional hour. It costs about $0.43 per student hour for a classroom teacher,
assuming 24 students per class and five class hours per day at a salary of $1200 per month. The cost of CAI far exceeds that of classroom instruction.

In addition to the cost of computer facilities, the number of hours required to write effective CAI programs is quite high. Blum and Bork (1969) estimate that anywhere from 10 to 200 hours of programmer's time may be necessary to produce tutorial material sufficient for one hour of terminal time, the lesser estimate being for drill and review programs. The cost of software for CAI would have a very high initial cost. Few public schools use CAI as an instructional tool because of the cost of software and computer facilities.

Computers have been used as a computational device. Solving problems concerned with science concepts is generally accepted as a successful way of learning science, but sometimes the calculations become so difficult and time consuming that the student loses sight of the science concepts involved. When the computer is used as a high speed calculator for doing calculations quickly and accurately, this problem can be eliminated. The computer programs can be written for specific computational tasks.

Computers have been used to develop a logical approach to problem solving. Computer-assisted problem solving can be used effectively as an instructional aid in teaching science, mathematics, economics and other subjects. The computer can be used to demonstrate concepts and provide a laboratory for mathematical experimentation and discovery. Writing a computer program leads to better understanding
of the problem or situation. The degree of understanding required to write a successful computer program to solve a problem is far greater than that required to carry out the hand calculation required to solve the problem. In addition, the computer takes the drudgery out of doing the arithmetic and provides more time for learning the more important concepts and developing the capacity to think through and analyze problems logically.

The use of the computer as a calculating device and as a device to assist in problem solving usually involves the students writing their own programs "off-line" and then executing them on the computer. From experience, about 10 minutes is needed "on-line" by a student for an hour's work. The cost of computer time would be about $0.50 per student hour of work on the Battelle system.

Computers can be used to simulate laboratory situations or what might be called Computer Simulated Experimentation (CSE). An experimental situation can be represented by a set of equations programmed into the computer. The student inputs a set of initial values. The computer generates data like the student would have collected in the actual experiment. Experimental errors can be built into the data output to make it realistic. The simulation program can be written so that the data generated by the computer include uncertainties corresponding to experimental errors. The magnitude of these uncertainties can be varied from trial to trial through the use of the computer's random number generator.

The student's action in conducting a Computer Simulated
Experiment is similar to what he would do if he were conducting an actual experiment. He starts both investigations by asking pertinent questions about the situation. He then designs an experiment that will enable him to answer his original question.

In a laboratory experiment, the student would manipulate the laboratory equipment or apparatus to obtain the data required. In a Computer Simulated Experiment, the student would manipulate the input and output data through the use of a computer terminal. Once the data is obtained, whether by laboratory experiment or by computer, the objective is to determine relationships from the data by curve plotting and data analysis.

CSE involves the use of a stored (on tape, cards, or central storage) simulation program which is used to generate data. The student interacts with the simulation program through the computer terminal. The time involved for each simulation trial is usually less than five minutes. The programs necessary for CSE can be relatively short, often incorporating only one scientific concept. The time required to write and de-bug a CSE program is from three to five hours. The use of the computer for CSE may reduce the constraints of high cost of computer time and the requirements of extensive software.

CSE offers teachers a number of advantages when compared to traditional methods of laboratory instruction. Among these are:

1. The necessary equipment to perform certain laboratory experiments may not be available because of expense, or it may be too complex or delicate to permit students to use it.
2. The number of experimental trials that can be performed may be too small to permit generalizations.

3. The experimental technique may be difficult and require an extensive period of development.

4. Actual experiments might expose the student to serious dangers.

5. The time scale may be too short or too long to permit students to make observations.

6. Experimental variables that are difficult to access can be measured.

7. No set-up of experimental apparatus is required.

Sufficient research has been conducted to indicate that the first three uses of the computer described herein have a place in the science classroom. Unfortunately, the present cost of CAI prevents its inclusion into the science programs of most public schools. The computer is extensively used as a computational tool and as an aid to the development of problem solving techniques in those schools having computer facilities.

It appears that CSE offers many advantages to teachers and students. Research is needed to determine whether the benefits derived from computer usage as a data generating device are sufficient to warrant its inclusion into the science laboratory structure. This research should take the form of determining whether:

1. Students develop skills in the processes of science through CSE as in the usual laboratory setting.
2. Students attain understanding of science concepts through CSE as in the usual laboratory setting.

3. Students become as involved in CSE as with actual experiments.

4. Student's attitudes toward CSE are different from their attitudes toward actual experiments.

5. The time required for CSE is less than the time required for laboratory experiments.

The Problem

CSE should provide a unique method for students to develop skills and strategies of inquiry because of the student's control over the input and output variables and a more efficient use of his time.

The objectives of this study were to compare the effectiveness of the exclusive use of CSE, the use of CSE and ordinary laboratory experiments, and the exclusive use of ordinary laboratory experiments.

The major problem of the study was to assess the effect of CSE on the attainment of process skills and acquisition of subject matter content in the physics laboratory. The students' ability to use the processes of science were evaluated by the physics students' design of experiments, the choice of input and output variables, ability to draw inferences, use of interpolation and extrapolation, ability to analyze data, and the ability to draw appropriate conclusions.

Acquisition of content was assessed by appropriate subject matter tests.

Three subproblems were (1) to determine whether students working with CSE became more involved in the experiment by performing
more trials than those students working exclusively with laboratory experiments, (2) to determine whether the students working with CSE had a favorable attitude toward CSE, and (3) to determine whether less time was required to perform a Computer Simulated Experiment than an ordinary experiment.

**Definition of Terms**

The terms used in this study are defined to furnish information for a more complete understanding of the problem stated in the preceding pages and of the hypotheses stated in the succeeding pages of this chapter.

1. **Computer Group (C)**. The computer group will have only an instruction sheet to describe the experiment and will use only computer simulation to obtain data for analysis.

2. **Computer Simulated Experiments (CSE)**. A Computer Simulated Experiment is a computer program run by students in which reliable information on the experimental situation is stored in the computer. The computer output corresponds to data collected in laboratory experiments.

3. **Content**. The term as used in this study refers to the attainment of subject matter knowledge and understanding of scientific facts, concepts, and principles.

4. **Laboratory Group (L)**. The laboratory group will perform the experiment, collect data, and analyze the data in the traditional manner.

5. **Laboratory-Computer Group (L-C)**. The laboratory-computer
group will set up the experiment, run through the experiment once, collect a sample set of data, but will use the computer simulation to obtain the data for analysis.

6. Processes of Science. Processes of science are specific mental skills which are any set of actions, changes, treatments, or transformations used in a special order to achieve the solution of a problem.

Hypotheses

The research hypotheses are as follows:

1. The three experimental groups, L, L-C, and C, do not differ significantly with respect to (a) attainment of process skills, (b) acquisition of content, (c) number of trials performed, and (d) time involved in the experiment or simulation and analysis.

2. There is no significant difference between the attitudes of students in groups L-C and C toward CSE as measured by the Student Attitude Questionnaire.

3. There is no significant difference between the performances of students on laboratory exercises 1, 2, 3, and 4 with respect to the (a) attainment of process skills, (b) number of trials performed, and (c) time involved in the experiment or simulation and analysis.

4. There is no significant difference between the performances of the Laboratory Group on laboratory exercises 1, 2, 3, and 4 with respect to the (a) attainment of process skills, (b) number of trials performed, and (c) time involved in the experiment and analysis.

5. There is no significant difference between the performances of the Laboratory-Computer Group on laboratory exercises 1, 2, 3, and
4 with respect to the (a) attainment of process skills, (b) number of trials performed, and (c) time involved in the experiment, simulation, and analysis.

6. There is no significant difference between the performances of the Computer Group on laboratory exercises 1, 2, 3, and 4 with respect to the (a) attainment of process skills, (b) number of trials performed, and (c) time involved in the simulation and analysis.

7. There is no interaction effect between the three experimental groups, L, L-C, and C, and the four laboratory exercises with respect to (a) attainment of process skills, (b) number of trials performed, and (c) time involved in the experiment or simulation and analysis.

Assumptions

1. Physics laboratory experiments can be performed by CSE so that realistic output data results.

2. The use of the processes of science is an important product of science teaching.

3. Instruments can be developed that will assess the process variables being investigated in this study.

4. Four laboratory situations will provide an adequate amount of time for student behaviour changes to occur.

5. Student's knowledge of subject matter can be assessed by a subject matter test.

6. Student's attitudes toward CSE can be measured by an attitude survey.
Limitations

1. This study was limited to the students in a single high school, Bexley High School.

2. There was a certain amount of interaction between members of the experimental groups. This interaction may have influenced the results of the study.

3. The computer simulations were conducted on only two computer terminals, preventing all students from conducting their simulations at the same time.

Delimitations

1. This study was limited to students enrolled in the physics classes at Bexley High School during the academic year 1972-1973.

2. Data were collected for four laboratory-simulation situations.

3. Only the use of the processes of science, acquired content knowledge, and attitude toward CSE were considered as outcomes of the laboratory-simulation situations.

4. The time spent in laboratory-simulation situations and data analysis was used to provide a measure of the student involvement in each of the laboratory-simulation situations.
CHAPTER II

REVIEW OF RELATED LITERATURE

From the literature available, pertinent investigations and related literature have been selected on the basis of relevancy to the present study. The chapter has been divided into five sections:

2. Computer as a Calculator and an Aid to Problem Solving.
4. Processes of Science.
5. Summary.

COMPUTER ASSISTED INSTRUCTION

Since the early sixties, grants of money have permitted certain schools to carry out fairly extensive CAI developmental programs. The majority of these projects have expended time and money on the development of CAI curriculum materials. Often, this development was not accompanied with carefully controlled research. The result has been a wealth of reports on or about CAI, but few evaluative reports.

The important features of CAI programs are described by Schwarz, Kromhout, and Edwards (1969). They suggest that although CAI was derived from programmed instruction, it is much more versatile and powerful because of the evaluative and decision logic of the computer. Instant feedback by the computer provides the student immediate
reinforcement or correction. Audio-visual materials can be included with a CAI presentation. The computer can guide a student through a sequence of questions dependent on his responses. The computer can give him a quiz, tell him his score, and branch him to appropriate study materials.

Educational alternatives open to CAI designers were listed by Hansen (1970) as: (1) selection of an appropriate media device for presentation of curriculum, (2) control of the rate of presentation, (3) control of the sequence of elements within the curriculum, (4) concurrent recording of all learning behaviors, and most importantly, (5) determination of the rate and sequence by which curriculum elements are presented to the student.

It can be seen that CAI programs should lend themselves to individualization of instruction. A number of researchers including Atkinson and Hansen (1966), Bitzer and Easly (1965), Suppes (1968), Cooley and Glaser (1969), Castleberry and Lagowski (1970), and Jerman (1972) suggest that CAI programs can make decisions and adjust to individual student differences with regard to sequence, rate of progress and amount of material presented.

Jerman (1972) sees the computer as a special tool to be used by educators to assist with the individualization of instruction. It is his contention that educators are not taking full advantage of the computer's capabilities. He feels that teachers who work with CAI must be professionals to the extent that they can handle either fast or slow students according to their specific needs. Along the same
Loughary (1967) calls for a redefinition of the roles of the teacher to take advantage of the computer's capabilities.

A broad range of courses has been programmed for CAI. To illustrate this range, a brief listing of subject area programs will be given. Schwarz, Kromhout, and Edwards (1969), Hansen, Dick, and Lippert (1968), and Bork and Luehrman (1968) describe physics programs. Chemistry programs are described by Boblick (1972), Castleberry and Lagowski (1970), and Dannhauser (1970). Other areas include mathematics and Russian by Suppes and Morningstar (1968); reading by Atkinson and Hansen (1966), and statistics by Grubb and Selfridge (1964).

Many of the CAI research reports involve a comparison of the results obtained using CAI with those obtained using conventional classroom techniques in a conventional setting. Typical of this type of research is a study reported by Suppes and Morningstar (1968). They evaluated three CAI programs involving mathematics drill-and-practice, a tutorial math program, and a college Russian course and found that in most cases the CAI groups performed significantly better than the control groups. Similar results were obtained by Boblick (1972) in a study of students writing chemical formulas. He reported that the CAI groups scored significantly higher on the posttest and had a significantly greater gain. Kromhout, Edwards, and Schwarz (1969) concluded that their CAI course in physics was successful in presenting the material and was also interesting and attractive to the average student.

An extension of this type of research involves studying such
factors as time involved and attitude along with academic achievement. Hansen, Dick, and Lippert (1968) at Florida State University investigated the effectiveness of an introductory physics course taught by CAI as compared with the conventional lecture method. They found that the CAI group had slightly higher mean scores on examinations although the difference was not significant. They found that there was a learning time savings of 12% with CAI over the conventional lecture method. Attitudes reported toward CAI were that students (1) had a moderately positive reaction, (2) had a personal feeling of greater concept mastery, and (3) had a desire for even more individualization.

In a review of literature and research related to CAI, Bundy (1968) reported a number of research conclusions. Those most relevant to this study are:

1. Most researchers report that students learn at least as well with CAI as with conventional instruction, although they usually do so in less time. Also reported were significantly higher achievement means with CAI over conventional instruction.

2. It is feasible and has been demonstrated in a limited way that the computer can be programmed to be responsive, i.e., adapt and modify its teaching logic in response to student performance and background. CAI, therefore, can provide extensive accommodation to individual differences.

3. The computer can record and manipulate a wide variety of learning data during instruction. Examples are sequence of learning
steps, response time, number of errors, and cumulative performance.

4. Students generally react favorably to CAI. Some students, however, get flustered by the machinery. Student attitude is generally related to personal performance with CAI.

It is Abelson's (1968) contention that CAI will prove to be one of the major advances in education. He points to its ability to provide individualized instruction and the fact that the time required for competence in performing many operations can be shortened over conventional methods. He does point out that current costs make the use of CAI prohibitive.

COMPUTER AS A CALCULATOR AND AN AID TO PROBLEM SOLVING

Although CAI is an exciting application of the computer's capabilities, most secondary school students who use the computer use it as a calculating tool and as a device to aid in problem solving. Computer programming can be taught at all levels in the secondary school. Often, computer programming is taught as a part of an existing course.

Blum and Bork (1969) state that it is as a calculator that the computer will have its greatest impact in science teaching. They feel that the computer should be used to introduce notions of numerical analysis, algorithm construction, symbol manipulation, and programming. In addition, they suggest that a course using computers has an added element of excitement and a strong motivational factor for many students. They see the computer handling many routine aspects of data analysis thus relieving the student of rote work and possibly allowing more
Ahl and Baily (1971) contend that the computer enables students to deal with realistic problems rather than oversimplified versions. They state that in school after school, the computer is turning bored, lethargic students into involved eager students. They believe that when the computer is used in this fashion, it allows students to do ordinary tasks more easily, that it motivates students to go beyond obtaining an answer, and permits more complex ideas to be taught, even though the answers do not come out even.

Schwarz, Kromhout, and Edwards (1969) state that problem solving is generally accepted as a successful way of learning physics, but sometimes the calculations become so difficult and time consuming that the student loses sight of the physics involved. The efficiency and versatility of the computer can save student time and allow the assignment of more basic and realistic problems.

Hughes (1970) contends that the use of the computer helps foster an inquiring atmosphere in the classroom. She claims that students readily make conjectures and verify or invalidate these with computer assistance. In an action research study, she found that students working with the computer demonstrated a greater content mastery and a more efficient method of solving problems.

Denver (1970) claims that when a student programs a concept, he understands it better and sooner than he would have before. The exercise of writing the program contributes to concept understanding.

The most enthusiastic endorsement of computers in the classroom
was found in a report by Lewellen (1971) concerning Project Local. In the investigation, a group of college bound juniors enrolled in a second year algebra course were divided into three groups. While all groups were taught the same mathematics, students in two groups received instruction in flow-charting and used this technique in doing their homework. Students in one of these two groups also learned computer programming and did homework problems on the computer. The third group was taught in the traditional manner. On a test of general scholastic ability, the computer group had a percent gain in group mean from pretest to posttest of 7.5. The control group and the flow chart group had gains of 2.9 and 5.1 respectively. On an abstract reasoning test, the computer group had a percent gain of 17.2. The control group and flow chart group had percent gains of 4.6 and 9.7 respectively. No information regarding the significance of the gains was provided. Lewellen concluded that students are able to learn more in less time when the computer is properly utilized in the educational process.

COMPUTER SIMULATED EXPERIMENTS

A device with the capabilities the computer possesses must certainly have potentials beyond that of solving problems. In view of the limitations on computer usage in the public schools, a promising innovation for science education appears to be that of using the computer for computer simulated experiments. While computer simulation is not new, the use of computer simulation in the school science laboratory is relatively recent and very little research has been done in this area.
The most definitive article on computer simulation was written by Showalter (1970). In his investigation, he used computer simulated experiments in a number of science areas. He points out that the role of the computer in an investigation using simulated experiments is something like that of a remote laboratory technician. It conducts experiments designed by the investigator and reports the resultant data to him.

Showalter lists the following criteria for good computer simulated experiments:

1. Data obtained by the student should be realistic.
2. Not all controllable variables should have a systematic effect on the data obtained.
3. There should be an unlimited range of permitted values for each controllable variable.
4. The student should feel he is investigating a real phenomenon.
5. Topics should go beyond that which can be done readily in the real laboratory.
6. Topics should be programmed so that the investigator makes a choice of dependent variables produced by the experiment as well as values for the independent variables.

Showalter concluded that computer simulated experiments:

1. Give students and teachers access to many natural phenomena that are otherwise impossible to study directly.
2. Provide a unique vehicle for students to develop skills and
strategies of inquiry.

3. Offer a unique medium for educational research into the problems associated with how individuals learn to inquire and how their strategies of inquiry develop and change.

4. Facilitate a more efficient use of the student's time than traditional laboratory activities.

5. Enable students to develop creativity in science and to develop an interest in science beyond that of conventional techniques.

6. Offer a possibility of reduced instructional costs when compared to other forms of CAI or even to ordinary instructional procedures.

Similarly, Bushnell and Allen (1967) in a section on computer simulation conclude that simulation offers many advantages over natural events themselves in that simulation brings a sense of immediacy to the learning task and may challenge the student to participate more actively. Boblick (1970) states that computer simulations of laboratory environments will enable the physics student to experiment with environments which are unattainable in any other form. Zinn (1968) feels that simulation permits study of experimental situations which may be too dangerous, too expensive, or too time consuming. The computer can provide the opportunity for teaching concepts which are at the higher levels of abstraction.

Writers warn that Computer Simulated Experiments should not supplant actual laboratory activities. Barrett (1968) suggests that we must not lose sight of the fact that science is a complex and disorderly
process, beginning with some knowledge about the phenomenon being studied, from which hunches and later, formal hypotheses may be derived. These are tested until a meaningful conclusion can be reached. He states that numbers alone are not the only stuff of science. Similarly, Lunetta and Dyrli (1970) feel that the laboratory work through a computer terminal should not replace the first-hand experience with laboratory equipment. They feel that computer simulations should be used to reduce laboratory busy work and allow students to obtain data on experiments which ordinarily utilize expensive or delicate equipment that would not be readily available.

Craig, Sherertz, Carlton and Ackerman (1971) in a report of their studies of computer experiments state that computer simulation provides a student with a richer experience in data interpretation and hypothesis making. Using computer simulated experiments, a series of useful experiments can be performed so rapidly that the student can afford to make a number of seemingly unprofitable tries. Emphasis shifts from laboratory technique details to the inductive reasoning process. They see computer experiments as a powerful laboratory tool.

Reviewing the supporting evidence that computer simulated laboratories can be helpful, Bundy (1968) lists the following uses of CSE:

1. Teaching laboratory procedures.

2. Exposing students to a variety of analytical problems and physical processes in considerably less time that actual laboratory analysis.

3. Providing an excellent adjunct to conventional instruction.
4. Reducing student stress in learning by allowing freedom to manipulate objects normally not permitted.

Most of the reports concerning CSE were related to the development of curriculum materials. A large number of laboratory simulation programs have been written. Most of these are designed for college laboratories. An attempt will be made to give a brief listing of a few of the simulation programs available.

The most extensive compilation of college level physics simulations is found in *Computer-Based Physics: An Anthology*, Ronald Blum, editor (1969). The book includes simulations on Data Reduction, Harmonic Motion, Relativistic Two-Body Collision, A Simulated Accelerator Laboratory, Computer Simulation of a Mass Spectrometer, Randomness and Radioactive Decay and Ballistics.

At the secondary school level, the **Huntington Computer Project** (1971) and the **Huntington Two Project** (1972) have developed and produced a series of computer simulations in biology, chemistry, earth science, physics, and social studies. A listing of a few of the physics simulations will indicate the scope of the Project. The physics simulations include B-field Plot, Bohr Atom, Radioactive Decay, E-field Plot, Lenses, Photo-electric Effect, Planck's Constant, Young's Experiment, Orbital Motion, V-field, Franck-Hertz Experiment and others.

Many journal articles report on the use of simulation. A few of the physics simulations are noted to illustrate the variety of simulations being used. Baltz and Machlup (1971) describe a satellite simulation. Goldberg, Schey, and Schwartz describe a simulation of the
scattering of a one-dimensional wave packet as it impinges on a square well potential. Grossberg (1969) explains how the computer can be used to simulate a prism spectrometer. Haddad (1968) describes a beginning physics pendulum experiment. Messina (1972) describes a laboratory exercise on eclipsing binaries for an introductory astronomy course. Shirer and Bartel (1967) describe a simulation that computes the photographic appearance of objects moving at relativistic velocities.

While simulations appear to offer many advantages over the traditional methods of performing laboratory work, it should only be a means of achieving the goals of science teaching. The advantages of simulations will have little merit if they do not facilitate at least an equivalent degree of acquisition of content and use of the processes of science by the student. In this regard, four investigations appear to have the greatest relevance to the present study. Hollen, Bunderson, and Dunham (1971) compared achievement and time required when one group of students performed a quantitative analysis of a particular group of elements in the laboratory and another group performed the same analysis using a computer simulation. The mean achievement scores for the computer group were approximately twice that of the traditional group but not significant. On the other hand, the mean time required by the computer group was slightly more than half that of the traditional group. This was significant at the .005 level.

Darol, Schwarz, and Hansen (1970) compared the acquisition of content, the ability to observe, and the ability to make predictions between two groups of students. A CAI physics lesson on magnetism was
supplemented with slides and film loops to provide a simulated encounter with simple magnetism experiments. Two groups of students took the CAI lesson, but one group viewed the simulated experiments, while the other group performed the actual laboratory experiments.

The investigators found no evidence to suggest that simulated laboratory experiments are any less effective than the performance of simple experiments in providing concrete referents to aid in the learning of abstract concepts and principles. The results appeared to suggest the merit of continued attempts to design appropriate laboratory simulations.

Boblick (1972) conducted an evaluation study to compare the effectiveness of the computer simulation as an instructional technique with the traditional laboratory experiment. Physics students were randomly assigned to either the laboratory group or a computer simulation group. They conducted an investigation of the Physical Science Study Committee (PSSC) laboratory experiment "Momentum Changes in an Explosion."

A four item pretest and a four item posttest was used to assess student attainment. On posttest score gain, the computer group scored significantly higher at the 0.001 level. The investigator concluded that computer simulations provide a more effective means by which high school students may discover the conservation of momentum.

Bron (1972) describes a project on computer aided physics laboratory instruction (project CAPLIN) for nonscience majors. In the program, the students first obtain data from traditional laboratory
experiments. The student then has the option to use parts of preprogrammed computer materials to assist with the analysis of data, provide graphical displays, and perform simulation of experiments with the possibility of inputting new data values. In evaluating the project by observation, discussions, and questionnaire, Bron found that the students benefited from the ease of data reduction, error analysis, and computer graphing. In addition, the time saved permitted additional laboratory activities to be performed.

PROCESSES OF SCIENCE

One of the major areas of investigation of this study will be that of the relationship between Computer Simulated Experimentation and the processes of science. It is generally agreed that the processes of science are synonymous with skills such as observing, measuring, experimenting, interpreting data, communicating and hypothesizing.

Burns and Brooks (1970) state that processes are specific mental skills which are any set of actions, changes, treatments, or transformations of cognitive or affective entities used in a strategy in a special order to achieve the solution of a problem associated with the learning act, the use of learning products, or the communication of things learned. They list 14 activities as processes. These are:

1. Abstracting
2. Analyzing
3. Classifying
4. Conceptualizing
5. Equating
6. Evaluating
7. Generalizing
8. Inferring
9. Ordering
10. Sequencing
As might be expected, studies related to the acquisition of process skills are somewhat inconclusive because of the difficulty of their measurement. Typical of the research into the processes of science is that of Thomas and Snider (1969) and Raun and Butts (1966). Thomas and Snider investigated the effects of Guided Discovery vs. Didactic (systematic instruction) method of instruction upon the acquisition of certain process skills by a sample of 140 eighth grade students. The process skills tested were determined by the instruments used to measure them. Critical thinking was measured by the Watson-Glaser Critical Thinking Appraisal. Problem solving was measured by the TAB Inventory of Science Processes. Creativity was measured by the Torrance Test of Creative Thinking. The experimenters found that Guided Discovery was favored for the acquisition of process skills.

In a study involving 95 fourth, fifth, and sixth grade students, Raun and Butts attempted to discover if the use of the processes of science could be enhanced by using various sequencing strategies. The processes specifically investigated were classifying, observing, using number relations, and recognizing and using space-time relations. They found that the most effective strategy involved using numbers followed by classifying, space-time relations, and observing.

It can be seen that although the processes of science are important parts of science teaching, their identification and measurement are somewhat difficult.
SUMMARY

The value of CAI in the classroom is well documented. CAI is here to stay as a viable means of instruction. When used for student drill-and-practice and as a tutorial device, the computer has been shown to be as effective and in many cases, more effective than traditional methods. It provides a degree of individualization of instruction not possible with traditional methods. In addition, the results have been obtained with a savings of time. Unfortunately, the cost and time required to prepare CAI programs rules out its use in most public school science classrooms at the present time.

The value of the computer as a calculator and an aid to problem solving has been demonstrated. Most schools with computer facilities are taking advantage of these aspects of the computer's capability. These obviously important features of the computer make it an invaluable teaching device.

There is evidence to suggest that the instructional potential of laboratory simulations is substantial. In addition, there is a wealth of simulation programs available. Learning data on student concept and principle learning, development of problem solving capabilities, development of scientific attitudes, and process skill formation is lacking at the present. It would appear that experimental research directed toward these objectives involving the computer as a laboratory simulation device is badly needed.
CHAPTER III

DESIGN OF THE STUDY

This chapter is divided into six sections. In the first section, a description of the research design is given. The selection and assignment of students to the treatment groups is discussed in the second section. A description of the laboratory exercises used in the study is given in the third section. This is followed by a description of the instruments used in the study. The fifth section describes the schedule of activities followed during the course of the study. The final section describes the manner in which the data were analyzed.

DESCRIPTION OF RESEARCH DESIGN

The experimental design selected for this study was the Two-factor Experiment with Repeated Measures on One Factor as described by Winer (1962:302). The experimental design chosen employs equivalent samples of students to provide a baseline against which to compare the effects of the experimental variables. Winer (1962:300-301) states that the primary purpose of repeated measures on the same elements is the control that this kind of design provides over individual differences between experimental units. In addition, the use of the same individuals or groups has the effect of reducing sampling error over the use of different individuals or groups.

Winer (1962:302) describes the general design of the experiment as follows:
Each G represents a random sample of size n from a common population of subjects. Each of the subjects in $G_1$ is observed under q different treatment combinations, all of these treatment combinations involving factor A at level $a_1$.

The specific design for this study is as follows:

**Laboratory Experiment**

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There were seventeen students in each of the three treatment groups, Laboratory, Laboratory-Computer, and Computer. Each of the treatment
groups performed four simulations and/or experiments, $E_1$, $E_2$, $E_3$, and $E_4$. The same students remained in each of the treatment groups throughout the study.

A detailed description of the actions of each of the treatment groups during each of the experiments is given in the third section of this chapter.

SELECTION AND ASSIGNMENT OF STUDENTS IN THE SAMPLE

This study was conducted with the physics classes at Bexley High School using the physics laboratory equipment and computer facilities. Fifty-one students were enrolled in two physics classes. These students constituted the population of the study.

A computer program was written to obtain a random assignment of students to the Laboratory Group, the Laboratory-Computer Group, and the Computer Group. The names of all fifty-one students were entered into the computer program. Using the computer's random number generator, the students were randomly assigned to the three treatment groups.

An independent measure of the student's aptitude was used to test equality of treatment groups. The Differential Aptitude Test, form M (see Bennett, 1966) is administered to all 10th grade students as part of Bexley's testing program. In addition, new students are given the test upon enrolling. Consequently, DAT scores were available for all students involved in the study. The DAT contains five sub-tests, Verbal Reasoning (VR), Numerical Ability (NA), Abstract Reasoning (AR), Mechanical Reasoning (MR), and Space Relations (SR).

The reliability coefficients of form M of the DAT for boys and
girls in grade 10 are shown in Table 1. The estimates of reliability (r) are based on odd-even scores corrected for range of norms group.

The validity coefficients between DAT scores and course grades earned in physics two years after the administration of DAT for students tested in White Plains, New York schools for VR, NA, AR, SR, and MR are 0.42, 0.50, 0.45, 0.34, and 0.41 respectively.

Table 2 shows the means and standard deviations of each of the treatment groups on the five DAT sub-tests.

To show that the three treatment groups were equivalent, the student's scores on the DAT sub-tests were analyzed using the BMD program IV, Analysis of Variance for One-way Design. The means of each treatment group were compared. The results are given in Table 3.

The F-ratio for the .10 significance level with 2 and 48 degrees of freedom is 2.42. As can be seen from Table 3, all F-ratios except that of the Numerical Analysis sub-test are far below the significant F-ratio.

LABORATORY EXERCISES

Each experimental group participated in four different laboratory exercises. The exercises used were Newton's Law Experiment, A Spring Experiment, the Coulomb Experiment, and The Millikan Experiment. These laboratory activities were chosen because they permit the L and L-C Groups to collect appropriate data and in addition, have certain features that permit simulations to be effective. The Laboratory exercises are essentially those described in Laboratory Guide-Physics developed by the Physical Science Study Committee (1965) on pages
### TABLE 1

RELIABILITY COEFFICIENTS OF FORM M OF THE DAT

<table>
<thead>
<tr>
<th>Test</th>
<th>Corr. $r$</th>
<th>Mean</th>
<th>S.D.</th>
<th>Corr. $r$</th>
<th>Mean</th>
<th>S.D.</th>
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<tr>
<td>VR</td>
<td>.91</td>
<td>22.3</td>
<td>9.1</td>
<td>.91</td>
<td>20.8</td>
<td>9.5</td>
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<td>NA</td>
<td>.92</td>
<td>21.8</td>
<td>8.1</td>
<td>.91</td>
<td>21.2</td>
<td>7.8</td>
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<tr>
<td>AR</td>
<td>.93</td>
<td>32.4</td>
<td>10.4</td>
<td>.94</td>
<td>30.3</td>
<td>10.7</td>
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<tr>
<td>MR</td>
<td>.86</td>
<td>42.9</td>
<td>10.1</td>
<td>.79</td>
<td>35.2</td>
<td>8.6</td>
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<tr>
<td>SR</td>
<td>.93</td>
<td>30.3</td>
<td>11.5</td>
<td>.91</td>
<td>28.4</td>
<td>11.1</td>
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TABLE 2
MEANS AND STANDARD DEVIATIONS OF DAT SUB-TESTS

<table>
<thead>
<tr>
<th>Test</th>
<th>L Group Mean</th>
<th>S.D.</th>
<th>L-C Group Mean</th>
<th>S.D.</th>
<th>C Group Mean</th>
<th>S.D.</th>
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<td>4.91</td>
<td>39.88</td>
<td>6.40</td>
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<td>32.00</td>
<td>4.27</td>
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<tr>
<td>AR</td>
<td>41.94</td>
<td>2.95</td>
<td>42.82</td>
<td>3.52</td>
<td>42.41</td>
<td>2.62</td>
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<tr>
<td>MR</td>
<td>51.24</td>
<td>5.21</td>
<td>50.47</td>
<td>6.79</td>
<td>52.76</td>
<td>5.30</td>
</tr>
<tr>
<td>SR</td>
<td>46.12</td>
<td>6.75</td>
<td>46.12</td>
<td>7.62</td>
<td>45.35</td>
<td>6.90</td>
</tr>
</tbody>
</table>
## TABLE 3

ANALYSIS OF VARIANCE FOR TREATMENT GROUPS ON DAT SUB-TESTS

<table>
<thead>
<tr>
<th>Test</th>
<th>Source of Variance</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Between</td>
<td>22.59</td>
<td>2</td>
<td>11.29</td>
<td>0.3721</td>
</tr>
<tr>
<td>VR</td>
<td>Within</td>
<td>1457.06</td>
<td>48</td>
<td>30.36</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>1479.64</td>
<td>50</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Between</td>
<td>94.16</td>
<td>2</td>
<td>47.08</td>
<td>2.4569</td>
</tr>
<tr>
<td>NA</td>
<td>Within</td>
<td>919.76</td>
<td>48</td>
<td>19.16</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>1013.92</td>
<td>50</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Between</td>
<td>6.63</td>
<td>2</td>
<td>3.31</td>
<td>0.3554</td>
</tr>
<tr>
<td>AR</td>
<td>Within</td>
<td>447.53</td>
<td>48</td>
<td>9.32</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>454.16</td>
<td>50</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Between</td>
<td>46.39</td>
<td>2</td>
<td>23.20</td>
<td>0.6863</td>
</tr>
<tr>
<td>MR</td>
<td>Within</td>
<td>1622.35</td>
<td>48</td>
<td>33.80</td>
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<tr>
<td></td>
<td>Total</td>
<td>1668.74</td>
<td>50</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Between</td>
<td>6.63</td>
<td>2</td>
<td>3.31</td>
<td>0.0657</td>
</tr>
<tr>
<td>SR</td>
<td>Within</td>
<td>2421.41</td>
<td>48</td>
<td>50.45</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>2428.03</td>
<td>50</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
35-37, Experiments III-1 and 2; on page 55, Experiment III-1; on pages 63 and 64, Experiment IV-3; and on pages 69 and 70, Experiment IV-6.

The computer simulations of each of the laboratory exercises were written such that the input and output data are approximately the same as in the corresponding laboratory situation. Included in each simulation is a built-in error term. The computer's random number generator is used to introduce an error of 2% or less in 67% of the output lines, an error of between 2 and 5% in 28% of the output lines, and an error of between 5 and 10% in 5% of the output lines. These numbers were chosen because experience has indicated that in a carefully performed experiment, the error incurred by students is less than 5%. However, students occasionally make larger errors. The 67, 28, and 5% of the cases chosen were attempts to approximate a normalized error introduction. This system of random error introduction is similar to that described by Schwendeman (1968).

The four computer simulations, Newton's Laws, A Spring Experiment, The Coulomb Experiment, and The Millikan Experiment were written and tested. Copies of the programs and the computer output are found in Appendix A. As the students responded to the simulation programs, their responses were stored and transferred to a separate file to which only the instructor had access. When this file was accessed, all information about student responses was obtained.

The laboratory exercises are as follows:

1. **Newton's Laws**

   This laboratory exercise involved the development of the
relationships between force, mass, velocity change, and acceleration. This experiment is difficult to perform in the laboratory due to a problem of producing a constant force independent of the mass and velocity.

The Laboratory Group performed the experiment with cars of different masses being accelerated on a linear air track by falling masses. Time and displacement were measured by a spark timer and wax tape. Using a stop watch, some students chose to measure the time required by the car to travel a certain distance. The students proceeded to collect data, analyze it and develop the relationships between the variables. A schematic representation of the apparatus is shown in Figure 1.

![Figure 1. Schematic Representation of Newton's Laws Apparatus](image.png)

The Computer Group performed the exercise using a simulation of the experiment described above. The student selected and entered values for the applied force, mass, distance over which the force acted, and a time interval for output measurements. Output options included time,
displacement, velocity, acceleration and mass. Included in the simulation was an Einstein relativistic effect.

The Laboratory-Computer Group performed one trial with the experimental apparatus described above. A sample set of data was collected. The students then moved to the computer terminals and used the simulation program to generate the laboratory data to be analyzed.

2. A Spring Experiment

This laboratory exercise involved a study of the oscillatory motion of a mass on a spring and the various energy changes that occurred as the mass oscillated. This experiment is difficult to perform because of the problem of measuring the position, velocity, and acceleration of the mass on the spring.

The Laboratory Group performed the experiment using different spring and mass combinations. The spring constant for each spring used was determined. For each spring-mass combination, the mass's rest position and high and low positions of oscillation were marked. Using a recording timer, the velocity of the mass was determined as it fell. From the measurements, spring potential energy, gravitational potential energy, kinetic energy, and total energy were calculated. A schematic representation of the apparatus is shown in Figure 2.

The Computer Group performed the exercises using a simulation of the experiment. The student selected and input values for the spring constant, the mass attached to the spring, and the height to which the mass was raised above the rest position before it was released. The computer provided the position, velocity, and acceleration of the mass
at various time intervals for one period. From these output data, spring potential energy, gravitational potential energy, kinetic energy, and total energy were calculated.

The Laboratory-Computer Group performed one trial with the spring and mass and used the computer simulation to generate laboratory data.

3. The Coulomb Experiment

This laboratory exercise involved the development of the relationships between the magnitude of the charge on two charged bodies, the distance between them and the force they experience. This experiment is difficult to perform because of electric charge leakage, air currents, and the fact that the force must be measured indirectly.

The Laboratory Group performed the experiment using the Coulomb Apparatus. This laboratory equipment consists of two small styrofoam spheres coated with a metallic paint. One is suspended from a plastic holder by an insulating thread. The other sphere is attached to a
wooden stand. Both spheres are contained in a cardboard box to insulate them from air currents. The spheres are charged and the sphere attached to the wooden stand is moved toward the suspended sphere. The Laboratory Group determined the sphere positions and developed the relationships described. A schematic diagram is shown in Figure 3.

![Figure 3: Schematic Representation of the Coulomb Apparatus](image)

The Computer Group performed the exercises using a simulation of the experiment described above. The student selected and entered values for six stand positions and the masses of each of the spheres. The computer generated a random charge for each sphere. The computer provided the position of the suspended sphere for each of the six stand positions. At the end of each trial, the student had the option of reducing the charge on the stand sphere by 1/2. From these data, the relationships described above were developed.

The Laboratory-Computer Group performed the exercises once using the Coulomb Apparatus. They then used the computer simulation to generate laboratory data.
4. The Millikan Experiment

This laboratory exercise involved the development of the concept of an electron charge and the calculation of its magnitude. Small spheres are allowed to fall between charged metal plates. Because they reach their terminal velocity very quickly, a measure of their speed is a measure of the resultant external force. If the force of gravity is known, the electric force can be determined and the magnitude of the electron charge calculated. The experiment is difficult to perform because the small spheres are difficult to see and their velocities are difficult to measure.

The Laboratory Group performed the experiment using the Millikan Apparatus. This laboratory equipment consists of two metallic plates separated by 3 mm. and charged to 500 volts. A latex solution is introduced between the plates with an atomizer. The latex particles acquire a static electric charge and move either up or down under the influence of the electric field. A telescope is used to view the particles. Using the applied voltage, the velocities of the particles, and the plate separation, the magnitude of the electric force and electric charge can be calculated. A schematic diagram is shown in Figure 4.

The Computer Group performed the exercise using a simulation of the experiment described. The student selected and input values for plate separation and applied voltage. The computer generated a random charge for each of ten spheres. The computer provided the terminal velocity for each of the ten spheres.

The Laboratory-Computer Group performed one trial with the
Figure 4. Schematic Representation of the Millikan Apparatus

Millikan Apparatus and used the computer simulation to generate laboratory data.

INSTRUMENTS UTILIZED IN THE STUDY

To provide data related to the experimental hypotheses, a number of different instruments were prepared and used. No commercially available instruments could be found to measure the specific dependent variables in this study.

Student Laboratory Activities

To provide data on the use of the processes of science during each of the laboratory exercises, a number of features of the student's laboratory activities were evaluated. The evaluation involved:

1. Number of Trials Performed

The number of trials performed by the students was a quantitative measure of their involvement in the experiment. This was an attempt to answer the question of whether students perform more trials when they (a) actually manipulate equipment, (b) manipulate equipment and then secure data through simulation, or (c) only do the experiment
through simulation. This number was furnished by the students in the Laboratory Group and was obtained from the computer file for the Laboratory-Computer and Computer Groups.

2. Student Manipulation of Input Variables

In this study, each problem posed to the students involved two independent input variables. By manipulating the laboratory equipment or input variables, they had control over the outcome of the experiment. Observation and collection of data were accomplished by the Laboratory Group in the traditional way. The CSE Groups, through their selection of input and output variables, observed and collected data. Information was derived from the laboratory data tables prepared by the Laboratory Group and the computer file for the Laboratory-Computer and Computer Groups. The information was quantified in the following manner:

a. An attempt was made to determine if the effect of both input variables was investigated. The number of different values used for input variable #1 was divided by the total number of trials. The result was converted to a percentage. The same operation was performed for variable #2. The percentages reflect an attempt on the part of the students to investigate the effect of both input variables. One point was awarded for each variable changed in at least 25% but in fewer than 75% of the trials. (Ideally, each variable should have been changed in 50% of the trials while the other variable was kept constant.) These points were used to provide a score for ranking the students.

b. The range of values of the input variables should have
been large enough to produce observable changes significantly larger than the error term. If the student used such a range, one point was awarded. These points were used to provide a score for ranking the students.

c. An attempt was made to determine if the students investigated the effect of one of the input variables while the other input variable was kept constant. A tabulation of the number of trials in which a student kept variable #1 constant and changed variable #2 was prepared. A trial was counted if it was a part of at least a three entry series. A three entry series was chosen because it represents a deliberate strategy on the part of the student rather than a chance happening. For example, if possible values for variable #1 were A₁, A₂, and A₃, and possible values for variable #2 were B₁, B₂, and B₃, trials A₁-B₁, A₁-B₂, and A₁-B₃ would be counted, but trials A₁-B₁, A₁-B₂, and A₂-B₃ would not be counted. A percentage (P) of single variable investigation trials were calculated. The most desirable experiment would involve investigating the effects of variable #1 in about 50% of the trials and the effects of variable #2 in about 50% of the trials. Points were awarded as follows: P = 0%, 0 points; 0%<P ≤ 20%, 1 point; 20%<P ≤ 40%, 2 points; 40%<P ≤ 60%, 3 points; 60%<P ≤ 80%, 2 points; 80%<P ≤ 100%, 1 point. The same procedure was followed for variables #2 and #1. The same system of awarding points was used. These points were used to provide a score for ranking the students.
d. An attempt was made to determine if the students incremented their input data in a logical manner or if it was merely a random selection of input data. Examples of logical input might be:

1. 10, 20, 30, 40, etc.
2. 1000, 900, 800, 700, etc.
3. 10, 1000, 400, 700, 500, 600, etc.
4. 10, 100, 200, 250, 300, 350, etc.

Examples of input data that would not be considered logical are:

1. 10, 50, 20, 100, 120, 30, etc.
2. 10, 100, 250, 300, 700, etc.

If in the judgment of the evaluator, a pattern of input variable incrementation could be discerned in at least 50% of the trials, one point was awarded. These points were used to provide a score for ranking the students.

e. A score representing the students' Total Data Manipulation Score was determined by adding the points from a, b, c, and d.

3. Evidence of an Attempt to Extrapolate Beyond Experimental Limits

An attempt was made to determine if students in the Computer and Laboratory-Computer Groups attempted to probe beyond the laboratory limits when given the opportunity. The total number of trials and the percentage of trials involving investigations beyond laboratory limits was tabulated to provide the evidence.

4. Experimental Conclusions
The laboratory experiments had several possible conclusions, ranging from very simple relationships to exact mathematical descriptions. The students were rated on whether they were able to draw proper conclusions. When A and B were input variables and C was the output variable, a rating scheme was used like the one shown below:

a. No conclusion, or an inaccurate conclusion. 0 points.

b. A correct simple relationship between an input variable and the output variable. 1 point. Example: As A increases, C increases.

c. Two correct simple relationships between the input variables and the output variable. 2 points. Example: As A increases, C increases and as B increases, C decreases.

d. At least one mathematically correct relationship between an input variable and the output variable. 3 points. Example: 

\[ C = \frac{k}{B} \]

e. Two mathematically correct relationships between the input variables and the output variable. 4 points. Example: 

\[ C = \frac{k_1}{B} \quad \text{and} \quad C = \frac{k_2}{A^2} \quad \text{or} \quad C = \frac{k_3}{A^2/B} \]

5. Time Required

Information about the time required for the experiment, computer simulation, and analysis was collected from the students. The Laboratory Group reported the amount of time spent in setting up the experimental apparatus, performing the experiment, collecting data, and analyzing data. The Laboratory-Computer Group reported the amount of time spent in setting up the experimental apparatus, performing a trial experiment, running the computer simulation, and analyzing the data.
The Computer Group reported the amount of time spent running the computer simulation and analyzing the data.

Written Examinations

1. Processes of Science

A written examination was prepared for each laboratory exercise (Appendix B). These written examinations were used to test the students on their ability to interpolate, extrapolate, make inferences, draw conclusions, make predictions, interpret graphs, and formulate hypotheses in situations similar to those encountered in the laboratory situations. In addition, each of the examinations contained a content component since the processes of science cannot be isolated from the content.

The student scores on each of the process examinations were converted to corresponding z scores or standard scores using the following formula: 
\[ z = \frac{X - M}{S} \] 
where \( X \) is the student test score, \( M \) is the mean of the student test scores, and \( S \) is the standard deviation of the scores. The z scores for each process test have the same mean and standard deviation. Hypotheses related to group mean differences were tested using these z scores.

The reliability of the examinations was determined through the use of the Kuder-Richardson Formula 20 reliability estimate. The formula for computing the reliability estimate is the following:
\[ \text{rel.} = \frac{K}{(K-1)} \left( 1 - \left( \sum q_i (1 - q_i) / S^2 \right) \right) \] 
where \( K \) is the number of items on the test, \( q_i \) is the proportion of the students missing item \( i \), and \( S^2 \) is the variance of the raw scores.
The number of students missing each test item, the number of items, the number of students, and the standard deviation of the raw scores were tabulated or calculated. These provided the data for $\bar{q}$, K, and $S^2$.

An attempt was made at Content Validation of the written examinations. Each of the items included in the instruments was selected to be a representative sample of the tasks or learnings the students were expected to utilize or acquire in the course of the experiments or simulations. The items included in the instruments were compared with the objectives of the laboratory exercises and were found to be satisfactory evaluative items.

a. Newton's Laws

The Newton's Laws Test consisted of fifty-one items. The first twelve items, 1a through 4c, required the students to use interpolation, extrapolation, and experimental conclusions to arrive at the answers. The next twenty-five items, 5a through 9f, dealt with experimental design and selection of appropriate experiments to reach conclusions. The final fourteen items, 10a through 13c required the students to develop experimental hypotheses from prepared graphs.

The reliability of the Newton's Laws Test, determined as described, was 0.82.

b. The Spring Experiment

The Spring Experiment Test consisted of nineteen items. The first nine items, 1 through 5c, required the students to analyze a
set of graphs obtained from a spring experiment. The items required the students to use experimental conclusions, interpolation, and extrapolation. The next two items, 6 and 7, dealt with experimental conclusions as experimental data were changed. The final eight items dealt with experimental design and selection of appropriate experiments to reach conclusions.

The reliability of the Spring Experiment Test, determined as described, was 0.65.

c. The Coulomb Experiment

The Coulomb Experiment Test consisted of nineteen items. Items 1 through 3 required the students to use experimental conclusions to analyze a laboratory situation involving the Coulomb Experiment data. The next eleven items, 4a through 5e, dealt with experimental design and selection of appropriate experiments to reach conclusions. The final five items, 1a through 3b, required the students to develop experimental hypotheses from prepared graphs.

The reliability of the Coulomb Experiment Test, determined as described, was 0.75.

d. The Millikan Experiment

The Millikan Experiment Test consisted of nineteen items. The first ten items, 1a through 1j, required the students to analyze data from a Millikan Experiment using previously determined experimental conclusions. The next nine items, 2a through 7b, required the students to use interpolation, extrapolation, and experimental conclusions to arrive at the answers.
The reliability of the Millikan Experiment Test, determined as described, was 0.92.

2. Content

A written examination to evaluate the acquisition of content knowledge was prepared (Appendix C). The test consisted of eighteen multiple choice questions selected from Tests of the Physical Science Study Committee (1959) and Series N (1964). Items 1 and 2 were questions from Test 6: Force and Momentum and were questions covering the relationship between force and acceleration. Items 3 and 4 were questions from Series N, Test 6: Force and Momentum and covered the relationships between force, mass and acceleration. Items 5 through 9 were questions from Test 7: Energy and covered the concept of conservation of energy. Items 10 and 11 were questions from Series N, Test 8: Electricity and Magnetism and were questions covering the Millikan Experiment. Items 12 through 16 were questions from Series N, Test 7: Energy and covered the conservation of spring potential energy. Items 17 and 18 were questions from Series N, Test 8: Electricity and Magnetism and covered the Coulomb Force Law. The questions were selected to cover the content in the four experiment-simulation activities.

The reliability of the examination was assessed through the use of the Kuder-Richardson Formula 20 reliability estimate. The reliability of the test was 0.62.

3. Attitude

Information concerning student attitude toward Computer Simulated Experiments was collected from the Laboratory-Computer and
Computer Groups by means of a Student Attitude Questionnaire. A copy of the Questionnaire can be found in Appendix D. The components of the Questionnaire were:

a. The relationship between CSE and laboratory experiments in terms of:
   1. Realism
   2. Student control of experiments.
   3. Rate at which the students work.
   4. Student involvement.

b. The computer as a mechanical device.

c. Availability of computer terminals

d. The appropriate use of CSE.

e. Possible lack of interpersonal relationships when working with CSE.

Each response on the Questionnaire was converted to a number value. A response of Strongly Agree was assigned a value of five, Agree was assigned a value of four, No Opinion was assigned a value of three, Disagree was assigned a value of two, and Strongly Disagree was assigned a value of one. These numbers were used to code and analyze student responses.

The reliability of the Student Attitude Questionnaire was determined using the Cronbach's alpha as computed by the Hoyt analysis of variance method.

A two-way analysis of variance, using the BMD 02V ANOVA program, was performed on the item responses and persons taking the test. From
the ANOVA program, the item, person, and item X person variances were found. The Hoyt method used the following computational formula:

\[ \text{rel.} = 1 - \frac{S_e^2}{S_p^2} \]

where \( S_e^2 \) is the error variance and \( S_p^2 \) is the item X person variance from the two way ANOVA and \( S_p^2 \) is the person variance from the same program. This reliability coefficient is an indication of the instrument's internal consistency.

The Questionnaire naturally divides into two sub-tests. The first sub-test consisted of seven items related to the computer as a mechanical device, availability of computer terminals, appropriate use of CSE and possible lack of interpersonal relationships when working with CSE. The reliability of each sub-test was determined as described above. The reliabilities of the first and second sub-tests were 0.59 and 0.65 respectively.

Laboratory-Simulation Sheet

A short description of each experiment and simulation was prepared and distributed to the students prior to the laboratory exercises. Included with the sheets were data tables, graph paper, and a page for conclusions. The Laboratory-Simulations Sheets are included in Appendix E.

SCHEDULE OF ACTIVITIES

Each laboratory situation involved the use of the physics laboratory equipment and two computer terminals. Seventeen students were assigned to each of the groups, L, L-C, and C. Due to the fact that the
laboratory situations require two students to conduct the experiments and record data, the students were assigned to the Laboratory group in pairs and in one case, three students worked together. Similarly, the students assigned to the Laboratory-Computer Group performed the laboratory work in the same way.

Generally, the students in groups L, and L-C performed their laboratory experiments during their regularly scheduled class period. However, the physics room was available four periods each day and sometimes the students used the equipment during these periods.

The computer terminals were scheduled by the students for use during their free periods. Consequently, the computer facilities were used all day long.

The procedures followed during the course of the study were as follows:

1. Two days were set aside for each of the laboratory-simulation exercises. During this time, the students performed the experiments or simulations and collected their data.

2. The students had a third day for analyzing data and drawing conclusions. All students were permitted to perform calculations using the computer facilities.

3. All student materials (laboratory reports, computer printouts, and time records) were collected on the fourth day.

4. The test covering the laboratory situation was administered on the fourth day.

5. The Student Attitude Questionnaire was administered at the conclusion of the study on April 13, 1973.
6. The subject matter test covering all of the laboratory situations was administered after all simulation and laboratory exercises were completed. The test was administered on April 13, 1973.

7. After each of the above items was collected, the data were tabulated and analyzed.

A time schedule for the series of laboratory exercises is shown below:

1. Experiment 1 - Newton's Laws - January 3, 4, 1973
4. Experiment 4 - The Millikan Experiment - April 9, 10, 1973.

ANALYSIS OF DATA

The data derived from the students' Laboratory Activities were converted to number data as described previously and recorded on a master list. The process tests were hand scored and the results included on the same list. The data were punched on IBM cards and identified by group, experiment, and student. A card was prepared for each student containing the results of each experiment. The data from all of the experiments were analyzed together.

The content examination was hand scored. The scores from this examination were punched on IBM cards and identified by group and student. The scores were analyzed separately from the other data.

The Student Attitude Questionnaire was hand scored. The responses from the Questionnaire were converted to number data and punched on IBM cards. The responses were identified by group and student. These scores were analyzed separately from the other data.

Statistical Analysis
Lordahl (1967) describes an analysis of variance technique appropriate to the repeated-measures design. He suggests that there are five sources of variance in addition to the total variance. Three of these are of primary interest and the other two serve as error terms in the F-ratios.

The sources of variance in the design are (1) between groups (G), (2) subjects within groups (Ss), (3) trials (T), (4) groups-by-trials interaction (G X T), and (5) subjects-by-trial interaction within groups (Ss X T). Appropriate F-ratios for testing the null hypotheses are related to the groups, trials, and groups-by-trials as follows:

1. Between groups

\[ F_{BG} = \frac{MS_{BG}}{MS_{SS}} \]

2. Trials

\[ F_T = \frac{MS_T}{MS_{SS} X T} \]

3. Groups-by-trials

\[ F_{G X T} = \frac{MS_{G X T}}{MS_{SS} X T} \]

Data were coded and processed with the computer using programs from the Biomedical (BMD) Computer Series (Dixon, 1968 and 1969) and the Clyde (1969) Computer Program. The repeated-measures were analyzed using the X69, Multivariate Analysis of Variance, program. The adjusted means were obtained using the Clyde Program. Other programs used were the 01D, Simple Data Description, 01V, Analysis of Variance for a One-Way Design, and 02R, Stepwise Regression. (The kind of information
available from each program is listed in Appendix F.) Levels of significance were reported at the .10 level.

Homogeneity of Variance

One of the basic assumptions underlying the use of the F statistic is that the variance due to experimental error within each of the treatment groups is homogenous. However, Glass (1970:372) points out that when sample sizes are equal, the effect of heterogeneous variances on the level of significance of the F-test is negligible. In this study, three treatment groups, each of seventeen students, were used. Consequently, the fixed effects of ANOVA should be unaffected by heterogeneous variances.

Analysis of Covariance

When the Analysis of Variance was performed to test the equivalence of treatment groups using the DAT Sub-tests, a significant difference was found between the three treatment groups' mean scores on the Numerical Ability Sub-test. Student scores on this Sub-test were correlated with scores on other criteria variables. The Numerical Ability Sub-test scores were used as a covariate in the analysis of covariance of those variables showing a relatively high correlation.

The analysis of covariance is based on the usual analysis of variance assumptions and assumptions related to regression effects. Since the F test is used, a homogeneity of covariance assumption is involved. Winer (1962:586) indicates that F tests used with the analysis of covariance are robust with respect to the violation of homogeneity of residual variance. In addition, it is assumed that the group
regressions for the dependent variable on the covariate are linear and that the slopes are homogeneous. The Clyde Computer Program was used to provide a test of the equality of regression in each cell. The test uses an F ratio in which the mean square related to the variation of the within cells regression coefficients about the pooled within cells regression coefficient is the numerator and the mean square related to the variation of residuals is the denominator.

**Multiple Comparisons**

For those parts of the study exhibiting significant F-ratios, a multiple comparison procedure was used to show where significant differences were. The comparison method used was the Scheffé method (S-method) described by Glass (1970:388 and 445). Glass defines comparisons of this type as contrasts and suggests that any contrast can be estimated by the following expression:

\[
\hat{\psi} = c_1 \bar{x}_{1.1} + c_2 \bar{x}_{2.2} + \ldots + c_I \bar{x}_{I.I}
\]

where \( c_1, c_2, \ldots, c_I \) are positive and negative real numbers that sum to zero.

For this study, consisting of \( I \) treatment groups and \( J \) experiments, the estimate of the variance of \( \hat{\psi} \) is given by:

\[
\hat{\sigma}_\psi^2 = \frac{MS_w}{\left( \frac{c_1^2}{n_1} + \frac{c_2^2}{n_2} + \ldots + \frac{c_I^2}{n_I} \right)}
\]

where \( MS_w \) is the mean square within groups, and \( n_1, \ldots, n_I \) are the total numbers of observations on which the means are based. The degrees of freedom associated with this estimate are \( N - IJ \) where \( N = n_1 + n_2 + \ldots + n_I \).
The steps in testing the significance of a contrast were as follows:

1. \( \hat{\psi} \) was obtained by specifying the coefficients, \( c_1, \ldots, c_I \), that determine the contrast of interest and multiplying the coefficients by the appropriate population means.

2. An estimate of the variance (\( \hat{\sigma}_\hat{\psi}^2 \)) was found.

3. \( \hat{\sigma}_\hat{\psi} \) was found by taking the square root of the variance estimate.

4. The ratio of \( \hat{\psi}/\hat{\sigma}_\hat{\psi} \) was found.

5. The absolute value of the ratio was compared with the square root of \((I - 1) \times \text{100}(1 - \alpha)\) percentile in the F-distribution with degrees of freedom \( I - 1 \) and \( N - IJ \) where \( I \) is the number of groups, \( J \) is the number of experiments, and \( N \) is the total number of observations. The hypothesis when:

\[
\left| \frac{\hat{\psi}}{\hat{\sigma}_\hat{\psi}} \right| > \sqrt{(I - 1) \times 1 - \alpha F_{I-1,N-IJ}}
\]

Techniques Used to Test The Hypotheses

Data from the laboratory activities and process tests were analyzed using the multivariate analysis of variance appropriate for the experimental design. The groups were found to be significantly different on the DAT Numerical Ability Sub-test. Therefore, analysis of covariance as well as analysis of variance was used to test the treatment effects. The between groups F-ratio was used to test the hypothesis of no differences between the performances of the treatment groups. The trials F-ratio was used to test the hypothesis of no
differences between the student performances on the four laboratory exercises. The hypothesis of no interaction between group and laboratory experiment was tested using the groups X trials F-ratio.

Scores of the content examination were analyzed using a one-way analysis of variance and a one-way analysis of covariance. The F-ratio obtained was used to test the hypothesis of no differences between the groups.

Data obtained from the Student Attitude Questionnaire were analyzed using analysis of variance for a one-way design. The F-ratio obtained was used to test the hypothesis of no differences between the Laboratory-Computer and Computer Groups.
CHAPTER IV

ANALYSIS OF RESULTS

This chapter consists of two parts. The first part contains a description of the variables measured for the study, data gathering instruments, and descriptive statistics obtained for each variable. The second part of the chapter consists of a presentation of the seven hypotheses of the study, the data and analyses used in determining whether each hypothesis was rejected or accepted, and an interpretation of these data.

Variables Measured

Eight variables were measured for this study. Two of these variables consisted of several sub-variables. Information was derived from several sources: the student's laboratory report (abbreviated SLR); computer print-out (CPO); process tests (PT); content tests (CT); and the Student Attitude Questionnaire (SAQ). A listing of the variables and the source of information is shown in Figure 5.

A description of the sample, based on Variables 1-5, is given for each of the laboratory experiment/simulation situations in Tables 4, 5, 6, and 7. The results of the content test is given in Table 8. A summary of responses to each of the items on the Student Attitude Questionnaire is given in Table 9.

When the student's attempt to extrapolate beyond experimental limits was measured, it was found that this attempt was performed in
1. Number of Trials Performed  
2. Total Data Manipulation Score  
   a. Variable #1 Values  
   b. Variable #2 Values  
   c. Data Range  
   d. Investigation of the Effect of Variable #1  
   e. Investigation of the Effect of Variable #2  
   f. Data Incrementation  
3. Experimental Conclusions  
4. Total Time Required  
   a. Time Required for Laboratory Experimentation  
   b. Time Required for Computer Simulation  
   c. Time Required for Experimental Analysis  
5. Process Test Scores  
6. Attempt to Extrapolate Beyond Experimental Limits  
7. Content Test Scores  
8. Attitude Toward CSE  

Figure 5. Variables Measured for the Study
TABLE 4
MEANS AND STANDARD DEVIATIONS OF STUDENT LABORATORY ACTIVITIES
AND PROCESSES OF SCIENCE TESTS.

Newton’s Laws

<table>
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<tr>
<th>Variable</th>
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<th>L-C Group (N=17)</th>
<th>C Group (N=17)</th>
<th>Total (N=51)</th>
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<td>11.20</td>
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<td>Time Required for Experimental Analysis</td>
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<td>91.50</td>
<td>119.10</td>
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<td></td>
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<td>69.50</td>
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<td></td>
<td>220.80</td>
<td>110.30</td>
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### TABLE 5
MEANS AND STANDARD DEVIATIONS OF STUDENT LABORATORY ACTIVITIES AND PROCESSES OF SCIENCE TESTS

**A Spring Experiment**

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<th>C Group (N=17)</th>
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TABLE 5 - Continued

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### TABLE 6
MEANS AND STANDARD DEVIATIONS OF STUDENT LABORATORY ACTIVITIES AND PROCESSES OF SCIENCE TESTS.

**The Coulomb Experiment**

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<td>0.00</td>
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<td>2.01</td>
<td>7.59</td>
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<td>Experimental Conclusions</td>
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<td>Mean S.D.</td>
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TABLE 8
MEANS AND STANDARD DEVIATIONS OF CONTENT EXAMINATION.a

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aThe Content Examination contained 18 items.
### TABLE 9

**SUMMARY OF RESPONSES TO STUDENT ATTITUDE QUESTIONNAIRE ITEMS.**

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<td>SA A N D SD</td>
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<td>6 7 2 2 0</td>
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<td>15</td>
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<td>2 3 3 6 3</td>
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*The Student Attitude Questionnaire is found in Appendix D.*
so few instances that an analysis was meaningless. A summary of these attempts is given in Table 10.

Due to the fact that the treatment groups exhibited significant mean score differences on the DAT Numerical Ability Sub-test, correlation coefficients were calculated between the criteria variables and the Numerical Ability Sub-test scores using the BMD program O2R, Stepwise Regression. The results are given in Table 11. The DAT Numerical Ability Sub-test score was used as a covariate in later analyses.

Table 11 shows that the Number of Trials Performed, Total Data Manipulation Score, Experimental Conclusions, and Test Scores exhibit a high correlation with the DAT Numerical Ability Sub-test on at least one of the experiments. The adjusted means of these laboratory activities were calculated using the DAT Numerical Ability Sub-test as the covariate. The adjusted means are shown in Table 12. In addition, the same covariate was used to compute the adjusted means of the content test. The content test adjusted means are shown in Table 13.

ANALYSIS OF DATA

Each of the seven hypotheses of the study was stated in the null form. The alpha level chosen was at least that of .10 level of significance.

Hypothesis 1. The three experimental groups, L, L-C, and C do not differ significantly with respect to (a) attainment of process skills, (b) acquisition of content, (c) number of trials performed, and (d) time involved in the experiment or simulation and analysis.

The process skills investigated were the ability to manipulate data as represented by a Data Manipulation Score, the ability to develop experimental conclusions, and the results of the written examinations
TABLE 10

EVIDENCE OF AN ATTEMPT TO EXTRAPOLATE BEYOND EXPERIMENTAL LIMITS

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Group</th>
<th>Number of Students</th>
<th>Total Number of Trials</th>
<th>Average % of Trials $^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_1$</td>
<td>L-C</td>
<td>5</td>
<td>27</td>
<td>49.8</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>5</td>
<td>8</td>
<td>10.6</td>
</tr>
<tr>
<td>$E_2$</td>
<td>L-C</td>
<td>0</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>2</td>
<td>5</td>
<td>18.0</td>
</tr>
<tr>
<td>$E_3$</td>
<td>L-C</td>
<td>0</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>0</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>$E_4$</td>
<td>L-C</td>
<td>2</td>
<td>6</td>
<td>20.5</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>5</td>
<td>20</td>
<td>15.4</td>
</tr>
</tbody>
</table>

$^a$ The Average % of Trials was calculated by averaging the percent of trials demonstrating an attempt to extrapolate beyond experimental limits for each of the students involved.
TABLE 11
CORRELATION OF SCORES ON DAT NUMERICAL ABILITY SUB-TEST TO STUDENT LABORATORY ACTIVITIES AND PROCESSES OF SCIENCE TESTS.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Trials Performed</td>
<td>0.036</td>
<td>0.376</td>
<td>0.198</td>
<td>0.263</td>
</tr>
<tr>
<td>Total Data Manipulation Score</td>
<td>0.066</td>
<td>0.312</td>
<td>0.180</td>
<td>-0.049</td>
</tr>
<tr>
<td>Experimental Conclusions</td>
<td>0.269</td>
<td>0.298</td>
<td>0.369</td>
<td>0.320</td>
</tr>
<tr>
<td>Total Time Required</td>
<td>-0.016</td>
<td>0.196</td>
<td>0.137</td>
<td>0.057</td>
</tr>
<tr>
<td>Test Scores (z-scores)</td>
<td>0.556</td>
<td>0.418</td>
<td>0.378</td>
<td>0.351</td>
</tr>
</tbody>
</table>
TABLE 12
MEANS OF CERTAIN STUDENT LABORATORY ACTIVITIES AND PROCESSES
OF SCIENCE TESTS ADJUSTED USING THE DAT NUMERICAL
ABILITY SUB-TEST AS THE COVARIATE.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Experiment</th>
<th>Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L Group</td>
<td>L-C Group</td>
</tr>
<tr>
<td>Number of Trials Performed</td>
<td>E₁</td>
<td>9.52</td>
</tr>
<tr>
<td></td>
<td>E₂</td>
<td>5.84</td>
</tr>
<tr>
<td></td>
<td>E₃</td>
<td>5.76</td>
</tr>
<tr>
<td></td>
<td>E₄</td>
<td>1.70</td>
</tr>
<tr>
<td>Total Data Manipulation Score</td>
<td>E₁</td>
<td>5.11</td>
</tr>
<tr>
<td></td>
<td>E₂</td>
<td>5.48</td>
</tr>
<tr>
<td></td>
<td>E₃</td>
<td>5.11</td>
</tr>
<tr>
<td></td>
<td>E₄</td>
<td>6.68</td>
</tr>
<tr>
<td>Experimental Conclusions</td>
<td>E₁</td>
<td>3.13</td>
</tr>
<tr>
<td></td>
<td>E₂</td>
<td>2.68</td>
</tr>
<tr>
<td></td>
<td>E₃</td>
<td>2.45</td>
</tr>
<tr>
<td></td>
<td>E₄</td>
<td>2.97</td>
</tr>
<tr>
<td>Test Scores (z-scores)</td>
<td>E₁</td>
<td>0.018</td>
</tr>
<tr>
<td></td>
<td>E₂</td>
<td>0.088</td>
</tr>
<tr>
<td></td>
<td>E₃</td>
<td>0.126</td>
</tr>
<tr>
<td></td>
<td>E₄</td>
<td>-0.034</td>
</tr>
<tr>
<td></td>
<td>L Group</td>
<td>L-C Group</td>
</tr>
<tr>
<td>---------------------</td>
<td>---------</td>
<td>-----------</td>
</tr>
<tr>
<td>Raw Score Means$^a$</td>
<td>11.94</td>
<td>12.00</td>
</tr>
<tr>
<td>Adjusted Score Means</td>
<td>12.20</td>
<td>12.26</td>
</tr>
</tbody>
</table>

$^a$The standard deviations are given in Table 8, page 71.
used to assess the ability to use the processes of science.

Data from the student laboratory reports, computer print-outs, and process tests related to the processes of science were analyzed using the BMD program X69, Multivariate Analysis of Variance and Covariance. The results of the Total Data Manipulation Score and the various sub-variables that comprise the Score are given in Tables 14, 15, 16, 17, 18, 19, and 20. The results of Experimental Conclusions are given in Table 24. The results of the Process Test Scores are given in Table 27.

Analysis of variance performed on the Total Data Manipulation Score showed differences between the treatment groups, significant at the .05 level. However, there was a significant interaction effect between experiments and subjects. A plot of the mean Total Data Manipulation Score versus Experiment was prepared and shown in Figure 6. Examination of the graphs showed the interaction to be disordinal. To determine if significant differences exist between the three groups, a one-way analysis of variance was performed on data from each of the four experiments. A summary of this analysis is given in Table 21.

Only Experiment 3 showed a significant difference between the group means. The data from Experiment 3 were subjected to further testing by the method of multiple comparisons described in Chapter 3. The .10 level was also used in this analysis. To detect treatment differences, it was necessary to examine the means of each trial. Since there were four trials, it was necessary to use an alpha level one-fourth that of the desired alpha. The .10 level of significance could
TABLE 14
ANALYSIS OF VARIANCE FOR TREATMENT GROUPS AND LABORATORY EXPERIMENTS ON TOTAL DATA MANIPULATION SCORE.

<table>
<thead>
<tr>
<th>Source of Variance</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Treatment Groups</td>
<td>37.26</td>
<td>2</td>
<td>18.63</td>
<td>4.31&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Between Experiments</td>
<td>100.76</td>
<td>3</td>
<td>33.59</td>
<td>8.89&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Subjects Within Groups</td>
<td>207.32</td>
<td>48</td>
<td>4.32</td>
<td></td>
</tr>
<tr>
<td>Groups X Experiment Interaction</td>
<td>58.03</td>
<td>6</td>
<td>9.67</td>
<td>2.56&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Experiment X Subjects Within Groups Interaction</td>
<td>544.18</td>
<td>144</td>
<td>3.78</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup>Significant at the .05 level. \( F(2,48) = 3.20 \) for significance at .05 level.

<sup>b</sup>Significant at the .001 level. \( F(3,144) = 5.64 \) for significance at .001 level.

<sup>c</sup>Significant at the .05 level. \( F(6,144) = 2.16 \) for significance at .05 level.
TABLE 15
ANALYSIS OF VARIANCE FOR TREATMENT GROUPS AND LABORATORY EXPERIMENTS ON VARIABLE #1 VALUES.

<table>
<thead>
<tr>
<th>Source of Variance</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Treatment Groups</td>
<td>2.13</td>
<td>2</td>
<td>1.06</td>
<td>7.82a</td>
</tr>
<tr>
<td>Between Experiments</td>
<td>4.12</td>
<td>3</td>
<td>1.37</td>
<td>12.04b</td>
</tr>
<tr>
<td>Subjects Within Groups</td>
<td>6.53</td>
<td>48</td>
<td>0.14</td>
<td></td>
</tr>
<tr>
<td>Groups X Experiment Interaction</td>
<td>2.97</td>
<td>6</td>
<td>0.50</td>
<td>1.19c</td>
</tr>
<tr>
<td>Experiment X Subjects Within Groups Interaction</td>
<td>16.41</td>
<td>144</td>
<td>0.11</td>
<td></td>
</tr>
</tbody>
</table>

aSignificant at the .01 level. $F(2,48) = 5.10$ for significance at .01 level.

bSignificant at the .001 level. $F(3,144) = 5.64$ for significance at .001 level.

cNot significant. $F(6,144) = 1.86$ for significance at .1 level.
# Table 16

Analysis of Variance for Treatment Groups and Laboratory Experiments on Variable 

<table>
<thead>
<tr>
<th>Source of Variance</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Treatment Groups</td>
<td>6.38</td>
<td>2</td>
<td>3.19</td>
<td>23.67&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Between Experiments</td>
<td>1.51</td>
<td>3</td>
<td>0.50</td>
<td>5.13&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Subjects Within Groups</td>
<td>6.47</td>
<td>48</td>
<td>0.13</td>
<td></td>
</tr>
<tr>
<td>Groups X Experiment Interaction</td>
<td>4.87</td>
<td>6</td>
<td>0.81</td>
<td>8.28&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Experiment X Subjects Within Groups Interaction</td>
<td>14.12</td>
<td>144</td>
<td>0.10</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup>Significant at the .001 level. \( F(2,48) = 8.05 \) for significance at .001 level.

<sup>b</sup>Significant at the .01 level. \( F(3,144) = 3.93 \) for significance at .01 level.

<sup>c</sup>Significant at the .001 level. \( F(6,144) = 3.91 \) for significance at .001 level.
TABLE 17
ANALYSIS OF VARIANCE FOR TREATMENT GROUPS AND LABORATORY EXPERIMENTS ON DATA RANGE.

<table>
<thead>
<tr>
<th>Source of Variance</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Treatment Groups</td>
<td>0.01</td>
<td>2</td>
<td>0.005</td>
<td>1.00</td>
</tr>
<tr>
<td>Between Experiments</td>
<td>0.01</td>
<td>3</td>
<td>0.005</td>
<td>1.00</td>
</tr>
<tr>
<td>Subjects Within Groups</td>
<td>0.24</td>
<td>48</td>
<td>0.005</td>
<td></td>
</tr>
<tr>
<td>Groups X Experiment Interaction</td>
<td>0.03</td>
<td>6</td>
<td>0.005</td>
<td>1.00</td>
</tr>
<tr>
<td>Experiment X Subjects Within Groups Interaction</td>
<td>0.71</td>
<td>144</td>
<td>0.005</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) Not significant. F(2,48) = 2.42 for significance at .1 level.

\(^b\) Not significant. F(3,144) = 2.13 for significance at .1 level.

\(^c\) Not significant. F(6,144) = 1.86 for significance at .1 level.
TABLE 18
ANALYSIS OF VARIANCE FOR TREATMENT GROUPS AND LABORATORY EXPERIMENTS ON INVESTIGATION OF THE EFFECT OF VARIABLE #1.

<table>
<thead>
<tr>
<th>Source of Variance</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Treatment Groups</td>
<td>8.60</td>
<td>2</td>
<td>4.30</td>
<td>5.46&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Between Experiments</td>
<td>59.78</td>
<td>3</td>
<td>19.93</td>
<td>19.90&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Subjects Within Groups</td>
<td>37.82</td>
<td>48</td>
<td>0.79</td>
<td></td>
</tr>
<tr>
<td>Groups X Experiment Interaction</td>
<td>22.54</td>
<td>6</td>
<td>3.76</td>
<td>3.75&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Experiment X Subjects Within Groups Interaction</td>
<td>144.17</td>
<td>144</td>
<td>1.00</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup>Significant at the .01 level. F(2,48) = 5.10 for significance at .01 level.

<sup>b</sup>Significant at the .001 level. F(3,144) = 5.64 for significance at .001 level.

<sup>c</sup>Significant at the .01 level. F(6,144) = 2.94 for significance at .01 level.
### TABLE 19

ANALYSIS OF VARIANCE FOR TREATMENT GROUPS AND LABORATORY EXPERIMENTS ON INVESTIGATION OF THE EFFECT OF VARIABLE #2.

<table>
<thead>
<tr>
<th>Source of Variance</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Treatment Groups</td>
<td>3.65</td>
<td>2</td>
<td>1.82</td>
<td>1.43&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Between Experiments</td>
<td>31.55</td>
<td>3</td>
<td>10.52</td>
<td>9.24&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Subjects Within Groups</td>
<td>61.35</td>
<td>48</td>
<td>1.28</td>
<td></td>
</tr>
<tr>
<td>Groups X Experiment Interaction</td>
<td>20.51</td>
<td>6</td>
<td>3.42</td>
<td>3.00&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Experiment X Subjects Within Groups Interaction</td>
<td>163.93</td>
<td>144</td>
<td>1.14</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup>Not significant. $F(2,48) = 2.42$ for significance at .1 level.

<sup>b</sup>Significant at the .001 level. $F(3,144) = 5.64$ for significance at .001 level.

<sup>c</sup>Significant at the .01 level. $F(6,144) = 2.94$ for significance at .01 level.
### TABLE 20

**ANALYSIS OF VARIANCE FOR TREATMENT GROUPS AND LABORATORY EXPERIMENTS ON DATA INCREMENTATION.**

<table>
<thead>
<tr>
<th>Source of Variance</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Treatment Groups</td>
<td>6.75</td>
<td>2</td>
<td>3.37</td>
<td>18.85&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Between Experiments</td>
<td>5.58</td>
<td>3</td>
<td>1.86</td>
<td>10.80&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Subjects Within Groups</td>
<td>8.59</td>
<td>48</td>
<td>0.18</td>
<td></td>
</tr>
<tr>
<td>Groups X Experiment Interaction</td>
<td>3.84</td>
<td>6</td>
<td>0.64</td>
<td>3.72&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Experiment X Subjects Within Groups</td>
<td>24.82</td>
<td>144</td>
<td>0.17</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> Significant at the .001 level. \(F(2,48) = 8.05\) for significance at .001 level.

<sup>b</sup> Significant at the .001 level. \(F(3,144) = 5.64\) for significance at .001 level.

<sup>c</sup> Significant at the .01 level. \(F(6,144) = 2.94\) for significance at .01 level.
Figure 6. Interaction of Experiment and Treatment Group of Total Data Manipulation Score
<table>
<thead>
<tr>
<th>Experiment</th>
<th>Mean Square</th>
<th>F(2,48)</th>
<th>P Less Than</th>
</tr>
</thead>
<tbody>
<tr>
<td>E_1</td>
<td>7.902</td>
<td>1.749</td>
<td>0.185</td>
</tr>
<tr>
<td>E_2</td>
<td>4.070</td>
<td>0.782</td>
<td>0.463</td>
</tr>
<tr>
<td>E_3</td>
<td>34.647</td>
<td>12.113</td>
<td>0.001*</td>
</tr>
<tr>
<td>E_4</td>
<td>1.020</td>
<td>0.333</td>
<td>0.718</td>
</tr>
</tbody>
</table>

*Significant
only be attained by testing at the .025 level or .10 divided by four. The means were 5.06, 7.59, and 7.47 for the L, L-C, and C groups respectively. The contrasts are shown in Table 22. None of the contrasts exceeded the critical value. The largest contrast was between the computer related Groups and the Laboratory Group.

Analysis of covariance was performed on the Total Data Manipulation Score and the results are shown in Table 23. The test of the equality of regression between the treatment groups on each of the four experiments produced F-ratios of .671, .143, 3.235, and .551 for experiments 1, 2, 3, and 4 respectively. For significance, the F-ratio must exceed 2.43. The data contradicts the hypothesis of homogeneity of regression for Experiment 3. Consequently, the results of the analysis of covariance were not used to make group comparisons.

Based on the analyses of data presented, there was a significant difference between the groups on Total Data Manipulation Score. However, the interaction was such that multiple comparisons on each of the experiments was required. No significant differences were found between pairs or combinations of groups. The largest contrast was found between the Laboratory and the computer related Groups. This evidence, taken with the fact that a computer related group had the highest mean Score in each of the experiments, leads one to believe that students had better control over data when working with the computer than when performing laboratory experiments.

Analysis of variance performed on Experimental Conclusions showed no significant differences between the three groups. The results
| Contrast<sup>a</sup> | $\hat{\psi}$ | $\hat{\sigma}_\psi^2$ | $\hat{\sigma}_\psi$ | $\left|\frac{\hat{\psi}}{\hat{\sigma}_\psi}\right|<sup>b</sup> |
|---------------------|--------------|-------------------|-------------------|-------------------|
| L - $L^0C$          | -2.53        | 4.08              | 2.02              | 1.25              |
| L - C               | -2.41        | 4.08              | 2.02              | 1.19              |
| $L^0C - C$          | 0.12         | 4.08              | 2.02              | 0.06              |
| ((L$^0C + C)/2) - L$| 2.47         | 3.06              | 1.75              | 1.41              |

<sup>a</sup> $L^0C$ represents the Laboratory-Computer Group

<sup>b</sup> $.975F_{2,48} = 4.00; \quad \sqrt{(2)(4.00)} = 2.83$ (Critical Value)
TABLE 23
ANALYSIS OF COVARIANCE FOR TREATMENT GROUPS AND LABORATORY EXPERIMENTS ON TOTAL DATA MANIPULATION SCORE (DAT NUMERICAL ABILITY SUB-TEST USED AS THE COVARIATE).

<table>
<thead>
<tr>
<th>Source of Variance</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Treatment Groups</td>
<td>716.51</td>
<td>2</td>
<td>358.25</td>
<td>111.23&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Between Experiments</td>
<td>354.66</td>
<td>3</td>
<td>118.22</td>
<td>45.47&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Subjects Within Groups</td>
<td>154.60</td>
<td>48</td>
<td>3.22</td>
<td></td>
</tr>
<tr>
<td>Groups X Experiment Interaction</td>
<td>302.89</td>
<td>6</td>
<td>50.48</td>
<td>19.42&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Experiment X Subjects Within Groups Interaction</td>
<td>371.80</td>
<td>143</td>
<td>2.60</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> Significant at the .001 level. $F(2,48) = 8.05$ for significance at .001 level.

<sup>b</sup> Significant at the .001 level. $F(3,143) = 5.64$ for significance at .001 level.

<sup>c</sup> Significant at the .001 level. $F(6,143) = 3.91$ for significance at .001 level.
of this analysis are shown in Table 24.

Analysis of covariance performed on Experimental Conclusions showed differences between the adjusted means to be significant at the .001 level as shown in Table 25. The test of equality of regression between the treatment groups on each of the four experiments produced F-ratios of .025, .247, .452, and .312 for experiments 1, 2, 3, and 4 respectively. For significance at the .10 level, the F-ratio must exceed 2.43. The data do not contradict the hypothesis of homogeneity of regression.

There was a significant interaction effect between experiments and treatments. A plot of adjusted mean Experimental Conclusion score versus Experiment is shown in Figure 7. Examination of the graphs showed that while the interaction was disordinal, the Laboratory-Computer Group had consistently higher mean scores. The interaction effect was primarily between the Computer and Laboratory Groups.

Figure 7. Interaction of Experiment and Treatment Group on Experimental Conclusions using Adjusted Means.
### TABLE 24
ANALYSIS OF VARIANCE FOR TREATMENT GROUPS AND LABORATORY EXPERIMENTS ON EXPERIMENTAL CONCLUSIONS.

<table>
<thead>
<tr>
<th>Source of Variance</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Treatment Groups</td>
<td>7.09</td>
<td>2</td>
<td>3.54</td>
<td>0.98&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Between Experiments</td>
<td>4.13</td>
<td>3</td>
<td>1.38</td>
<td>2.11&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Subjects Within Groups</td>
<td>173.76</td>
<td>48</td>
<td>3.62</td>
<td></td>
</tr>
<tr>
<td>Groups X Experiment Interaction</td>
<td>3.62</td>
<td>6</td>
<td>0.60</td>
<td>0.92&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Experiment X Subjects Within Groups Interaction</td>
<td>93.99</td>
<td>144</td>
<td>0.65</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup>Not significant. $F(2,48) = 2.42$ for significance at .1 level.

<sup>b</sup>Not significant. $F(3,144) = 2.13$ for significance at .1 level.

<sup>c</sup>Not significant. $F(6,144) = 1.86$ for significance at .1 level.
### TABLE 25

**ANALYSIS OF COVARIANCE FOR TREATMENT GROUPS AND LABORATORY EXPERIMENTS ON EXPERIMENTAL CONCLUSIONS (DAT NUMERICAL ABILITY SUB-TEST USED AS THE COVARIATE).**

<table>
<thead>
<tr>
<th>Source of Variance</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Treatment Groups</td>
<td>222.40</td>
<td>2</td>
<td>111.20</td>
<td>52.75a</td>
</tr>
<tr>
<td>Between Experiments</td>
<td>29.88</td>
<td>3</td>
<td>9.96</td>
<td>19.96b</td>
</tr>
<tr>
<td>Subjects Within Groups</td>
<td>101.20</td>
<td>48</td>
<td>2.11</td>
<td></td>
</tr>
<tr>
<td>Groups X Experiment Interaction</td>
<td>42.79</td>
<td>6</td>
<td>7.13</td>
<td>14.29c</td>
</tr>
<tr>
<td>Experiment X Subjects Within Groups</td>
<td>71.35</td>
<td>143</td>
<td>0.50</td>
<td></td>
</tr>
</tbody>
</table>

*a* Significant at the .001 level. *F*(2,48) = 8.05 for significance at .001 level.

*b* Significant at the .001 level. *F*(3,143) = 5.64 for significance at .001 level.

*c* Significant at the .001 level. *F*(6,143) = 3.91 for significance at .001 level.
The data were subjected to further testing by the method of multiple comparisons. The means were 2.807, 3.263, and 2.798 for the L, L-C, and C Groups respectively. The contrasts are shown in Table 26. The mean Experimental Conclusion score of the Laboratory-Computer Group when compared with the Laboratory and Computer Group combination is very nearly equal to the critical value.

A significant difference existed between the adjusted Experimental Conclusion score means. The Laboratory-Computer Group had a consistently higher adjusted mean score than the other groups and it was shown that this approached significance. The null hypothesis was rejected in favor of the Laboratory-Computer Group.

Analysis of variance was performed on the mean z-scores obtained from the process tests used to evaluate the student's ability to use the processes of science. The results of that analysis is shown in Table 27. No significant differences between the groups were found.

Analysis of covariance was performed on the z-scores. The results of that analysis is shown in Table 28. Again, no significant differences were found. The test of equality of regressions between the treatment groups on each of the four experiments produced F-ratios of .549, .622, .398, and .580 for experiments 1, 2, 3, and 4 respectively. For significance at the .1 level, the F-ratio must exceed 2.43. The data do not contradict the hypothesis of homogeneity of regression. However, it is interesting to note that in the plot of adjusted mean z-score versus Experiment in Figure 8, the means of the Laboratory-Computer and Laboratory groups were consistently higher than the Computer Group.
## TABLE 26

**Scheffé Multiple Comparison Test on Experimental Conclusion Means**

| Contrast          | \( \hat{\psi} \) | \( \hat{\sigma}_\psi^2 \) | \( \hat{\sigma}_\psi \) | \( \left| \frac{\hat{\psi}}{\hat{\psi}} \right| \) |
|-------------------|-------------------|-----------------------------|-----------------------------|-------------------------------------------------|
| \( L - L^\circ C \) | -0.456            | 0.062                       | 0.249                       | 1.832                                           |
| \( L - C \)       | 0.009             | 0.062                       | 0.249                       | 0.036                                           |
| \( L^\circ C - C \)| 0.465             | 0.062                       | 0.249                       | 1.868                                           |
| \( ((L + C)/2) - L^\circ C \)| 0.460 | 0.465                       | 0.216                       | 2.133                                           |

<table>
<thead>
<tr>
<th>a L( ^\circ C ) represents the Laboratory-Computer Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>b ( .90 F_{2,192} = 2.33; \sqrt{2} (2.33) = 2.159 ) (Critical Value)</td>
</tr>
<tr>
<td>Source of Variance</td>
</tr>
<tr>
<td>----------------------------------------</td>
</tr>
<tr>
<td>Between Treatment Groups</td>
</tr>
<tr>
<td>Between Experiments</td>
</tr>
<tr>
<td>Subjects Within Groups</td>
</tr>
<tr>
<td>Groups X Experiment Interaction</td>
</tr>
<tr>
<td>Experiment X Subjects Within Groups</td>
</tr>
</tbody>
</table>

\(^a\)Not significant. \(F(2,48) = 2.42\) for significance at .1 level.

\(^b\)Not significant. \(F(3,144) = 2.13\) for significance at .1 level.

\(^c\)Not significant. \(F(6,144) = 1.86\) for significance at .1 level.
TABLE 28

ANALYSIS OF COVARIANCE FOR TREATMENT GROUPS AND LABORATORY EXPERIMENTS ON TEST SCORES (z-SCORES) (DAT NUMERICAL ABILITY SUB-TEST USED AS THE COVARIATE).

<table>
<thead>
<tr>
<th>Source of Variance</th>
<th>Sum of Square</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Treatment Groups</td>
<td>0.17</td>
<td>2</td>
<td>0.09</td>
<td>0.10^a</td>
</tr>
<tr>
<td>Between Experiments</td>
<td>0.04</td>
<td>3</td>
<td>0.01</td>
<td>0.02^b</td>
</tr>
<tr>
<td>Subjects Within Groups</td>
<td>42.65</td>
<td>48</td>
<td>0.89</td>
<td></td>
</tr>
<tr>
<td>Groups X Experiment Interaction</td>
<td>0.59</td>
<td>6</td>
<td>0.10</td>
<td>0.17^c</td>
</tr>
<tr>
<td>Experiment X Subjects Within Groups Interaction</td>
<td>83.66</td>
<td>143</td>
<td>0.59</td>
<td></td>
</tr>
</tbody>
</table>

^a Not significant. F(2,48) = 2.42 for significance at .1 level.

^b Not significant. F(3,143) = 2.13 for significance at .1 level.

^c Not significant. F(6,143) = 1.86 for significance at .1 level.
The null hypothesis cannot be rejected. The lack of group differences suggest that the groups were nearly equivalent when using the processes of science on written examination.

The acquisition of content was assessed through the use of a content examination. Data from the content examination was analyzed using a one-way analysis of variance. The results of that analysis are shown in Table 29. Analysis of variance showed no significant difference between the groups' mean scores on the content examination.

Analysis of covariance using the DAT Numerical Ability Sub-test as the covariate was performed on the mean scores. These results are shown in Table 30. The test of equality of regression between the
### TABLE 29

**ANALYSIS OF VARIANCE FOR TREATMENT GROUPS ON CONTENT EXAMINATION.**

<table>
<thead>
<tr>
<th>Source of Variance</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between</td>
<td>5.22</td>
<td>2</td>
<td>2.61</td>
<td>0.29&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Within</td>
<td>430.47</td>
<td>48</td>
<td>8.97</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>435.69</td>
<td>50</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup>Not significant. F(2,48) = 2.42 for significance at .1 level.

### TABLE 30

**ANALYSIS OF COVARIANCE FOR TREATMENT GROUPS ON CONTENT EXAMINATION (DAT NUMERICAL ABILITY SUB-TEST USED AS THE COVARIATE).**

<table>
<thead>
<tr>
<th>Source of Variance</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between</td>
<td>21.72</td>
<td>2</td>
<td>10.86</td>
<td>1.40&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Within</td>
<td>363.82</td>
<td>47</td>
<td>7.74</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>385.54</td>
<td>49</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup>Not significant. F(2,47) = 2.42 for significance at .1 level.
treatment groups produced an F-ratio of 0.194. For significance at the .1 level, the F-ratio must exceed 2.43. The data do not contradict the hypothesis of homogeneity of regression. While the analysis of covariance increased the F-ratio considerably, the difference was still not significant. It is interesting to note that the Laboratory-Computer Group had the highest mean and adjusted mean score.

The null hypothesis cannot be rejected. It appears that the three groups were nearly equivalent with respect to the acquisition of content information.

Analysis of variance performed on the Number of Trials showed differences between the three groups, significant at the .001 level. The results of this analysis are given in Table 31. While the interaction effect between the experiments and treatments was significant, a plot of the Number of Trials Performed versus Experiment, Figure 9, showed that the graphs did not cross. The data was subjected to further analysis using the multiple comparison technique. The means were 5.28, 10.30, and 12.96 for the L, L-C, and C Groups respectively. The contrasts are shown in Table 32. All contrasts shown are significant.

Analysis of covariance was performed on the Number of Trials and the results are shown in Table 33. A plot of the adjusted Number of Trials Performed versus Experiment was shown in Figure 10. No new information was derived from these analyses.

Significant differences existed between the groups. The Computer Group performed a significantly higher Number of Trials than the other Groups. The Laboratory-Computer Group performed a significantly higher
TABLE 31
ANALYSIS OF VARIANCE FOR TREATMENT GROUPS AND LABORATORY EXPERIMENTS ON NUMBER OF TRIALS PERFORMED.

<table>
<thead>
<tr>
<th>Source of Variance</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Treatment Groups</td>
<td>2066.30</td>
<td>2</td>
<td>1033.15</td>
<td>32.09(^a)</td>
</tr>
<tr>
<td>Between Experiments</td>
<td>311.69</td>
<td>3</td>
<td>103.90</td>
<td>10.50(^b)</td>
</tr>
<tr>
<td>Subjects Within Groups</td>
<td>1545.17</td>
<td>48</td>
<td>32.19</td>
<td></td>
</tr>
<tr>
<td>Groups X Experiment Interaction</td>
<td>512.40</td>
<td>6</td>
<td>85.40</td>
<td>3.25(^c)</td>
</tr>
<tr>
<td>Experiment X Subjects Within Groups Interaction</td>
<td>1425.27</td>
<td>144</td>
<td>9.90</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\)Significant at the .001 level. \(F(2,48) = 8.05\) for significance at .001 level.

\(^b\)Significant at the .001 level. \(F(3,144) = 5.64\) for significance at .001 level.

\(^c\)Significant at the .01 level. \(F(6,144) = 2.94\) for significance at .01 level.
Figure 9. Interaction of Experiment and Treatment Group on Number of Trials Performed
TABLE 32

SCHEFFE MULTIPLE COMPARISON TEST ON NUMBER OF TRIALS PERFORMED

| Contrast^a | $\hat{\psi}$ | $\hat{\sigma}_\hat{\psi}^2$ | $\hat{\sigma}_\hat{\psi}^2$ | $|\hat{\psi}|/\hat{\sigma}_\hat{\psi}$ | b |
|------------|--------------|----------------|----------------|----------------------------|---|
| L - L°C    | -5.02        | 0.95           | 0.97           | 5.16*                      |   |
| L - C      | -7.68        | 0.95           | 0.97           | 7.89*                      |   |
| L°C - C    | -2.66        | 0.95           | 0.97           | 2.73*                      |   |
| ((L°C + C)/2) - L | 6.35 | 0.71           | 0.84           | 7.54*                      |   |

^a L°C represents the Laboratory-Computer Group

^b $0.90_{F,2,192} = 2.33$; $\sqrt{(2) (2.33)} = 2.16$ (Critical Value)
TABLE 33
ANALYSIS OF COVARIANCE FOR TREATMENT GROUPS AND LABORATORY EXPERIMENTS ON NUMBER OF TRIALS PERFORMED (DAT NUMERICAL ABILITY SUB-TEST USED AS THE COVARIATE).

<table>
<thead>
<tr>
<th>Source of Variance</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Treatment Groups</td>
<td>1702.97</td>
<td>2</td>
<td>851.48</td>
<td>72.67(^a)</td>
</tr>
<tr>
<td>Between Experiments</td>
<td>340.15</td>
<td>3</td>
<td>113.38</td>
<td>14.96(^b)</td>
</tr>
<tr>
<td>Subjects Within Groups</td>
<td>562.41</td>
<td>48</td>
<td>11.72</td>
<td></td>
</tr>
<tr>
<td>Groups X Experiment Interaction</td>
<td>1753.22</td>
<td>6</td>
<td>292.20</td>
<td>38.55(^c)</td>
</tr>
<tr>
<td>Experiment X Subjects Within Groups</td>
<td>1084.05</td>
<td>143</td>
<td>7.58</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) Significant at the .001 level. \(F(2,48) = 8.05\) for significance at .001 level.

\(^b\) Significant at the .001 level. \(F(3,143) = 5.64\) for significance at .001 level.

\(^c\) Significant at the .001 level. \(F(6,143) = 3.91\) for significance at .001 level.
Figure 10. Interaction of Experiment and Treatment Group on Number of Trials Performed Using Adjusted Means.
Number of Trials than the Laboratory Group. The null hypothesis was rejected.

The time involved in the experiment or simulation and analysis was determined from student records. Analysis of variance was performed on Time Required for Experimental Analysis, Table 34, and Total Time Required, Table 35. The analyses showed that no significant differences existed between the three groups. A plot of Total Time Required versus Experiment is shown in Figure 11. With the exception of Experiment 1, the Laboratory-Computer and Computer Groups used more time than the Laboratory Group. Experiment 1 might be considered an introductory experiment in which the computer related groups were learning how to use the computer and analyze their results. In addition, the Laboratory Group may have experienced a reverse Hawthorne effect and were trying to insure that they performed as well as the other groups.

![Figure 11. Interaction of Experiment and Treatment Group on Total Time Required.](image)
### TABLE 34

ANALYSIS OF VARIANCE FOR TREATMENT GROUPS AND LABORATORY EXPERIMENTS ON TIME REQUIRED FOR EXPERIMENTAL ANALYSIS.

<table>
<thead>
<tr>
<th>Source of Variance</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Treatment Groups</td>
<td>9698.88</td>
<td>2</td>
<td>4849.44</td>
<td>0.65&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Between Experiments</td>
<td>362323.13</td>
<td>3</td>
<td>120774.38</td>
<td>37.53&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Subjects Within Groups</td>
<td>356391.63</td>
<td>48</td>
<td>7424.82</td>
<td></td>
</tr>
<tr>
<td>Groups X Experiment Interaction</td>
<td>136108.13</td>
<td>6</td>
<td>22684.69</td>
<td>7.05&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Experiment X Subjects Within Groups Interaction</td>
<td>463409.13</td>
<td>144</td>
<td>3218.12</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> Not significant. $F(2,48) = 2.42$ for significance at .1 level.

<sup>b</sup> Significant at the .001 level. $F(3,144) = 5.64$ for significance at .001 level.

<sup>c</sup> Significant at the .001 level. $F(6,144) = 3.91$ for significance at .001 level.
TABLE 35

ANALYSIS OF VARIANCE FOR TREATMENT GROUPS AND LABORATORY EXPERIMENTS ON TOTAL TIME REQUIRED.

<table>
<thead>
<tr>
<th>Source of Variance</th>
<th>Sum of Square</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Treatment Groups</td>
<td>23086.63</td>
<td>2</td>
<td>11543.31</td>
<td>1.36 a</td>
</tr>
<tr>
<td>Between Experiments</td>
<td>265112.88</td>
<td>3</td>
<td>188370.94</td>
<td>54.41 b</td>
</tr>
<tr>
<td>Subjects Within Groups</td>
<td>406010.56</td>
<td>48</td>
<td>8458.55</td>
<td></td>
</tr>
<tr>
<td>Groups X Experiment Interaction</td>
<td>122695.63</td>
<td>6</td>
<td>20449.27</td>
<td>5.91 c</td>
</tr>
<tr>
<td>Experiment X Subjects Within Groups</td>
<td>498489.13</td>
<td>144</td>
<td>3461.73</td>
<td></td>
</tr>
</tbody>
</table>

a Not significant. $F(2,48) = 2.42$ for significance at .1 level.

b Significant at the .001 level. $F(3,144) = 5.64$ for significance at .001 level.

c Significant at the .001 level. $F(6,144) = 3.91$ for significance at .001 level.
No statistical significance was found with respect to the Total Time Required or the Time Required for Experimental Analysis. Since no significant differences existed on these two aspects of Time Required, a statistical comparison of the time required for obtaining data was not performed. However, a graphical comparison of the groups can be made. When the Time Required for Laboratory Experimentation and the Time Required for Computer Simulation, found in Tables 4, 5, 6, and 7 were added and plotted versus Experiment, Figure 12 resulted. As can be seen, the Laboratory-Computer and Computer Groups required more time to obtain data than the Laboratory Group in all experiments except Experiment 4. This provided further evidence that Computer Simulated Experiments generally do not reduce the amount of time required for laboratory work.

![Figure 12. Interaction of Experiment and Treatment Group on Time Required for Experiment and/or Simulation.](image-url)
The null hypothesis cannot be rejected. It appears that the amount of time spent in laboratory situations is independent of the method of performing the experiment.

Hypothesis 2. There is no significant difference between the attitudes of students in group L-C and C toward CSE as measured by the Student Attitude Questionnaire.

The decision to reject or not reject this hypothesis was based on data derived from the Student Attitude Questionnaire. A one-way analysis of variance was performed on responses obtained from each of the items. The results of that analysis are shown in Table 36. No item had a sufficiently high F-ratio to indicate a significant difference between the groups. Only items 1 and 13 approach significance. However, as indicated by the mean responses, the Laboratory-Computer Group tended to view CSE somewhat more favorably than the Computer Group. Due to the lack of significance, the null hypothesis was not rejected.

Hypothesis 3. There is no significant difference between the performances of students on laboratory exercises 1, 2, 3, and 4 with respect to the (a) attainment of process skills, (b) number of trials performed, and (c) time involved in the experiment or simulation and analysis.

When the results of the analysis of variance of each of the process variables were studied, it was found that:

1. Differences existed between the four experiments with respect to Total Data Manipulation Score. An investigation of the interaction was such that no decisive statement could be made about the differences.

2. No significant differences existed between the four experiments with respect to Experimental Conclusions score as shown in Table 24.
<table>
<thead>
<tr>
<th>Item</th>
<th>L-C Group</th>
<th>C Group</th>
<th>Mean Square</th>
<th>F&lt;sup&gt;b&lt;/sup&gt;(1,32)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.7647 1.2515</td>
<td>2.1176 0.9926</td>
<td>3.56</td>
<td>2.7896</td>
</tr>
<tr>
<td>2</td>
<td>4.2353 0.8314</td>
<td>4.0000 1.0000</td>
<td>0.47</td>
<td>0.5565</td>
</tr>
<tr>
<td>3</td>
<td>4.4118 0.7952</td>
<td>4.2941 0.7717</td>
<td>0.12</td>
<td>0.1916</td>
</tr>
<tr>
<td>4</td>
<td>1.8824 1.1663</td>
<td>2.2941 1.0467</td>
<td>0.47</td>
<td>1.1737</td>
</tr>
<tr>
<td>5</td>
<td>3.7647 0.8314</td>
<td>3.7647 0.8314</td>
<td>0.00</td>
<td>0.0000</td>
</tr>
<tr>
<td>6</td>
<td>4.1176 0.8575</td>
<td>3.7647 0.8314</td>
<td>1.06</td>
<td>1.4845</td>
</tr>
<tr>
<td>7</td>
<td>2.5294 1.2805</td>
<td>2.6471 1.1147</td>
<td>0.27</td>
<td>0.0816</td>
</tr>
<tr>
<td>8</td>
<td>2.4118 0.6183</td>
<td>2.4118 0.9393</td>
<td>0.00</td>
<td>0.0000</td>
</tr>
<tr>
<td>9</td>
<td>3.5294 0.7998</td>
<td>3.6471 1.1147</td>
<td>0.12</td>
<td>0.1250</td>
</tr>
<tr>
<td>10</td>
<td>2.7647 0.9034</td>
<td>2.5882 0.8703</td>
<td>0.27</td>
<td>0.3364</td>
</tr>
<tr>
<td>11</td>
<td>2.1176 0.6966</td>
<td>2.1765 0.7276</td>
<td>0.03</td>
<td>0.0580</td>
</tr>
<tr>
<td>12</td>
<td>2.7059 0.8489</td>
<td>2.4118 0.9393</td>
<td>0.74</td>
<td>0.9174</td>
</tr>
<tr>
<td>13</td>
<td>2.3529 0.7859</td>
<td>2.7647 0.9034</td>
<td>1.44</td>
<td>2.0103</td>
</tr>
<tr>
<td>14</td>
<td>4.2941 0.8489</td>
<td>3.9412 0.8269</td>
<td>1.06</td>
<td>1.5078</td>
</tr>
<tr>
<td>15</td>
<td>2.5294 1.1246</td>
<td>2.7059 1.3117</td>
<td>1.88</td>
<td>0.1773</td>
</tr>
</tbody>
</table>

*aThe Questionnaire results were quantified as follows: Strongly Agree = 5; Agree = 4; No Opinion = 3; Disagree = 2; Strongly Disagree = 1.*

*b*F* = 2.87 for significance at .1 level.*
3. No significant differences existed between the four experiments with respect to z-scores on the process tests as shown in Table 27.

With the exception of the Total Data Manipulation Score, no significant process skill differences were found between the experiments. A disordinal interaction was produced by the Total Data Manipulation Score. The Score results provided no assistance in making a decision. Therefore, the null hypothesis was not rejected.

Analysis of variance of the Number of Trials Performed showed differences between experiments significant at the .001 level as shown in Table 31. The data were subjected to further analysis using the multiple comparison technique. The means were 11.27, 8.25, 10.06, and 8.45 for $E_1$, $E_2$, $E_3$, and $E_4$ respectively. The contrasts are shown in Table 37. The significant contrasts are noted.

There were significant differences between the groups on Number of Trials Performed in each of the experiments. Significant differences existed between experiments and groups of experiments. Therefore, the null hypothesis was rejected.

Analysis of variance on the Time Required for Experimental Analysis and Total Time Required showed differences between the experiments significant at the .001 level as shown in Tables 34 and 35. The technique of multiple comparisons was used on the Total Time Required. The means were 174.1, 241.5, 118.1, and 110.2 minutes for experiments $E_1$, $E_2$, $E_3$, and $E_4$ respectively. The contrasts are shown in Table 38. Significant contrasts are noted.
TABLE 37
SCHEFFE MULTIPLE COMPARISON TESTS ON MEAN NUMBER OF TRIALS PERFORMED

| Contrast | $\hat{\psi}$ | $\hat{s}_\psi^2$ | $\hat{s}_\psi$ | $|\hat{\psi}/\hat{s}_\psi|$ |
|----------|--------------|----------------|--------------|-----------------|
| $E_1 - E_2$ | 3.02 | 0.39 | 0.62 | 4.85* |
| $E_1 - E_3$ | 1.21 | 0.39 | 0.62 | 1.94 |
| $E_1 - E_4$ | 2.82 | 0.29 | 0.62 | 4.53* |
| $E_2 - E_3$ | -1.81 | 0.39 | 0.62 | 2.91* |
| $E_2 - E_4$ | -0.20 | 0.39 | 0.62 | 0.32 |
| $E_3 - E_4$ | 1.61 | 0.39 | 0.62 | 2.58* |
| $((E_1+E_3)/2) - ((E_2+E_4)/2)$ | 2.32 | 0.19 | 0.44 | 5.27* |

$^{a} .9^{0.90^{F,3,192}} = 2.11; \sqrt{(3)\,(2.11)} = 2.52$ (Critical Value)
### TABLE 38
Scheffé Multiple Comparison Test on Total Time Required

| Contrast                      | $\hat{\psi}$ | $\hat{\phi}$ | $\hat{\psi}$ | $\left| \frac{\hat{\psi}}{\hat{\phi}} \right|^a$ |
|-------------------------------|--------------|--------------|--------------|-----------------------------------------------|
| $E_1 - E_2$                   | -67.4        | 126.2        | 11.2         | 6.00*                                         |
| $E_1 - E_3$                   | 56.0         | 126.2        | 11.2         | 4.99*                                         |
| $E_1 - E_4$                   | 63.9         | 126.2        | 11.2         | 5.69*                                         |
| $E_2 - E_3$                   | 123.4        | 126.2        | 11.2         | 10.99*                                        |
| $E_2 - E_4$                   | 131.3        | 126.2        | 11.2         | 11.69*                                        |
| $E_3 - E_4$                   | 7.9          | 126.2        | 11.2         | 0.70                                          |
| $E_1 - ((E_3+E_4)/2)$         | 59.9         | 95.6         | 9.78         | 6.13*                                         |
| $E_2 - ((E_3+E_4)/2)$         | 127.3        | 95.6         | 9.78         | 13.02*                                        |
| $((E_1+E_2)/2) - ((E_3+E_4)/2)$ | 93.6       | 63.1         | 7.95         | 11.78*                                        |

$^a_{.90 F_{3,192} = 2.11; \ \ \sqrt{(3)(2.11)} = 2.52}$ (Critical Value)
Significant differences existed between the Number of Trials Performed by the groups as well as between individual groups. The null hypothesis was rejected.

**Hypothesis 4.** There is no significant difference between the performances of the Laboratory Group on laboratory exercises 1, 2, 3, and 4 with respect to the (a) attainment of process skills, (b) number of trials performed, and (c) time involved in the experiment and analysis.

Data collected from the Laboratory Group were summarized in Table 39. The data were analyzed in an attempt to detect trend effects.

The results of the analysis of variance performed on process variables showed no significant differences between the performances of the Laboratory Group on the various laboratory exercises with respect to Experimental Conclusions or process Test Scores. However, the differences between the results of the experiments were significant at the .01 level for the Total Data Manipulation Score. These results were further analyzed using the multiple comparison technique. The means were 5.12, 5.29, 5.06, and 6.71 for experiment E₁, E₂, E₃, and E₄ respectively. The contrasts are shown in Table 40. None of the contrasts were significant. The largest contrast was between Experiments 1, 2, and 3 and Experiment 4.

The null hypothesis was rejected. There were significant differences between the experiments. These differences were not sufficiently large to show significant pair or combination differences.

Analysis of variance performed on the Number of Trials Performed showed differences significant at the .001 level. The results were further analyzed using the multiple comparison technique. The means
**TABLE 39**

**SUMMARY OF LABORATORY GROUP STATISTICS: MEANS, STANDARD DEVIATIONS, AND MEAN SQUARE AND F-RATIO FROM ANALYSIS OF VARIANCE.**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean $E_1$</th>
<th>S.D.</th>
<th>Mean $E_2$</th>
<th>S.D.</th>
<th>Mean $E_3$</th>
<th>S.D.</th>
<th>Mean $E_4$</th>
<th>S.D.</th>
<th>Mean Square</th>
<th>$F(3,64)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Trials Performed</td>
<td>9.41</td>
<td>2.29</td>
<td>5.76</td>
<td>2.63</td>
<td>4.24</td>
<td>1.75</td>
<td>1.71</td>
<td>0.47</td>
<td>176.6</td>
<td>45.63$^a$</td>
</tr>
<tr>
<td>Total Data Manipulation Score</td>
<td>5.12</td>
<td>1.05</td>
<td>5.29</td>
<td>1.86</td>
<td>5.06</td>
<td>2.01</td>
<td>6.71</td>
<td>0.92</td>
<td>10.37</td>
<td>4.37$^b$</td>
</tr>
<tr>
<td>Experimental Conclusions</td>
<td>3.06</td>
<td>1.20</td>
<td>2.59</td>
<td>1.23</td>
<td>2.35</td>
<td>1.22</td>
<td>2.88</td>
<td>1.05</td>
<td>1.66</td>
<td>1.20$^c$</td>
</tr>
<tr>
<td>Total Time Required (min.)</td>
<td>221</td>
<td>110</td>
<td>216</td>
<td>88</td>
<td>86</td>
<td>33</td>
<td>83</td>
<td>36</td>
<td>101932</td>
<td>18.32$^d$</td>
</tr>
<tr>
<td>Test Scores (z-scores)</td>
<td>-.10</td>
<td>1.20</td>
<td>-.01</td>
<td>1.16</td>
<td>0.01</td>
<td>1.11</td>
<td>-.12</td>
<td>1.04</td>
<td>0.10</td>
<td>0.08$^e$</td>
</tr>
</tbody>
</table>

$^a$Significant at the .001 level. $F(3,64) = 6.15$ for significance at .001 level.

$^b$Significant at the .01 level. $F(3,64) = 4.12$ for significance at .01 level.

$^c$Not significant.

$^d$Significant at the .001 level.

$^e$Not significant.
| Contrast              | \( \hat{\psi} \) | \( \hat{\sigma}^2 \) | \( \hat{\sigma}^2 \) | \( \left| \frac{\hat{\psi}}{\hat{\sigma}} \right| \) |
|----------------------|-----------------|-----------------|-----------------|-----------------|
| \( E_1 - E_2 \)     | 0.17            | 1.22            | 1.11            | 0.15            |
| \( E_1 - E_3 \)     | 0.06            | 1.22            | 1.11            | 0.05            |
| \( E_1 - E_4 \)     | -1.59           | 1.22            | 1.11            | 1.44            |
| \( E_2 - E_3 \)     | 0.23            | 1.22            | 1.11            | 0.21            |
| \( E_2 - E_4 \)     | -1.42           | 1.22            | 1.11            | 1.29            |
| \( E_3 - E_4 \)     | -1.65           | 1.22            | 1.11            | 1.49            |
| \( E_4 - (E_1 + E_2 + E_3)/3 \) | 1.56            | 0.81            | 0.90            | 1.73            |

\(^a\) \( .90^F_{3,64} = 2.18; \sqrt{(3)(2.18)} = 2.56 \) (Critical Value)
were 9.41, 5.76, 4.24, and 1.71 for experiments $E_1$, $E_2$, $E_3$, and $E_4$ respectively. The contrasts are shown in Table 41. None of the contrasts were significant.

The null hypothesis was rejected. There were significant differences between the experiments. However, none of the differences were sufficiently large to produce pair significance.

Analysis of variance performed on the Total Time Required showed differences significant at the .001 level. The technique of multiple comparison was used in an attempt to find individual differences. The means were 220.8, 215.8, 85.6, and 82.8 minutes for experiments $E_1$, $E_2$, $E_3$, and $E_4$ respectively. The contrasts are shown in Table 42. None of the contrasts were significant. The largest contrast was between Experiments 1 and 2 and Experiments 3 and 4.

The null hypothesis was rejected. There were significant differences between the experiments. However, the differences were not sufficiently large to show individual or group differences.

**Hypothesis 5.** There is no significant difference between the performances of the Laboratory-Computer Group on laboratory exercises 1, 2, 3, and 4 with respect to the (a) attainment of process skills, (b) number of trials performed, and (c) time involved in the experiment, simulation, and analysis.

Data collected from the Laboratory-Computer Group were summarized in Table 43. The results were similar to those of the Laboratory Group.

No significant differences were found with respect to Experimental Conclusions or process Test Scores. Differences between the results of the experiments were significant at the .01 level for the
TABLE 41

SCHIFFÉ MULTIPLE COMPARISON TEST ON NUMBER OF TRIALS
PERFORMED FOR LABORATORY GROUP

| Contrast | $\hat{\psi}$ | $\hat{\sigma}^2_{\psi}$ | $\hat{\gamma}_{\psi}$ | $|\hat{\psi}_{68,1,1}|^a$ |
|----------|--------------|-----------------|-----------------|-----------------|
| $E_1 - E_2$ | 3.65 | 20.78 | 4.56 | 0.80 |
| $E_1 - E_3$ | 5.17 | 20.78 | 4.56 | 1.13 |
| $E_1 - E_4$ | 7.70 | 20.78 | 4.56 | 1.69 |
| $E_2 - E_3$ | 1.52 | 20.78 | 4.56 | 0.33 |
| $E_2 - E_4$ | 4.05 | 20.78 | 4.56 | 0.89 |
| $E_3 - E_4$ | 2.53 | 20.78 | 4.56 | 0.55 |

$a \quad .90_F 3,64 = 2.18; \quad \sqrt{(3)(2.18)} = 2.56 \quad \text{(Critical Value)}$
TABLE 42

SCHEFFÉ MULTIPLE COMPARISON TEST ON TOTAL TIME REQUIRED FOR LABORATORY GROUP

| Contrast                  | $\hat{\psi}$ | $\hat{\sigma}^2_{\hat{\psi}}$ | $\hat{\sigma}_{\hat{\psi}}$ | $|\hat{\psi}/\hat{\sigma}_{\hat{\psi}}|$ |
|---------------------------|--------------|---------------------------------|-----------------|-------------------|
| $E_1 - E_2$               | 5.0          | 12000                           | 109.5           | 0.05              |
| $E_1 - E_3$               | 135.2        | 12000                           | 109.5           | 1.23              |
| $E_1 - E_4$               | 138.0        | 12000                           | 109.5           | 1.26              |
| $E_2 - E_3$               | 130.2        | 12000                           | 109.5           | 1.19              |
| $E_2 - E_4$               | 133.0        | 12000                           | 109.5           | 1.21              |
| $E_3 - E_4$               | 2.8          | 12000                           | 109.5           | 0.03              |
| $(\langle E_1 + E_2 \rangle/2) - (\langle E_3 + E_4 \rangle/2)$ | 134.1        | 5996                            | 77.4            | 1.73              |

* $0.90^3,64 = 2.18; \sqrt{(3)(2.18)} = 2.56$ (Critical Value)
<table>
<thead>
<tr>
<th>Variable</th>
<th>Experiment E₁</th>
<th>Experiment E₂</th>
<th>Experiment E₃</th>
<th>Experiment E₄</th>
<th>Mean Square</th>
<th>F(3,64)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>S.D.</td>
<td>Mean</td>
<td>S.D.</td>
<td>Mean</td>
<td>S.D.</td>
</tr>
<tr>
<td>Number of Trials Performed</td>
<td>11.3</td>
<td>2.66</td>
<td>9.06</td>
<td>2.73</td>
<td>11.2</td>
<td>3.35</td>
</tr>
<tr>
<td>Total Data Manipulation Score</td>
<td>5.00</td>
<td>2.32</td>
<td>6.00</td>
<td>2.76</td>
<td>7.59</td>
<td>1.46</td>
</tr>
<tr>
<td>Experimental Conclusions</td>
<td>3.18</td>
<td>1.24</td>
<td>3.29</td>
<td>1.05</td>
<td>3.12</td>
<td>1.17</td>
</tr>
<tr>
<td>Total Time Required (min.)</td>
<td>166</td>
<td>69</td>
<td>278</td>
<td>70</td>
<td>137</td>
<td>32</td>
</tr>
<tr>
<td>Test Scores (z-scores)</td>
<td>0.02</td>
<td>0.98</td>
<td>-0.05</td>
<td>0.99</td>
<td>-0.03</td>
<td>0.81</td>
</tr>
</tbody>
</table>

¹ Significant at the .1 level. F(3,64) = 2.18 for significance at .1 level.

ᵇ Significant at the .01 level. F(3,64) = 4.12 for significance at .01 level.

ᶜ Not significant.

ᵈ Significant at the .001 level. F(3,64) = 6.15 for significance at .001 level.

e Not significant.
Total Data Manipulation Score. The results were further analyzed using the multiple comparison technique. The means were 5.00, 6.00, 7.59, and 7.06 for Experiment E₁, E₂, E₃, and E₄ respectively. The contrasts are shown in Table 44. None of the contrasts were significant. The largest contrasts were between Experiments 3 and 4 and Experiment 1 and between Experiments 3 and 4 and Experiments 1 and 2.

The null hypothesis was rejected. There were significant differences between the experiments. The differences were not sufficiently large to show pair or group differences.

Analysis of variance performed on the Number of Trials Performed showed differences significant at the .1 level. The multiple comparison technique was used to further analyze the results. The means were 11.29, 9.06, 11.24, and 9.59 for experiment E₁, E₂, E₃, and E₄ respectively. The contrasts are shown in Table 45. None of the contrasts were significant.

The null hypothesis was rejected. Significant differences existed between the experiments. However, the differences were not large enough to produce pair significance.

Analysis of variance performed on the Total Time Required showed differences significant at the .001 level. Further analysis was performed using the technique of multiple comparisons. The means were 166.4, 277.9, 137.2, and 121.8 minutes for experiment E₁, E₂, E₃, and E₄ respectively. The contrasts are shown in Table 46. None of the contrasts were significant. The largest contrasts were between Experiments 3 and 4 and Experiment 2 and between all other experiments and
TABLE 44
SCHEFFE MULTIPLE COMPARISON TEST ON TOTAL DATA MANIPULATION SCORE FOR LABORATORY-COMPUTER GROUP

| Contrast     | $\hat{\psi}$ | $\hat{\sigma}^2$ | $\hat{\chi}^2$ | $|\hat{\psi} / \hat{\sigma}^2|_a$ |
|--------------|---------------|------------------|-----------------|----------------------------------|
| $E_1 - E_2$  | -1.00         | 2.64             | 1.63            | 0.62                             |
| $E_1 - E_3$  | -2.59         | 2.64             | 1.63            | 1.59                             |
| $E_1 - E_4$  | -2.06         | 2.64             | 1.63            | 1.27                             |
| $E_2 - E_3$  | -1.59         | 2.64             | 1.63            | 0.98                             |
| $E_2 - E_4$  | -1.06         | 2.64             | 1.63            | 0.65                             |
| $E_3 - E_4$  | 0.53          | 2.64             | 1.63            | 0.32                             |
| $((E_3+E_4)/2) - E_1$ | 2.33 | 1.98             | 1.41            | 1.66                             |
| $((E_3+E_4)/2) - ((E_1+E_2)/2)$ | 1.83 | 1.32             | 1.15            | 1.59                             |

$a_{.90 F_3, 64} = 2.18; \sqrt{(3)(2.18)} = 2.56$ (Critical Value)
| Contrast       | $\hat{\psi}$ | $\hat{\sigma}^2_\psi$ | $\hat{\sigma}_\psi$ | $\left| \frac{\hat{\psi}}{\hat{\sigma}_\psi} \right|^a$ |
|---------------|--------------|----------------------|-------------------|------------------------|
| $E_1 - E_2$   | 2.23         | 2.61                 | 1.62              | 1.38                   |
| $E_1 - E_3$   | 0.05         | 2.61                 | 1.62              | 0.03                   |
| $E_1 - E_4$   | 1.70         | 2.61                 | 1.62              | 1.05                   |
| $E_2 - E_3$   | -2.18        | 2.61                 | 1.62              | 1.35                   |
| $E_2 - E_4$   | -0.53        | 2.61                 | 1.62              | 0.33                   |
| $E_3 - E_4$   | 1.65         | 2.61                 | 1.62              | 1.02                   |

$^a \frac{.90^F_{3,64}}{\sqrt(3)} = 2.18; \quad \sqrt(3) (2.18) = 2.56 \ (Critical \ Value)$
TABLE 46

SCHEFFE MULTIPLE COMPARISON TEST OF TOTAL TIME REQUIRED
FOR LABORATORY-COMPUTER GROUP

| Contrast                  | $\hat{\psi}$ | $\hat{\psi}^2$ | $\hat{\psi}^3$ | $|\frac{\hat{\psi}}{\hat{\psi}}|_{a}^a$ |
|---------------------------|---------------|----------------|----------------|------------------------------------------|
| $E_1 - E_2$               | -111.5        | 9947           | 99.74          | 1.12                                     |
| $E_1 - E_3$               | 29.2          | 9947           | 99.74          | 0.29                                     |
| $E_1 - E_4$               | 44.6          | 9947           | 99.74          | 0.45                                     |
| $E_2 - E_3$               | 140.7         | 9947           | 99.74          | 1.41                                     |
| $E_2 - E_4$               | 156.1         | 9947           | 99.74          | 1.57                                     |
| $E_3 - E_4$               | 15.4          | 9947           | 99.74          | 0.15                                     |
| $E_1 - (E_3+E_4)/2$       | 36.9          | 7461           | 86.38          | 0.43                                     |
| $E_2 - (E_3+E_4)/2$       | 148.4         | 7461           | 86.38          | 1.72                                     |
| $((E_1+E_2)/2) - ((E_3+E_4)/2)$ | 73.8          | 4974           | 70.53          | 1.05                                     |

$^a_{.90F_{3,64} = 2.18; \sqrt{3}(2.18) = 2.56}$ (Critical Value)
Experiment 2. The contrast between Experiments 3 and 4 and Experiments 1 and 2 was relatively large.

The null hypothesis was rejected. Significant differences existed between the experiments. The differences were not large enough to produce pair or combination differences.

Hypothesis 6. There is no significant difference between the performance of the Computer Group on laboratory exercises 1, 2, 3, and 4 with respect to the (a) attainment of process skills, (b) number of trials performed, and (c) time involved in the simulation and analysis.

Data collected from the Computer Group were summarized in Table 47. The results were similar to the two previous groups.

No significant differences were found with respect to Experimental Conclusions or process test scores. Differences between the results of the experiments were significant at the .01 level for Total Data Manipulation Score. The results were further analyzed using the multiple comparison technique. The means were 6.24, 5.06, 7.47, and 7.18 for experiment $E_1$, $E_2$, $E_3$, and $E_4$ respectively. The contrasts are shown in Table 48. None of the contrasts were significant. The largest contrast was between Experiments 3 and 4 and Experiment 2. The contrast between Experiments 3 and 4 and Experiments 1 and 2 was fairly large.

Analysis of variance on the Number of Trials Performed showed significance at the .1 level. The technique of multiple comparison was used to further analyze the data. The means were 13.1, 9.94, 14.7, and 14.1 for experiment $E_1$, $E_2$, $E_3$, and $E_4$ respectively. The contrasts are shown in Table 49. None of the contrasts were significant. The largest contrast was between Experiments 3 and 4 and Experiment 2.
### TABLE 47

**SUMMARY OF COMPUTER GROUP STATISTICS: MEANS, STANDARD DEVIATIONS, AND MEAN SQUARE AND F-RATIO FROM ANALYSIS OF VARIANCE.**

<table>
<thead>
<tr>
<th>Variable</th>
<th>E&lt;sub&gt;1&lt;/sub&gt; Mean</th>
<th>S.D.</th>
<th>E&lt;sub&gt;2&lt;/sub&gt; Mean</th>
<th>S.D.</th>
<th>E&lt;sub&gt;3&lt;/sub&gt; Mean</th>
<th>S.D.</th>
<th>E&lt;sub&gt;4&lt;/sub&gt; Mean</th>
<th>S.D.</th>
<th>Mean Square</th>
<th>F(3,64)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Trials Performed</td>
<td>13.1</td>
<td>4.33</td>
<td>9.94</td>
<td>2.41</td>
<td>14.7</td>
<td>7.62</td>
<td>14.1</td>
<td>7.11</td>
<td>75.90</td>
<td>2.28&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Total Data Manipulation Score</td>
<td>6.24</td>
<td>2.66</td>
<td>5.06</td>
<td>2.14</td>
<td>7.47</td>
<td>1.55</td>
<td>7.18</td>
<td>1.88</td>
<td>20.09</td>
<td>4.58&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Experimental Conclusions</td>
<td>3.29</td>
<td>1.21</td>
<td>2.82</td>
<td>1.29</td>
<td>2.88</td>
<td>1.22</td>
<td>2.88</td>
<td>1.27</td>
<td>0.80</td>
<td>0.52&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Total Time Required (min.)</td>
<td>135</td>
<td>52</td>
<td>231</td>
<td>104</td>
<td>132</td>
<td>73</td>
<td>126</td>
<td>54</td>
<td>42781</td>
<td>7.91&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>Test Scores (z-scores)</td>
<td>0.18</td>
<td>0.82</td>
<td>0.08</td>
<td>0.89</td>
<td>0.02</td>
<td>1.12</td>
<td>0.01</td>
<td>1.12</td>
<td>0.09</td>
<td>0.09&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup>Significant at the .1 level. \( F(3,64) = 2.18 \) for significance at .1 level.

<sup>b</sup>Significant at the .01 level. \( F(3,64) = 4.12 \) for significance at .01 level.

<sup>c</sup>Not significant.

<sup>d</sup>Significant at the .001 level. \( F(3,64) = 6.15 \) for significance at .001 level.

<sup>e</sup>Not significant.
TABLE 48
SCHIFFÉ MULTIPLE COMPARISON TEST ON MEAN TOTAL DATA
MANIPULATION SCORE FOR COMPUTER GROUP

| Contrast                          | $\hat{\psi}$ | $\hat{\sigma}_\psi^2$ | $\hat{\sigma}_\psi^\wedge$ | $|\hat{\psi}/\hat{\sigma}_\psi^\wedge|^{a}$ |
|----------------------------------|--------------|------------------------|-----------------------------|----------------------------------|
| $E_1 - E_2$                      | 1.18         | 2.36                   | 1.54                        | 0.77                             |
| $E_1 - E_3$                      | -1.23        | 2.36                   | 1.54                        | 0.80                             |
| $E_1 - E_4$                      | -0.94        | 2.36                   | 1.54                        | 0.61                             |
| $E_2 - E_3$                      | -2.41        | 2.36                   | 1.54                        | 1.57                             |
| $E_2 - E_4$                      | -2.12        | 2.36                   | 1.54                        | 1.38                             |
| $E_3 - E_4$                      | 0.29         | 2.36                   | 1.54                        | 0.19                             |
| $((E_3+E_4)/2) - E_2$            | 2.27         | 1.77                   | 1.33                        | 1.71                             |
| $((E_3+E_4)/2) - ((E_1+E_2)/2)$  | 1.68         | 1.18                   | 1.09                        | 1.55                             |

$^{a} .90 \text{F}_{3,64} = 2.18; \sqrt{(3)(2.18)} = 2.56$ (Critical Value)
| Contrast                      | $\hat{\psi}$ | $\hat{\psi}^2$ | $\hat{\sigma}^2$ | $\left|\frac{\hat{\psi}}{\hat{\sigma}}\right|$ |
|------------------------------|--------------|-----------------|-------------------|-----------------------------------------------|
| $E_1 - E_2$                  | 3.18         | 8.93            | 2.99              | 1.06                                          |
| $E_1 - E_3$                  | -1.59        | 8.93            | 2.99              | 0.53                                          |
| $E_1 - E_4$                  | -0.94        | 8.93            | 2.99              | 0.31                                          |
| $E_2 - E_3$                  | -4.77        | 8.93            | 2.99              | 1.60                                          |
| $E_2 - E_4$                  | -4.12        | 8.93            | 2.99              | 1.38                                          |
| $E_3 - E_4$                  | 0.65         | 8.93            | 2.99              | 0.22                                          |
| $((E_3+E_4)/2) - E_2$        | 4.46         | 6.70            | 2.59              | 1.72                                          |

\[
.90^\text{F}_{3,64} = 2.18; \quad \sqrt(3) (2.18) = 2.56 \quad \text{(Critical Value)}
\]
The null hypothesis was rejected. There were significant differences between the experiments. The differences were not large enough to produce significant pair or combination differences.

Analysis of variance performed on Total Time Required showed differences significant at the .001 level. Further analysis was performed using the technique of multiple comparisons. The means were 135.3, 231.0, 131.6, and 126.0 minutes for experiment $E_1$, $E_2$, $E_3$, and $E_4$ respectively. The contrasts are shown in Table 50. None of the contrasts were significant. The largest contrast was between Experiments 1, 3, and 4 and Experiment 2. The contrast between Experiments 2 and Experiments 3 and 4 was fairly large.

The null hypothesis was rejected. Significant differences existed between the experiments. The differences were not large enough to produce significant pair or combination differences.

**Hypothesis 7.** There is no interaction effect between the three experimental groups, L, L-C, and C, and the four laboratory exercises with respect to (a) attainment of process skills, (b) number of trials performed, and (c) time involved in the experiment or simulation and analysis.

The data from the study variables were analyzed using analysis of variance. The Groups by Experiment Interaction F-ratio was used as a basis for accepting or rejecting the null hypothesis. This analysis was used to determine whether certain experiments are better suited for computer simulations than others.

When the results of the analysis of variance of each of the process variables were studied, it was found that:

1. An interaction effect, significant at the .05 level, existed
### TABLE 50
Scheffé Multiple Comparison Test on Total Time Required for Computer Group

<table>
<thead>
<tr>
<th>Contrast</th>
<th>( \hat{\psi} )</th>
<th>( \hat{\sigma}^2 )</th>
<th>( \hat{\omega} )</th>
<th>( \sqrt{\frac{\hat{\sigma}^2}{\hat{\omega}}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( E_1 - E_2 )</td>
<td>95.7</td>
<td>5033</td>
<td>70.94</td>
<td>1.35</td>
</tr>
<tr>
<td>( E_1 - E_3 )</td>
<td>3.7</td>
<td>5033</td>
<td>70.94</td>
<td>0.05</td>
</tr>
<tr>
<td>( E_1 - E_4 )</td>
<td>9.3</td>
<td>5033</td>
<td>70.94</td>
<td>0.13</td>
</tr>
<tr>
<td>( E_2 - E_3 )</td>
<td>99.4</td>
<td>5033</td>
<td>70.94</td>
<td>1.40</td>
</tr>
<tr>
<td>( E_2 - E_4 )</td>
<td>105.0</td>
<td>5033</td>
<td>70.94</td>
<td>1.48</td>
</tr>
<tr>
<td>( E_3 - E_4 )</td>
<td>5.6</td>
<td>5033</td>
<td>70.94</td>
<td>0.08</td>
</tr>
<tr>
<td>( E_2 ) ( \left( E_3 + E_4 \right)/2 )</td>
<td>102.2</td>
<td>3775</td>
<td>61.44</td>
<td>1.66</td>
</tr>
<tr>
<td>( E_2 ) ( \left( E_1 + E_3 + E_4 \right)/3 )</td>
<td>101.0</td>
<td>3355</td>
<td>59.28</td>
<td>1.74</td>
</tr>
</tbody>
</table>

\( ^a \quad .90 F_{3, 64} = 2.18; \quad \sqrt{(3)(2.18)} = 2.56 \) (Critical Value)
for Total Data Manipulation Score as shown in Table 14. A plot of the interaction effect, shown in Figure 6, shows that in Experiment 3, the computer related groups had the highest mean scores. But, as shown in Table 22, the difference was not significant. The null hypothesis was rejected even though no decision was made about the type of interaction.

2. No significant interaction effect existed with respect to Experimental Conclusions as shown in Table 24.

3. No significant interaction effect existed with respect to z-scores on the process tests as shown in Table 27.

Analysis of variance on the Number of Trials Performed showed an interaction effect significant at the .01 level as shown in Table 31. A plot of the interaction effect, shown in Figure 9, shows the computer related groups performed many more trials than the Laboratory Group on Experiments 3 and 4. The null hypothesis was rejected. Significant interaction did exist.

Analysis of variance on Total Time Required showed an interaction effect significant at the .001 level. A plot of the interaction effect, shown in Figure 11, shows that the computer related groups required less time on Experiment 1, but more time on all other experiments. The null hypothesis is rejected. There is a significant interaction effect. The effect is not so pronounced as to produce obvious differences.

SUMMARY

The criteria variables involved acquisition of process skills; acquisition of content, attitude, number of trials performed, and time
required. When the data related to these variables were analyzed, these findings resulted.

Hypothesis 1. The three experimental groups, L, L-C, and C do not differ significantly with respect to (a) attainment of process skills, (b) acquisition of content, (c) number of trials performed, and (d) time involved in the experiment or simulation and analysis.

1. Attainment of Process Skills
   a. Data Manipulation Score Rejected
   b. Experimental Conclusions Rejected
   c. Process Tests Not Rejected

2. Acquisition of Content Not Rejected

3. Number of Trials Performed Rejected

4. Total Time Required Not Rejected

Hypothesis 2. There is no significant difference between the attitudes of students in groups L-C and C toward CSE as measured by the Student Attitude Questionnaire.

1. Attitude Not Rejected

Hypothesis 3. There is no significant difference between the performances of students on laboratory exercises 1, 2, 3, and 4 with respect to the (a) attainment of process skills, (b) number of trials performed, and (c) time involved in the experiment or simulation and analysis.

1. Attainment of Process Skills
   a. Data Manipulation Score Not Rejected
   b. Experimental Conclusions Not Rejected
   c. Process Tests Not Rejected

2. Number of Trials Performed Rejected

3. Total Time Required Rejected

Hypothesis 4. There is no significant difference between the performances of the Laboratory Group on laboratory exercises 1, 2, 3, and 4 with respect to the (a) attainment of process skills, (b) number
of trials performed, and (c) time involved in the experiment and analysis.

1. Attainment of Process Skills
   a. Data Manipulation Score  Rejected
   b. Experimental Conclusions  Not Rejected
   c. Process Tests  Not Rejected

2. Number of Trials Performed  Rejected
3. Total Time Required  Rejected

Hypothesis 5. There is no significant difference between the performances of the Laboratory-Computer Group on laboratory exercises 1, 2, 3, and 4 with respect to the (a) attainment of process skills, (b) number of trials performed, and (c) time involved in the experiment, simulation, and analysis.

1. Attainment of Process Skills
   a. Data Manipulation Score  Rejected
   b. Experimental Conclusions  Not Rejected
   c. Process Tests  Not Rejected

2. Number of Trials Performed  Rejected
3. Total Time Required  Rejected

Hypothesis 6. There is no significant difference between the performances of the Computer Group on laboratory exercises 1, 2, 3, and 4 with respect to the (a) attainment of process skills, (b) number of trials performed, and (c) time involved in the simulation and analysis.

1. Attainment of Process Skills
   a. Data Manipulation Score  Rejected
   b. Experimental Conclusions  Not Rejected
   c. Process Tests  Not Rejected

2. Number of Trials Performed  Rejected
3. Total Time Required  Rejected
Hypothesis 7. There is no interaction effect between the three experimental groups, L, L-C, and C, and the four laboratory exercises with respect to (a) attainment of process skills, (b) number of trials performed, and (c) time involved in the experiment or simulation and analysis.

1. Attainment of Process Skills
   a. Data Manipulation Score Rejected
   b. Experimental Conclusions Not Rejected
   c. Process Tests Not Rejected

2. Number of Trials Performed Rejected

3. Total Time Required Rejected

Discussion of Results

A summary of the results related to each of the criteria variables follows. Statistically significant results are indicated by asterisks.

1. Data Manipulation Score
   a. A computer related Group had the highest mean score in every experiment (Figure 6).
   b. The greatest difference in Data Manipulation Score existed between the combination of Laboratory-Computer and Computer Groups and the Laboratory Group (Table 22).
   c. The Laboratory Group did not reach a high level of Data Manipulation Score performance until Experiment 4 (Table 40).
   d. The Laboratory-Computer and Computer Groups attained a high level of Data Manipulation Score performance on Experiment 3 and maintained it through the remaining Experiment (Tables 44 and 48).

2. Experimental Conclusions
a. The Laboratory-Computer Group had consistently higher mean Experimental Conclusion scores (Figure 7).

b. The greatest difference in Experimental Conclusion scores existed between the Laboratory-Computer Group and the Laboratory and Computer Group combination (Table 26).*

3. Process Tests

The Computer Group had mean scores on the Process Tests which were consistently lower than the mean scores of the Laboratory and the Laboratory-Computer Groups (Figure 8).

4. Acquisition of Content

The Laboratory-Computer Group had the highest mean and adjusted mean score. The Computer Group had the lowest mean and adjusted mean score (Table 13).

5. Number of Trials Performed

a. The Computer Group performed the largest Number of Trials and the Laboratory Group performed the fewest Number of Trials (Figure 9).*

b. The Laboratory Group performed fewer Trials as the experiments progressed (Table 41).

c. No pattern of Trials could be discerned for the Laboratory-Computer and Computer Groups (Tables 45 and 49).

6. Total Time Required

a. Excluding Experiment 1, the computer related Groups required the greatest amount of time (Figure 11).

b. The Laboratory Group used less time as the experiments progressed (Table 42).
c. The Laboratory-Computer and Computer Groups required a maximum amount of time for Experiment 2. In general, there was a decrease in the Time Required as the experiments proceeded (Tables 46 and 50).

7. Attitude

a. The Laboratory-Computer Group tended to agree that getting data from the computer was like doing a real experiment (Item 1) while the Computer Group tended to disagree (Table 36).

b. The Laboratory-Computer Group tended to agree that data generation is an important use of the computer (Item 13) while the Computer Group tended to disagree (Table 36).

c. The Laboratory-Computer Group generally views CSE more favorably than the Computer Group as indicated by their mean Attitude responses (Table 36).
CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

This chapter consists of four parts: a summary of the study, an interpretation of the findings as they relate to the seven research hypotheses involved in the study, conclusions and recommendations.

SUMMARY

The major problem of the study was to assess the effect of Computer Simulated Experiments on the attainment of process skills and acquisition of subject matter content in the physics laboratory. Three sub-problems were (1) to determine if students working with CSE became more involved in the experiment by performing more trials than those students working exclusively with laboratory experiments, (2) to determine if the students working with CSE had a favorable attitude toward CSE, and (3) to determine if less time was required to perform a Computer Simulated Experiment than an ordinary experiment.

The study took place over a four month period. During that period, fifty-one students from two physics classes were involved in four laboratory experiments and simulations. At the conclusion of the experiments and simulations, a content examination and the Student Attitude Questionnaire were administered.

The fifty-one students were randomly assigned to one of three treatment groups. There were seventeen students in each of the three groups.

Data related to the research variables were collected from
laboratory reports, computer print-outs, and from written instruments. The interpretation of the data analyses will be considered in the following sections of this chapter.

**INTERPRETATION OF RESULTS**

**Hypothesis 1**

Hypothesis 1 is the statement that the three experimental groups, L, L-C, and C do not differ significantly with respect to (a) attainment of process skills, (b) acquisition of content, (c) number of trials performed, and (d) time involved in the experiment or simulation and analysis.

The process skills investigated were the ability to manipulate data as represented by a Data Manipulation Score, the ability to develop experimental conclusions, and the ability to use the processes of science on written examinations.

When the data related to the Data Manipulation Score were analyzed, it was found that in each experiment, a computer related group had the highest mean Score. The computer related groups attained a high Data Manipulation Score on Experiment 3 and maintained that level through Experiment 4. The Laboratory Group attained a high Data Manipulation Score only on Experiment 4. These differences were not at the .10 level of significance, however.

It appears that the computer related groups, after recognizing the potential of the computer as a data generating device and after acquiring sufficient experience using the computer, were able to more effectively perform those activities associated with getting information
related to a laboratory situation.

Analysis of data related to the ability to develop experimental conclusions showed that the adjusted mean Experimental Conclusion score of the Laboratory-Computer Group was higher than the other two groups in every experiment. It was further shown that the difference between the Laboratory-Computer Group and the Laboratory and Computer Group combination was significant, favoring the Laboratory-Computer Group.

After the second experiment, members of the Laboratory Group commented that they had to do more work than students in the other groups. They contended that laboratory data was more difficult to analyze than computer generated data.

It appears that working with the laboratory equipment to obtain an understanding of the physical situation, coupled with the ease of using the computer to generate data, permitted students to progress further in translating the results of the laboratory situations into meaningful conclusions. No differences could be detected between the Laboratory and Computer Groups.

When data from the process tests were analyzed, no significant differences between the groups could be found. However, it is interesting to note that in Figure 9, the means of the Laboratory-Computer and Laboratory Groups were consistently higher than the Computer Group. Throughout the course of the study, students in the Computer Group commented that working with the computer did little to extend their understanding of physical situations. It appears that this is reflected in their consistently lower adjusted scores. The lack of significance
may be attributed to the fact that there was interaction between the students in the various groups and that all students had access to and used textbooks and other materials. These may have acted to mask the effect of the treatments.

The acquisition of content was assessed through the use of a content examination. Analysis of variance showed no significant differences between the groups. While an analysis of covariance increased the F-ratio considerably, the differences were still not significant. It is interesting to note that the Laboratory-Computer Group had the highest mean score and the Computer Group had the lowest mean score. The lack of significance may be attributed to the fact that content knowledge is acquired in a number of ways, such as laboratory work, textual reading, class discussions, and audio-visuals. Apparently, the contribution of the laboratory was not sufficiently large to produce significant differences.

Analysis of variance performed on the Number of Trials showed significant differences between the three groups. Comparisons of group means showed that the Computer Group had a significantly higher Number of Trials Performed than both the Laboratory-Computer and Laboratory Groups. The Laboratory-Computer Group had a significantly higher mean Number of Trials Performed than the Laboratory Group.

It might be assumed that the Number of Trials Performed would be facilitated by the ease of performing computer trials. Apparently, this was the case. But, it is important to note that the Computer Group performed a significantly higher mean Number of Trials than the Laboratory-Computer Group. It would appear that those students exposed to
the laboratory situation treat the computer as an extension of their laboratory work, performing enough trials to permit them to completely investigate the relationships. On the other hand, those students having no exposure to the laboratory situation perform an excessive number of trials. It was observed that students in the Computer Group would start to analyze their data and find it incomplete. Then they would return to the computer to obtain more data. They appeared to treat the Simulations as a game situation rather than as a laboratory situation.

The time involved in the experiment or simulation and analysis was determined from student records. Analysis of variance of Time Required for Experimental Analysis and of Total Time Required showed no significant differences between the groups. A plot of these variables versus Experiment, Figure 11, showed that with the exception of Experiment 1, the Laboratory-Computer and Computer Groups used more time than the Laboratory Group. This appears surprising until one considers that the computer related groups performed more trials and had more data to analyze. The use of CSE permits a more thorough investigation of laboratory situations but does not reduce the time required for laboratory work.

**Hypothesis 2**

Hypothesis 2 is the statement that **there is no significant difference between the attitudes of students in groups L-C and C toward CSE as measured by the Student Attitude Questionnaire.**

This hypothesis could not be rejected on the basis of available evidence. The results of the analysis of variance showed that no item had a sufficiently high F-ratio to indicate a significant difference
between the groups. However, the Laboratory-Computer Group tended to view CSE somewhat more favorably than the Computer Group.

It is useful to examine two items, 1 and 13, that had a high F-ratio in more detail. Item 1 is the statement that "Getting data from the computer is just like doing a real experiment." The Laboratory-Computer Group had a greater tendency to agree with this statement than the Computer Group. Item 13 is the statement that "The use of the computer as a calculator to solve problems is more important than the use of the computer to generate laboratory data." The Laboratory-Computer Group had a greater tendency to disagree with this statement than the Computer Group. While the differences between the two groups were not significant, the groups appeared to view CSE somewhat differently. The Laboratory-Computer Group appeared to view CSE as an extension of laboratory work and an important way to use the computer. The Computer Group saw CSE somewhat differently, almost separated from laboratory activities.

Hypothesis 3

In this hypothesis, it is postulated that There is no significant difference between the performances of students on laboratory exercises 1, 2, 3, and 4 with respect to the (a) attainment of Process skills, (b) number of trials performed, and (c) time involved in the experiment or simulation and analysis. This hypothesis was used to determine whether observed changes were only a function of the four different laboratory experiments.

When the results of the analysis of variance of each of the
process variables were studied, it was found that differences existed between the four experiments on Total Data Manipulation Score but the interaction was so pronounced that no decision could be made. No significant differences existed with respect to Experimental Conclusions or process tests. It appears that there is little relationship between the type of experiment performed and the attainment of process skills.

Significant differences existed between the Number of Trials Performed but no pattern could be discerned.

There were significant differences between the Time Required in each of the experiments. These results were logical since the experiment analysis in Experiments 1 and 2 involved the preparation and analysis of a number of graphs. Such activities are time consuming and the time used in the analysis is reflected in the total time required.

**Hypotheses 4, 5, and 6**

Hypotheses 4, 5, and 6 will be discussed together since they are so closely related. These hypotheses were used to determine whether trend effects existed within each of the treatment groups over the course of the laboratory and/or simulation exercises. Hypothesis 4 is the statement that There is no significant difference between the performances of the Laboratory Group on laboratory exercises 1, 2, 3, and 4 with respect to the (a) attainment of process skills, (b) number of trials performed, and (c) time involved in the experiment and analysis. Hypotheses 5 and 6 are identical except they deal with the Laboratory-Computer and Computer Groups respectively. These hypotheses represent
an attempt to detect trend effects within treatment groups.

When the results of the analyses of variance were studied, only three of the variables, Total Data Manipulation Score, Number of Trials Performed, and Total Time Required exhibited significant mean differences. Each of these will be considered separately.

The Total Data Manipulation Score for the Laboratory Group is fairly constant throughout the study. The Score for the computer related groups generally increases to a fairly high level and remains there. This is an indication that as students become more familiar with the computer as a data generating device, they can use it more effectively to attain their laboratory goals.

An examination of the Number of Trials Performed shows a gradual decrease for the Laboratory Group, but a fairly constant Number for the Laboratory-Computer and Computer Groups. Those laboratory experiments associated with electrical measurement, Experiments 3 and 4, were particularly difficult to perform in the laboratory due to tedious measurements. The gradual decrease in Number of Trials for the Laboratory Group but fairly constant Number for the other Groups seems to indicate that the Number of Trials Performed in the laboratory is related to the difficulty of actually performing the experiment, but the Number of Trials Performed on the computer is nearly independent of the difficulty of performing the laboratory exercises.

An examination of the Total Time Required shows that it is probably a function of the type of data analysis performed. Experiments
and 2 required a detailed graphical analysis. Consequently, the time required was greater. Beyond that, the groups had nearly constant times.

Hypothesis 7

The hypothesis that there is no interaction effect between the three experimental groups, L, L-C and C, and the four laboratory exercises with respect to (a) attainment of process skills, (b) number of trials performed, and (c) time involved in the experiment or simulation and analysis was an attempt to determine whether certain experiments were better suited for computer simulations than others. Investigation of the interaction effects failed to reveal any relationship. However, it should be pointed out that all laboratory experiments were selected because they could be fairly easily simulated using CSE. This may have acted to reduce the interaction effect.

CONCLUSIONS

Computer Simulated Experiments have a place in the high school physics laboratory. The evidence does not suggest that the use of CSE is less effective than the use of traditional laboratory activities with respect to student acquisition of content knowledge and the application of processes of science skills to written situations. But more important, it was shown that students using CSE were able to investigate the laboratory situation more thoroughly, from the standpoint of collecting and using data, than the traditional laboratory group.

When one investigates the results of the ability to draw
experimental conclusions, it becomes clear that students must have a first hand experience with the laboratory equipment through, at least, trial data collection runs. Under those conditions, the students are able to take advantage of an understanding of the physical situation and the ease of collecting and manipulating data, to become more effective in reaching meaningful laboratory conclusions.

Students who have a first hand experience with the laboratory equipment and an experiment appear to view CSE differently from those without the experience. The Laboratory-Computer Group had a slightly more favorable attitude toward CSE than the Computer Group. But more important was the fact that the Computer Group performed significantly more trials than the Laboratory-Computer Group. In many cases, members of the Computer Group performed an excessive number of trials, more than could be analyzed, and used only part of them. It appears that the students see the computer as a laboratory tool only after some laboratory exposure.

Total time spent on laboratory activities was not reduced by the use of CSE. More trials were performed and more time was required for the analysis.

RECOMMENDATIONS

It has been shown that the use of Computer Simulated Experiments can be of significant value to the secondary school science teacher. Computer Simulated Experiments can be most effectively used after the student has been exposed to real laboratory experiences. CSE should not replace the first hand experience with laboratory equipment. Only after performing trial experiments will the data
obtained by CSE be meaningful.

Computer Simulated Experiments can be used effectively with laboratory experiments that are difficult or tedious to perform. CSE can make the task of obtaining data for analysis relatively simple.

Computer Simulated Experiments can be used effectively with laboratory experiments that yield data that is difficult to analyze. If extraneous variables such as friction or air resistance act to mask the physical effect under investigation, CSE can be used to eliminate such variables. In addition, CSE can be used to compare the results of experiments with and without these extraneous variables. The students, by selecting appropriate input data, have more control over the data they obtain for analysis.

Computer Simulated Experiments can be used with any laboratory experiment that can be described by mathematical equations. CSE can be used with most physics, chemistry, and many biology experiments.

Science teachers need to become more aware of the power of the computer as a laboratory tool. Such instruction should be included in the undergraduate teacher education programs. The teachers could become familiar with the types of laboratory activities that lend themselves to CSE along with the expected outcomes.

Recommendations related to further research are as follows:

1. Replication studies should be conducted to determine the outcomes of CSE when used with chemistry and biology classes.

2. A more detailed investigation of the approach to CSE used by those students exposed to a laboratory situation and those
not receiving laboratory instruction should be undertaken. The findings of this study with respect to students' strategies are not easily explained. To aid in providing an explanation, certain problems should be explored. These are (a) to determine whether different patterns of input responses are used by the two groups, (b) to determine whether the input responses of the two groups are realistic when compared with actual laboratory data, (c) to determine the minimum number of responses required by each group before data analysis is begun, and (d) to compare the strategies, determined by a, b, and c, of each group with their strategies in a strictly game situation having characteristics similar to a laboratory situation.

3. An investigation of whether CSE can be used by students to investigate the laws of nature in unfamiliar environments, such as in accelerating reference systems, should be undertaken.
APPENDIX A

COMPUTER SIMULATION PROGRAMS AND SAMPLE RUNS
**NEwTon's LAws Computer SImulation**

```plaintext
10= PROGRAM DYN (INPUT, OUTPUT)
20= DATA ENDLST/9R*ENDLST/ 
30= DATA DL1, DL2, DL3/4HTIME, 4HDISPLACE, 4HIMENT/ 
40= DATA DL4, DL5, DL6, DL7/8HVELOCITY, 8HACCELER, 4HTION, 4HMASS/ 
50= PRINT 6 
60= FORMAT(IHO, *PLEASE TYPE YOUR LAST NAME.*) 
70= CALL FREFLD(NAME, ENDLST) 
80= CALL CLOCK(IDATE, ITIME) 
90= PRINT 4, IDATE, ITIME 
100=4 FORMAT (1HO, 9X, A8, 10X, R6) 
110=9 N=0 
120= K=0 
130= T=0 
140= D=0 
150= V=0 
160= PRINT 10 
170=10 FORMAT(IHO, 44HINPUT THE MASS OF THE BODY, THE FORCE ACTING) 
180= PRINT 20 
190=20 FORMAT(2X, 44HON IT AND THE COORDINATE AT WHICH THE FORCE) 
200= PRINT 30 
210=30 FORMAT(2X, 45HSTOPS ACTING, THE INPUT DATA SHOULD BE IN THE) 
220= PRINT 40 
230=40 FORMAT(2X, 44HINPUT M, F, L. ALL INPUT DATA MUST BE IN) 
240= PRINT 50 
250=50 FORMAT(2X, 3HDEGIMAL FORM, I.E. 3.0, .02, ETC.) 
260= CALL FREFLD(M, F, XL, ENDLST) 
270= PRINT 60 
280= PRINT 70 
290=70 FORMAT(2X, 28HDO YOU WANT TO SELECT A TIME INTERVAL?) 
300= PRINT 80 
310=80 CALL FREFLD(IOT, ENDLST) 
320= IF(IOT)10C, 100, 80 
330=80 K=K+1 
340= PRINT 90 
350=90 FORMAT(2X, 40HINPUT THE TIME INTERVAL YOU WANT TO USE.) 
360= CALL FREFLD(T3, ENDLST) 
370=105 PRINT 105 
380=105 FORMAT(2X, 41HINPUT AN INTEGER BETWEEN 1 AND 10 CORRESP) 
390=110 PRINT 110 
400=110 FORMAT(2X, 45HENDING TO THE OUTPUT VARIABLE OR COMBINATION) 
410= PRINT 120 
420=120 FORMAT(2X, 37HOF VARIABLES YOU WISH TO INVESTIGATE.) 
430= CALL FREFLD(I10, ENDLST) 
440=125 IRC=IFIX(XI+FX+XL)+1.0 
450=111 IF(IRC-20)114, 114, 112 
460=112 RC=IFIX(IRC) 
470= RC=HC/10.0 
480= IRC=IFIX(IRC) 
490= C0. TO 111 
500=114 DJ, 129 J=1, IRC 
510= R1=RANF(0) 
520= R2=RANF(0) 
530= R3=RANF(0) 
540=129 CONTINUE 
550=134 IF(.95-R2)150, 150, 140 
560=140 R4=.50.0 
570= .0 TO 175 
580=150 IF(.95-R2)170, 170, 160 
```
152
590=160  R4=20.0
600=  G0 T0 '175
610=170  R4=10.0
620=  G0 T0 '175.
630=175  IF(.5-R1)180,180,185
640=180  R3=-R3
650=185  CONTINUE
660=  A=F/XM
670=  A=A+A*R3/R4
680= IF(N)205,205,601
690=205  CONTINUE
700=  G0. T0 (210,220,230,240,250,260,270,280,290,300),10
710=210  PRINT 211,DL1,DL2,DL3
720=211  FORMAT(2X,A4,9X,A8,A4)
730=212  PRINT 213,T,D
740=213  FORMAT(1X,2(E11.3,4X))
750=  G0 T0 440
760=220  PRINT 221,DL1,DL4
770=221  FORMAT(2X,A4,9X,A8)
780=222  PRINT 213,T,D,V
790=  G0 T0 440
800=230  PRINT 231,DL1,DL5,DL6
810=231  FORMAT(2X,A4,9X,A8,A4)
820=232  PRINT 213,T,A
830=  G0 T0 440
840=240  PRINT 241,DL1,DL7
850=241  FORMAT(2X,A4,9X,A8)
860=242  PRINT 213,T,XM
870=  G0 T0 440
880=250  PRINT 251,DL1,DL2,DL3,DL4
890=251  FORMAT(2X,A4,9X,A8,A4,3X,A8)
900=252  PRINT 253,T,D,V
910=253  FORMAT(1X,3(E11.3,4X))
920=  G0 T0 440
930=260  PRINT 261,DL1,DL2,DL3,DL5,DL6
940=261  FORMAT(2X,A4,9X,A8,A4,3X,A8,A4)
950=262  PRINT 253,T,D,A
960=  G0 T0 440
970=270  PRINT 271,DL1,DL2,DL3,DL4,DL5,DL6
980=271  FORMAT(2X,A4,9X,A8,A4,3X,A8,7X,A8,A4)
990=272  PRINT 273,T,D,V,A
1000=273  FORMAT(1X,4(AE11.3,4X))
1010=  G0 T0 440
1020=280  PRINT 281,DL1,DL2,DL3,DL4,DL5,DL6,DL7
1030=281  FORMAT(2X,A4,9X,A8,A4,3X,A8,7X,A8,A4)
1040=282  PRINT 283,T,D,V,A,XM
1050=283  FORMAT(1X,5(E11.3,4X))
1060=  G0 T0 440
1070=290  PRINT 291,DL1,DL4,DL7
1080=291  FORMAT(2X,A4,9X,A8,7X,A4)
1090=292  PRINT 253,T,D,XH
1100=  G0 T0 440
1110=300  PRINT 301,DL1,DL5,DL6,DL7
1120=301  FORMAT(2X,A4,9X,A8,3X,A4)
1130=302  PRINT 253,T,A,XH
1140=440  IF(N)445,445,550
1150=445  IF(K)450,450,550
1160=450  T1=SQRT(2.0*XL/A)
1170=  IF(1.0-T1)510,510,460
1180=460  P=10.0
1190=465  T2=P*T1
1200=  IF(T2-1.0)470,480,480
1210=470  P=P+10.0
1220=  GO TO 465
1230=480  T2=IF(T2)
1240=  XT2=FLOAT(IF(T2)
1250=  IF((T2-XT2)-.5)490,500,500
1260=490  T2=XT2
1270=  G6..T0 505
1280=500  T2=XT2+1
1290=505  T3=T2/(1.0*P)
1300=  G6..T0 550
1310=510  IT1=IF(T1)
1320=  XT1=FLOAT(IF(T1)
1330=  IF((T1-XT1)-.5)520,530,530
1340=520  T1=XT1
1350=  G6..T0 540
1360=530  T1=XT1+1.0
1370=540  T3=T1/10.0
1380=550  T=T+T3
1390=555  D=D+V*T3+A*T3**2/2.0
1400=  V=V+A*T3
1410=  IF(1.0-V**2/9E17)>560,570,570
1420=560  PRINT 561
1430=561  FORMAT(2X,43HTHE VELOCITY APPROACHES THE SPEED OF LIGHT.)
1440=  G6..T0 610
1450=570  XM2=XM/50RT(1.0-V**2/9E17)
1460=  IF(ABS(XM-XM2)/XM-.03)590,580,580
1470=580  XM=XM2
1480=590  IF(D-XL)600,610,610
1490=600  N=N+1
1500=  IF(N<20)125,125,610
1510=610  G9..T0(212,222,232,242,252,262,272,282,292,302),10
1520=611  PRINT 611
1530=612  FORMAT(2X,*DO YOU WISH ANOTHER TRIAL?*)
1540=  PRINT 612
1550=613  FORMAT(2X,*IF YES, ENTER 1; IF NO, ENTER 0.*)
1560=  CALL FIREFLD(ICC,ENLST)
1570=  IF(ICC-1)625,9,9
1580=625  CALL CLOCK(IDATE,ITIME)
1590=  PRINT 4,ITIME
1600=  STOP
1610=  END
NEWTON'S LAWS SAMPLE RUNS

PLEASE TYPE YOUR LAST NAME.
Hughes

04/20/73 162820

INPUT THE MASS OF THE BODY, THE FORCE ACTING
ON IT AND THE COORDINATE AT WHICH THE FORCE
STOPS ACTING. THE INPUT DATA SHOULD BE IN THE
FORM OF N, F, L. ALL INPUT DATA MUST BE IN
DECIMAL FORM, I.E. 3.0, .02, ETC.

DO YOU WANT TO SELECT A TIME INTERVAL?
ENTER 1 FOR YES OR 0 FOR NO.

INPUT AN INTEGER BETWEEN 1 AND 10 CORRESPONDING TO THE OUTPUT VARIABLE OR COMBINATION
OF VARIABLES YOU WISH TO INVESTIGATE.

<table>
<thead>
<tr>
<th>TIME</th>
<th>DISPLACEMENT</th>
<th>VELOCITY</th>
<th>ACCELERATION</th>
<th>MASS</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0E+00</td>
<td>0.0E+00</td>
<td>0.0E+00</td>
<td>0.999E+01</td>
<td>0.100E+01</td>
</tr>
<tr>
<td>0.600E-01</td>
<td>0.180E-01</td>
<td>0.599E+00</td>
<td>0.101E+02</td>
<td>0.100E+01</td>
</tr>
<tr>
<td>0.120E+00</td>
<td>0.721E-01</td>
<td>0.180E+01</td>
<td>0.101E+02</td>
<td>0.100E+01</td>
</tr>
<tr>
<td>0.180E+00</td>
<td>0.162E+00</td>
<td>0.181E+01</td>
<td>0.100E+02</td>
<td>0.100E+01</td>
</tr>
<tr>
<td>0.240E+00</td>
<td>0.289E+00</td>
<td>0.241E+01</td>
<td>0.975E+01</td>
<td>0.100E+01</td>
</tr>
<tr>
<td>0.300E+00</td>
<td>0.451E+00</td>
<td>0.300E+01</td>
<td>0.989E+01</td>
<td>0.100E+01</td>
</tr>
<tr>
<td>0.360E+00</td>
<td>0.649E+00</td>
<td>0.359E+01</td>
<td>0.991E+01</td>
<td>0.100E+01</td>
</tr>
<tr>
<td>0.420E+00</td>
<td>0.882E+00</td>
<td>0.418E+01</td>
<td>0.102E+02</td>
<td>0.100E+01</td>
</tr>
<tr>
<td>0.480E+00</td>
<td>0.115E+01</td>
<td>0.480E+01</td>
<td>0.964E+01</td>
<td>0.100E+01</td>
</tr>
<tr>
<td>0.540E+00</td>
<td>0.146E+01</td>
<td>0.537E+01</td>
<td>0.100E+02</td>
<td>0.100E+01</td>
</tr>
<tr>
<td>0.600E+00</td>
<td>0.180E+01</td>
<td>0.597E+01</td>
<td>0.102E+02</td>
<td>0.100E+01</td>
</tr>
</tbody>
</table>

DO YOU WISH ANOTHER TRIAL?
IF YES, ENTER 1; IF NO, ENTER 0.

1

1.0, 20, 0.2

DO YOU WANT TO SELECT A TIME INTERVAL?
ENTER 1 FOR YES OR 0 FOR NO.

1.

INPUT THE TIME INTERVAL YOU WANT TO USE.

1.06.

INPUT AN INTEGER BETWEEN 1 AND 10 CORRESPONDING TO THE OUTPUT VARIABLE OR COMBINATION OF VARIABLES YOU WISH TO INVESTIGATE.

1.

TIME DISPLACEMENT VELOCITY ACCELERATION MASS
0.E+00 0.E+00 0.E+00 0.197E+02 0.100E+01
0.600E-01 0.355E-01 0.118E+01 0.209E+02 0.100E+01
0.120E+00 0.144E+00 0.244E+01 0.199E+02 0.100E+01
0.180E+00 0.326E+00 0.363E+01 0.201E+02 0.100E+01
0.240E+00 0.580E+00 0.484E+01 0.200E+02 0.100E+01
0.300E+00 0.907E+00 0.604E+01 0.200E+02 0.100E+01
0.360E+00 0.130E+01 0.724E+01 0.201E+02 0.100E+01
0.420E+00 0.178E+01 0.844E+01 0.205E+02 0.100E+01

DO YOU WISH ANOTHER TRIAL?
IF YES, ENTER 1; IF NO, ENTER 0.

1.


1.0, 30, 0.2

DO YOU WANT TO SELECT A TIME INTERVAL?
ENTER 1 FOR YES OR 0 FOR NO.

1.

INPUT THE TIME INTERVAL YOU WANT TO USE.

1.06.

INPUT AN INTEGER BETWEEN 1 AND 10 CORRESPONDING TO THE OUTPUT VARIABLE OR COMBINATION OF VARIABLES YOU WISH TO INVESTIGATE.

1.

TIME DISPLACEMENT VELOCITY ACCELERATION MASS
0.E+00 0.E+00 0.E+00 0.300E+02 0.100E+01
0.600E-01 0.540E-01 0.180E+01 0.303E+02 0.100E+01
0.120E+00 0.217E+00 0.362E+01 0.297E+02 0.100E+01
0.180E+00 0.407E+00 0.540E+01 0.299E+02 0.100E+01
0.240E+00 0.665E+00 0.720E+01 0.310E+02 0.100E+01
0.300E+00 0.135E+01 0.906E+01 0.295E+02 0.100E+01
0.360E+00 0.195E+01 0.108E+02 0.313E+02 0.100E+01

DO YOU WISH ANOTHER TRIAL?
IF YES, ENTER 1; IF NO, ENTER 0.

1.

STOP 04/20/73 163641
A SPRING EXPERIMENT COMPUTER SIMULATION

10 PROGRAM SPRING (INPUT, OUTPUT)
20 DATA ENDLST/9HENDLIST/
30 PRINT 5
40 FORMAT(1HO,*PLEASE TYPE YOUR LAST NAME.*)
50 CALL FLRED(NAME, ENDLST)
60 CALL CLOCK(IDATE, ITIME)
70 PRINT 6, IDATE, ITIME
80 FORMAT(1HO,*INPUT THE SPRING CONSTANT, THE MASS AND*)
90 FORMAT(1HO,*THE DISTANCE ABOVE THE REST POSITION IN*)
100 PRINT 20
210 FORMAT(1HO,*THIS PROGRAM SIMULATES THE ACTION OF A *)
220 FORMAT(1HO,*MASS ON A SPRING OSCILLATING IN THE *)
230 FORMAT(1HO,*EARTH'S GRAVITATIONAL FIELD TO PERFORM*)
240 FORMAT(1HO,*THE EXPERIMENT, THE MASS IS RAISED A*)
250 FORMAT(1HO,*CERTAIN DISTANCE ABOVE THE MASS'S REST*)
260 FORMAT(1HO,*POSITION AND RELEASED TO APPROXIMATE A*)
270 FORMAT(1HO,*REAL EXPERIMENT, YOU MUST KNOW THE SPRING*)
280 FORMAT(1HO,*CONTRACT IN NEWTONS/METER, THE MASS*)
290 FORMAT(1HO,*IN KILOGRAMS) ATTACHED TO THE SPRING,*)
300 FORMAT(1HO,*AND THE DISTANCE (IN METERS) THE MASS IS*)
310 FORMAT(1HO,*RAISED ABOVE THE REST POSITION BEFORE IT*)
320 FORMAT(1HO,*IS RELEASED THE BODY WILL BE CONSIDERED*)
330 FORMAT(1HO,*TO HAVE ZERO GRAVITATIONAL ENERGY AT THE*)
340 FORMAT(1HO,*REST POSITION ALL POSITION MEASUREMENTS*)
350 FORMAT(1HO,*WILL BE MADE FROM THE REST POSITION THE*)
360 FORMAT(1HO,*SIGN CONVENTION WILL BE POSITIVE FOR UP *)
370 FORMAT(1HO,*AND NEGATIVE FOR DOWN*)
380 FORMAT(1HO,*INPUT THE SPRING CONSTANT, THE MASS AND*)
390 FORMAT(1HO,*THE DISTANCE ABOVE THE REST POSITION IN*)
400 PRINT 100
410 FORMAT(1HO,*INPUT THE SPRING CONVENTION WILL BE POSITIVE FOR UP*)
420 FORMAT(1HO,*AND NEGATIVE FOR DOWN*)
430 FORMAT(1HO,*INPUT THE SPRING CONSTANT, THE MASS AND*)
440 FORMAT(1HO,*THE DISTANCE ABOVE THE REST POSITION IN*)
450 PRINT 100
460 FORMAT(1HO,*DECADE FOR THE SPRING CONSTANT, THE MASS AND*)
470 FORMAT(1HO,*THE DISTANCE ABOVE THE REST POSITION IN*)
480 FORMAT(1HO,*INPUT THE SPRING CONSTANT, THE MASS AND*)
490 CALL FLRED(XM, XM, ENDLST)
500 RI=0
510 R3=1.0
520 D=9.8
530 IF(XM*9.8/XK-D)<210, 220, 220
540 PRINT 215
550 FORMAT(1HO,*YOU HAVE RAISED THE MASS HIGHER THAN THE*)
560 FORMAT(1HO,*UNESTRETCHED POSITION OF THE SPRING*)
570 GO TO 180
590=220 PRINT 230 FORMAT(1HO,10X,4HTIME,11X,8HPOSITION, 7X,8HVELOCITY, 5X, 6HACC) ....
610= PRINT 250 FORMAT(9X,6H(SEC. *), 11X,9HFROM REST, 19X, 7HERATION) ....
630= \( W = \text{SORT}(XK/XH) \)
640= \( T = 2.0 * 3.1416 / V \)
650= IF(T<1.0)275;275,290
660=275 P=10.0 ....
670=278 T=PT.
680= IF(T<1.0)280,280,285
690=280 P=P*10.0
700= GG.73.278
710=285 IT=IFIX(T)
720= T=FLOAT(IT)/P
730= GG.70.300
740=290 IT=IFIX(T)
750= T=FLOAT(IT)
760=300 XN=0 ....
770= DO.,505 JCC=1,11
780= IC=0. ....
790=305 IC=IC+1
800= IF(JCC=1)375,375,307
810=307 RI=RANF(O) ....
820= R2=RANF(O) ....
830= IF(R1<5) 310,310,320
840=310 RI=RI' ....
850= IF(R2<68)330,330,340
860=330 R3=50.0
870= GO TO.370
880=340 IF(R2>95)350,350,360
890=350 R3=20.0 ...
900= GO TO.370
910=360 R3=10.0 ...
920=370 CONTINUE ...
930=375 GG.70.(380,390,400)IC
940=380 Y=(D*COS(W*XN))*(1.0+RI/R3)
950= GG.70.305 ...
960=390 V=(W*D*SIN(W*XN))*(1.0+RI/R3)
970= GG.70.305 ...
980=400 A=(-W**2*D*COS(W*XN))*(1.0+RI/R3)
990= CONTINUE ...
1000=410 FORMAT(IX,4(F15.5))
1010=500 XN=XN+T/10.0 ...
1020=505 CONTINUE ...
1030= PRINT 510 ...
1040=510 FORMAT(1HO,*DO YOU WISH ANOTHER TRIAL?*)
1050= PRINT 511 ...
1060=511 FORMAT(1X,*1=YES; 0=NO.*)
1070= CALL FREFLD(ICC,ENDLST)
1080= IF(ICC=1520,520,180)
1090=520 CALL CLOCK(IDATE,ITIME)
1100= PRINT 6, IDATE, ITIME
1110= STOP
1120= END
A SPRING EXPERIMENT SAMPLE RUNS

PLEASE TYPE YOUR LAST NAME.
HUGHES

04/20/73  164708

THIS PROGRAM SIMULATES THE ACTION OF A MASS ON A SPRING OSCILLATING IN THE EARTH'S GRAVITATIONAL FIELD. TO PERFORM THE EXPERIMENT, THE MASS IS RAISED A CERTAIN DISTANCE ABOVE THE MASS'S REST POSITION AND RELEASED. TO APPROXIMATE A REAL EXPERIMENT, YOU MUST KNOW THE SPRING CONSTANT (IN NEWTONS/METER), THE MASS (IN KILOGRAMS) ATTACHED TO THE SPRING, AND THE DISTANCE (IN METERS) THE MASS IS RAISED ABOVE THE REST POSITION BEFORE IT IS RELEASED. THE BODY WILL BE CONSIDERED TO HAVE ZERO GRAVITATIONAL ENERGY AT THE REST POSITION. ALL POSITION MEASUREMENTS WILL BE MADE FROM THE REST POSITION. THE SIGN CONVENTION WILL BE POSITIVE FOR UP AND NEGATIVE FOR DOWN.

INPUT THE SPRING CONSTANT, THE MASS AND THE DISTANCE ABOVE THE REST POSITION IN DECIMAL FORM.
3: 40.0, 5.1

<table>
<thead>
<tr>
<th>TIME (SEC.)</th>
<th>POSITION FROM REST</th>
<th>VELOCITY</th>
<th>ACCELERATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00000</td>
<td>0.10000</td>
<td>0.00000</td>
<td>-8.00000</td>
</tr>
<tr>
<td>0.07000</td>
<td>0.08092</td>
<td>-0.53362</td>
<td>-6.74534</td>
</tr>
<tr>
<td>0.14000</td>
<td>0.03175</td>
<td>-0.86616</td>
<td>-5.45064</td>
</tr>
<tr>
<td>0.21000</td>
<td>-0.02979</td>
<td>-0.84766</td>
<td>2.40631</td>
</tr>
<tr>
<td>0.28000</td>
<td>-0.08164</td>
<td>-0.02578</td>
<td>6.49670</td>
</tr>
<tr>
<td>0.35000</td>
<td>-0.09060</td>
<td>-0.01011</td>
<td>7.93491</td>
</tr>
<tr>
<td>0.42000</td>
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</tr>
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<td>0.49000</td>
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<tr>
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<td>0.08130</td>
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<td>0.70000</td>
<td>0.10369</td>
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<td>-8.25109</td>
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</table>

DO YOU WISH ANOTHER TRIAL?
YES: Y = NO: N
1 = 1
**INPUT. THE SPRING CONSTANT, THE MASS AND THE DISTANCE ABOVE THE REST POSITION IN DECYMAL FORM.**

<table>
<thead>
<tr>
<th>TIME (SEC.)</th>
<th>POSITION FROM REST</th>
<th>VELOCITY</th>
<th>ACCELERATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00000</td>
<td>0.10000</td>
<td>0.00000</td>
<td>-4.00000</td>
</tr>
<tr>
<td>0.02000</td>
<td>0.06348</td>
<td>-0.34656</td>
<td>-0.43999</td>
</tr>
<tr>
<td>0.04000</td>
<td>-0.02153</td>
<td>-0.34926</td>
<td>1.25556</td>
</tr>
<tr>
<td>0.06000</td>
<td>-0.09138</td>
<td>-0.19694</td>
<td>1.78141</td>
</tr>
<tr>
<td>0.09000</td>
<td>-0.09986</td>
<td>-0.00502</td>
<td>1.98346</td>
</tr>
<tr>
<td>1.00000</td>
<td>-0.06655</td>
<td>0.35783</td>
<td>1.26901</td>
</tr>
</tbody>
</table>

**DO YOU WISH ANOTHER TRIAL?**
1=YES; 0=NO.

1

**INPUT. THE SPRING CONSTANT, THE MASS AND THE DISTANCE ABOVE THE REST POSITION IN DECYMAL FORM.**

<table>
<thead>
<tr>
<th>TIME (SEC.)</th>
<th>POSITION FROM REST</th>
<th>VELOCITY</th>
<th>ACCELERATION</th>
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<tr>
<td>0.00000</td>
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<tr>
<td>0.04000</td>
<td>-0.02153</td>
<td>-0.34926</td>
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<td>0.06000</td>
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<td>-0.19694</td>
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<tr>
<td>1.00000</td>
<td>-0.06655</td>
<td>0.35783</td>
<td>1.26901</td>
</tr>
</tbody>
</table>

**DO YOU WISH ANOTHER TRIAL?**
1=YES; 0=NO.

1

STOP 04/20/73 165607
THE COULOMB EXPERIMENT COMPUTER SIMULATION

10  PROGRAM COUL (INPUT,OUTPUT)
20  DIMENSION DC(20)
30  DATA ENDLST/9RSENDLST/
40  IC=1
50  PRINT 5.
60=5  FORMAT(1HO,*PLEASE TYPE YOUR LAST NAME.*)
70  CALL FREFLDCMAME,ENDLST)
80  CALL CLOCK(IDATE,ITIME)
90  PRINT 6, DATE, ITIME
100=6  FORMAT(1HO,9X,A8,10X,R6)
110  PRINT 10.
120=10  FORMAT(2X,*THIS PROGRAM SIMULATES AN EXPERIMENT IN *)
130  PRINT 20.
140=20  FORMAT(2X,*WHICH A CHARGED METALLIC SPHERE ON AN *)
150  PRINT 30.
160=30  FORMAT(2X,*INSULATING STAND IS BROUGHT CLOSE TO AN*)
170  PRINT 40.
180=40  FORMAT(2X,*IDENTICAL CHARGED METALLIC SPHERE ON AN*)
190  PRINT 50.
200=50  FORMAT(2X,*INSULATING THREAD 25 CM LONG. THE SPHERE*)
210  PRINT 60.
220=60  FORMAT(2X,*ON THE THREAD CAN SWING IN ONLY ONE*)
230  PRINT 70.
240=70  FORMAT(2X,*VERTICAL PLANE. A RANDOM CHARGE WILL BE*)
250  PRINT 80.
260=80  FORMAT(2X,*PLACED ON ONE OF THE SPHERES. THEN THE*)
270  PRINT 90.
280=90  FORMAT(2X,*SPHERES WILL BE TOUCHED TOGETHER SO THAT*)
290  PRINT 100.
300=100  FORMAT(2X,*THE CHARGE WILL BE SHARED EQUALLY. THE*)
310  PRINT 110.
320=110  FORMAT(2X,*METALLIC SPHERE ON THE INSULATING STAND*)
330  PRINT 120.
340=120  FORMAT(2X,*IS INITIALLY POSITIONED AT THE X=0 CM.*)
350  PRINT 130.
360=130  FORMAT(2X,*POSITION. THE SPHERE ON THE THREAD IS AT*)
370  PRINT 140.
380=140  FORMAT(2X,*THE X=6 CM. POSITION. THE SPHERE ON THE*)
390  PRINT 150.
400=150  FORMAT(2X,*STAND IS BROUGHT TOWARD THE OTHER SPHERE.*)
410  PRINT 160.
420=160  FORMAT(2X,*YOU MAY INPUT STAND POSITIONS UP TO AND*)
430  PRINT 170.
440=170  FORMAT(2X,*INCLUDING 6 CM. THE COMPUTER WILL*)
450  PRINT 180.
460=180  FORMAT(2X,*DETERMINE THE POSITION OF THE SUSPENDED*)
470  PRINT 190.
480=190  FORMAT(2X,*SPHERE. AT THE CONCLUSION OF EACH TRIAL.*)
490  PRINT 191.
500=191  FORMAT(2X,*YOU MAY WISH TO GO ON WITH A NEW TRIAL, OR YOU*)
510  PRINT 192.
520=192  FORMAT(2X,*MAY WISH TO REDUCE THE CHARGE ON THE STAND SPHER
530  PRINT 194.
540=194  FORMAT(2X,*BY 1/2.*)
550=195  PRINT 200.
161

560=200 FORMAT(110,1X*INPUT SIX POSITIONS OF THE STAND SPHERE*)
570= PRINT 210
580=210 FORMAT(2X,*YOU WOULD LIKE TO INVESTIGATE THE INPUT*)
590= PRINT 220
600=220 FORMAT(2X,*DATA MUST BE IN DECIMAL FORM.*)
610= CALL FREFLD(D(1),D(2),D(3),D(4),D(5),D(6),ENDLST)
620= N=1
630=225 IF(D(N)-6.0)245,245,230
640=230 PRINT 240
650=240 FORMAT(2X,*YOU WOULD LIKE TO INVESTIGATE. THE INPUT*)
660= GO TO 195
670=245 N=N+1
680= IF(N-6)225,225,250
690=250 IR=IFIX(D(1)+D(2)+D(3)+D(4)+D(5)+D(6)+1.0)
700= IF(IR-1252,252,310
710=252 D0_260 M=1,IR
720= R1=RANF(0)
730= R2=RANF(0)
740= R3=RANF(0)
750= R4=RANF(0)
760= R5=RANF(0)
770=260 CONTINUE
780= IF(R1-.75)262,262,261
790= DIV=1000
800= GO TO 269
810=262 IF(R1-.50)264,264,263
820=263 DIV=100.0
830= GO TO 250.
840=264 IF(N1-.25)266,266,265
850=265 DIV=10.0
860= GO TO 269
870=266 DIV=1.0
880=269 Q3=R2*(10.0**12)/DIV
890= Q4=Q3
900= PRINT 270
910=270 FORMAT(2X,*INPUT THE MASS (IN DECIMAL FORM) OF THE*)
920= PRINT 280
930=280 FORMAT(2X,*SPHERES IN GRAMS. THE MASS SHOULD BE LESS*)
940= PRINT 290
950=290 FORMAT(2X,*THAN 100.0 GRAMS.*)
960=295 CALL FREFLD(INM,ENDLST)
970= IF(INM-100.0)310,310,300
980=300 PRINT 301
990=301 FORMAT(2X,*THE MASS YOU SELECTED IS TOO LARGE FOR*)
1000= PRINT 302
1010=302 FORMAT(2X,*THE EXPERIMENT. INPUT A NEW MASS.*)
1020= GO TO 295
1030=310 PRINT 320
1040=320 FORMAT(2X,*INPUT Spheres IN POSITION OF)
1050= PRINT 330
1060=330 FORMAT(6X,12HSTAND SPHERE, 3X, 12HSUSP. SPHERE)
1070= D0_320 N=1,6
1080= XK1=.23063E-27+Q3*Q4
1090= XK2=(6.0-D(N))/100.0
1100= XK3=X2M**9.8/250.0
1110= XK4=XK1/XK3
1120= A2=X2+XK2
1130= A1=(XK2)**2
1140= A0=-XK4
1150 \( q = (a1)/3.0 - (a2+2)/9.0 \)
1160 \( r = ((a1+a2-3.0)*a0)/6.0 - (a2+3)/27.0 \)
1170 \( s1 = r + \sqrt{(a3+a4+a0)} \times \sqrt{(a3+a4+a0)} \)
1180 \( s2 = r - \sqrt{(a3+a4+a0)} \times \sqrt{(a3+a4+a0)} \)
1190 \( x = s1 + s2 - a2/3.0 \)
1200 \( if (r3 = 5) 340, 340, 350 \)
1210 \( r4 = -r4 \)
1220 \( 340, 350 \)
1230 \( x = 60+100.0 \times x \)
1240 \( 360 \)
1250 \( 390, 390 \)
1260 \( r6 = 20.0 \)
1270 \( 400 \)
1280 \( 50.0 \)
1290 \( 400 \)
1300 \( print (430 \times D(1), x) \)
1310 \( format (1x, 2(e15.3)) \)
1320 \( continue \)
1330 \( print (430) \)
1340 \( format (1190 \times type 0 to end the program! for a *) \)
1350 \( print (431) \)
1360 \( format (1x, completely new trail! 2 to reduce the *) \)
1370 \( print (432) \)
1380 \( format (1x, charge on the stand sphere by 1/2 *) \)
1390 \( call frfld(cic, endlst) \)
1400 \( if (ic-1) 1400, 195, 440 \)
1410 \( print (440) \)
1420 \( print (441) \)
1430 \( format (1190 \times the charge on the stand sphere has been *) \)
1440 \( print (442) \)
1450 \( format (1x, cut in half.*) \)
1460 \( q4 = q4/2 \)
1470 \( 195 \)
1480 \( call clock(idate, itime) \)
1490 \( print 6.0, idate, itime \)
1500 \( stop \)
1510 \( end \)
THE COULOMB EXPERIMENT SAMPLE RUNS

PLEASE TYPE YOUR LAST NAME.

HUGHES

04/20/73

072046

THIS PROGRAM SIMULATES AN EXPERIMENT IN WHICH A CHARGED METALLIC SPHERE ON AN INSULATING STAND IS BROUGHT CLOSE TO AN IDENTICAL CHARGED METALLIC SPHERE ON AN INSULATING THREAD 25 CM LONG. THE SPHERE ON THE THREAD CAN SING IN ONLY ONE VERTICAL PLANE. A RANDOM CHARGE WILL BE PLACED ON ONE OF THE SPHERES. THEN THE SPHERES WILL BE TOUCHED TOGETHER SO THAT THE CHARGE WILL BE SHARED EQUALLY. THE METALLIC SPHERE ON THE INSULATING STAND IS INITIALLY POSITIONED AT THE X=0 CM. POSITION. THE SPHERE ON THE THREAD IS AT THE X=6 CM. POSITION. THE SPHERE ON THE STAND IS BROUGHT TOWARD THE OTHER SPHERE. YOU MAY INPUT STAND POSITIONS UP TO AND INCLUDING 6 CM. THE COMPUTER WILL DETERMINE THE POSITION OF THE SUSPENDED SPHERE. AT THE CONCLUSION OF EACH TRIAL, YOU MAY WISH TO GO ON WITH A NEW TRIAL, OR YOU MAY WISH TO REDUCE THE CHARGE ON THE STAND SPHERE BY 1/2.

INPUT SIX POSITIONS OF THE STAND SPHERE YOU WOULD LIKE TO INVESTIGATE. THE INPUT DATA MUST BE IN DECIMAL FORM:

6* 1.0 2.0 3.0 4.0 5.0 6.0

INPUT THE MASS (IN DECIMAL FORM) OF THE SPHERES IN GRAMS. THE MASS SHOULD BE LESS THAN 100.0 GRAMS:

5.0

POSITION OF STAND SPHERE | POSITION OF SUSP. SPHERE
0.100E+01 | 0.963E+01
0.200E+01 | 0.101E+02
0.300E+01 | 0.106E+02
0.400E+01 | 0.112E+02
0.500E+01 | 0.118E+02
0.600E+01 | 0.125E+02

163
TYPE 0 TO END THE PROGRAM; 1 FOR A COMPLETELY NEW TRIAL; 2 TO REDUCE THE CHARGE ON THE STAND SPHERE BY 1/2.

1  2

THE CHARGE ON THE STAND SPHERE HAS BEEN CUT IN HALF.

INPUT SIX POSITIONS OF THE STAND SPHERE YOU WOULD LIKE TO INVESTIGATE. THE INPUT DATA MUST BE IN DECIMAL FORM.

1  0  2  0  3  0  4  0  5  0  6  0

<table>
<thead>
<tr>
<th>POSITION OF STAND SPHERE</th>
<th>POSITION OF SUSP. SPHERE</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.100E+01</td>
<td>0.844E+01</td>
</tr>
<tr>
<td>0.200E+01</td>
<td>0.887E+01</td>
</tr>
<tr>
<td>0.300E+01</td>
<td>0.936E+01</td>
</tr>
<tr>
<td>0.400E+01</td>
<td>0.990E+01</td>
</tr>
<tr>
<td>0.500E+01</td>
<td>0.105E+02</td>
</tr>
<tr>
<td>0.600E+01</td>
<td>0.112E+02</td>
</tr>
</tbody>
</table>

TYPE 0 TO END THE PROGRAM; 1 FOR A COMPLETELY NEW TRIAL; 2 TO REDUCE THE CHARGE ON THE STAND SPHERE BY 1/2.

1  2

THE CHARGE ON THE STAND SPHERE HAS BEEN CUT IN HALF.

INPUT SIX POSITIONS OF THE STAND SPHERE YOU WOULD LIKE TO INVESTIGATE. THE INPUT DATA MUST BE IN DECIMAL FORM.

1  0  2  0  3  0  4  0  5  0  6  0

<table>
<thead>
<tr>
<th>POSITION OF STAND SPHERE</th>
<th>POSITION OF SUSP. SPHERE</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.100E+01</td>
<td>0.756E+01</td>
</tr>
<tr>
<td>0.200E+01</td>
<td>0.792E+01</td>
</tr>
<tr>
<td>0.300E+01</td>
<td>0.836E+01</td>
</tr>
<tr>
<td>0.400E+01</td>
<td>0.887E+01</td>
</tr>
<tr>
<td>0.500E+01</td>
<td>0.945E+01</td>
</tr>
<tr>
<td>0.600E+01</td>
<td>0.101E+02</td>
</tr>
</tbody>
</table>

TYPE 0 TO END THE PROGRAM; 1 FOR A COMPLETELY NEW TRIAL; 2 TO REDUCE THE CHARGE ON THE STAND SPHERE BY 1/2.

1  0

04/20/73  172644
THE MILLIKAN EXPERIMENT COMPUTER SIMULATION

100 PROGRAM MILL (INPUT, OUTPUT)
200 DIMENSION V(20)
300 DATA ENDLIST, 9RSINDLST/
400 PRINT 5.
500=5 FORMAT(1HO, *PLEASE TYPE YOUR LAST NAME.*)
600 CALL FRENSDL(NAME, ENDLST)
700 CALL CLOCK(I DATE, ITIME)
800 PRINT 6, I DATE, ITIME
900=6 FORMAT(2HO, 9X, A8, 10X, R6)
100 PRINT 10.
110=10 FORMAT(2X, *THIS PROGRAM SIMULATES THE MOTION OF SMALL*)
120 PRINT 20.
130=20 FORMAT(2X, *PLASTIC SPHERES (USED TO CALIBRATE ELECTRON*)
140 PRINT 30.
150=30 FORMAT(2X, *MICROSCOPES) IN AN ELECTRIC FIELD. THE*)
160 PRINT 40.
170=40 FORMAT(2X, *SPHERES USUALLY ACQUIRE A FEW IONIC CHARGES.*)
180 PRINT 50.
190=50 FORMAT (2X, *CONSEQUENTLY, THEY EXPERIENCE A FORCE*)
200 PRINT 60.
210=60 FORMAT(2X, *IN AN ELECTRIC FIELD, IN THIS EXPERIMENT*)
220 PRINT 70.
230=70 FORMAT(2X, *YOU WILL CONTROL THE VOLTAGE APPLIED TO*)
240 PRINT 80.
250=80 FORMAT(2X, *THE CHARGED PLATES AND THE PLATE SEPARATION.*)
260 PRINT 90.
270=90 FORMAT(2X, *THE COMPUTER WILL GENERATE THE DISTANCE*)
280 PRINT 100.
290=100 FORMAT(2X, *TRAVELED BY TEN OBSERVED SPHERES IN ONE*)
300 PRINT 110.
310=110 FORMAT(2X, *SECOND, THE SPHERES HAVE A MASS OF *)
320 PRINT 120.
330=120 FORMAT(2X, *2.86 X 10**-15 KG, AND A DIAMETER OF*)
340 PRINT 130.
350=130 FORMAT(2X, *1.8 MICRONS. THE SPHERES FREE FALL AT*)
360 PRINT 140.
370=140 FORMAT(2X, *0.0943 MM/SEC.*)
380=145 PRINT 150.
390=150 FORMAT(1HO, *INPUT THE APPLIED VOLTAGE (IN VOLTS)*)
400 PRINT 160.
410=160 FORMAT(1X, *AND THE PLATE SEPARATION (IN MILLIMETERS).*
420 PRINT 170.
430=170 FORMAT(1X, *THE TOP PLATE WILL ALWAYS BE THE + PLATE.*)
440 CALL FRENSDL(VL, S, ENDLST)
450=180 FORMAT(2X, *SPHERE VELOCITIES IN MM/SEC*)
460=180 FORMAT(2X, *INPUT THE APPLIED VOLTAGE (IN VOLTS)*)
470 D0...250 N=1,10
480 DI=RANF(0)
490=190 IF(DI > 0.5) 190, 190, 200
500=QI=FLOAT(10)
510=10 IF(D1 > 0.5) 190, 190, 200
520=QI=QI
530=800 F=0.6800E13+VL*2800E-13*QI/5
540 V(N)=F
550=250 CONTINUE
560= PRINT 260, V(1), V(2), V(3), V(4), V(5), V(6), V(7), V(8), V(9), V(10)
570 FORMAT(10F7.3)
580 PRINT 270
590 FORMAT(1HO,*DO YOU WISH ANOTHER TRIAL? YES=1 NO=0.)
600 CALL FREFLD(ICC,ENDLST)
610 IF (ICC) 280,280,145
620 CALL CLOCK(IDATE,ITIME)
630 PRINT 6,IDATE,ITIME
640 STOP
650 END
THE MILLIKAN EXPERIMENT SAMPLE RUNS

PLEASE TYPE YOUR LAST NAME.
HUGHES
04/20/73
174641
04/20/73

THIS PROGRAM SIMULATES THE MOTION OF SMALL PLASTIC SPHERES (USED TO CALIBRATE ELECTRON MICROSCOPES) IN AN ELECTRIC FIELD. THE SPHERES USUALLY ACQUIRE A FEW IONIC CHARGES. CONSEQUENTLY, THEY EXPERIENCE A FORCE IN AN ELECTRIC FIELD. IN THIS EXPERIMENT YOU WILL CONTROL THE VOLTAGE APPLIED TO THE CHARGED PLATES AND THE PLATE SEPARATION. THE COMPUTER WILL GENERATE THE DISTANCE TRAVELED BY TEN OBSERVED SPHERES IN ONE SECOND. THE SPHERES HAVE A MASS OF 2.86 x 10^-15 KG. AND A DIAMETER OF 1.38 MICRONS. THE SPHERES FREE FALL AT 9.0943 MM/SEC.

INPUT THE APPLIED VOLTAGE (IN VOLTS) AND THE PLATE SEPARATION (IN MILLIMETERS). THE TOP PLATE WILL ALWAYS BE THE + PLATE.

21  200.0 5.0
SPHERES VELOCITIES IN MM/SEC
0.008 0.137 0.310 0.202 0.223 -0.099 -0.099 0.030 -0.121 0.094

DO YOU WISH ANOTHER TRIAL? YES=I; NO=O.

21  400.0 5.0
SPHERE VELOCITIES IN MM/SEC
-0.293 0.160 -0.379 0.310 -0.164 -0.336 0.525 -0.336 -0.078 -0.293

DO YOU WISH ANOTHER TRIAL? YES=I; NO=O.
INPUT THE APPLIED VOLTAGE (IN VOLTS)
AND THE PLATE SEPARATION (IN MILLIMETERS).
THE TOP PLATE WILL ALWAYS BE THE + PLATE.

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Separation</th>
<th>Sphere Velocities (mm/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2t 600.0, 0.5</td>
<td>0.094  -0.229 -0.164  0.094  0.482  0.546  -0.293  0.611  -0.293  0.605</td>
<td></td>
</tr>
</tbody>
</table>

DO YOU WISH ANOTHER TRIAL? YES=1; NO=0.

INPUT THE APPLIED VOLTAGE (IN VOLTS)
AND THE PLATE SEPARATION (IN MILLIMETERS).
THE TOP PLATE WILL ALWAYS BE THE + PLATE.

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Separation</th>
<th>Sphere Velocities (mm/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2t 800.0, 0.5</td>
<td>-0.767  1.042 -0.164  -0.336  -0.853  -0.767  0.697  0.697  -0.767  -0.853</td>
<td></td>
</tr>
</tbody>
</table>

DO YOU WISH ANOTHER TRIAL? YES=1; NO=0.

INPUT THE APPLIED VOLTAGE (IN VOLTS)
AND THE PLATE SEPARATION (IN MILLIMETERS).
THE TOP PLATE WILL ALWAYS BE THE + PLATE.

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Separation</th>
<th>Sphere Velocities (mm/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2t 1000.0, 0.5</td>
<td>-0.336  0.525  0.740  0.310  1.171  0.094  -0.336  0.310  0.633  -0.767</td>
<td></td>
</tr>
</tbody>
</table>

DO YOU WISH ANOTHER TRIAL? YES=1; NO=0.

STOP 04/20/73 175106
APPENDIX B

WRITTEN EXAMINATIONS—PROCESSES
NEWTON'S LAWS

I. A student performs an experiment similar to the one you just completed. After making appropriate measurements, he prepares the following data table: (Input data: $m = 1$ kg.; $F = 10$ nt.; length of table = 2 meters).

<table>
<thead>
<tr>
<th>Time (sec.)</th>
<th>Displacement (meters)</th>
<th>Velocity (meters/sec.)</th>
<th>Acceleration (meters/sec$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>.06</td>
<td>.018</td>
<td>.600</td>
<td>10.6</td>
</tr>
<tr>
<td>.12</td>
<td>.074</td>
<td>1.23</td>
<td>10.0</td>
</tr>
<tr>
<td>.18</td>
<td>.169</td>
<td>1.88</td>
<td>9.71</td>
</tr>
<tr>
<td>.30</td>
<td>4.64</td>
<td>3.05</td>
<td>9.69</td>
</tr>
<tr>
<td>.42</td>
<td>.990</td>
<td>4.22</td>
<td>11.2</td>
</tr>
</tbody>
</table>

1. From these data, what is your estimate of the value of the following variables at 0.24 sec?
   (a) Displacement
   (b) Velocity
   (c) Acceleration

2. From these data, what is your estimate of the value of the following variables at .054 sec.?
   (a) Displacement
   (b) Velocity
   (c) Acceleration

3. Suppose the mass being accelerated were changed to 2 kg. but the force kept at 10 nt. What is your estimate of the value of the following variables at 0.12 sec.?
   (a) Displacement
   (b) Velocity
   (c) Acceleration
4. Suppose the force acting on the body were changed to 20 newtons but the mass kept at 1 kg. What is your estimate of the value of the following variables at 0.12 sec.?

   (a) Displacement
   (b) Velocity
   (c) Acceleration

II. A student wants to investigate the relationships between force, mass, acceleration, velocity, and displacement. He has available a nearly friction-free cart having a mass of 500 grams (0.5 kg.), a set of standard masses to provide loads for the cart, a stop watch, a recording timer (frequency of 60 cycles per second), a meter stick, and a set of springs. The cart can be pulled forward with a constant force by applying the force through the spring or springs which are kept stretched at a constant length as the cart is pulled along. The student knows that for each 10 cm. each spring is stretched, the force increases by 2 newtons. A schematic diagram is shown below.


   Cart and Mass                      Cart and Mass

   Equipment is available to perform the experiments using the mass-spring combinations indicated below:

1. The student uses one spring attached to the cart and keeps it stretched 10 cm. He places masses of 10 grams, 20 grams, 30 grams, 40 grams and 50 grams respectively in the cart for each trial.

2. The student uses one spring attached to the cart and keeps it stretched 10 cm. He places masses of 500 grams, 1000 grams, 1500 grams, 2000 grams, and 2500 grams respectively in the cart for each trial.

3. The student uses one spring attached to the cart and keeps it stretched 10 cm. He places masses of 500 grams, 1000 grams, 1500 grams, 2000 grams, and 2500 grams respectively in the cart for each trial. He then replaces the one spring with two springs, each stretched 10 cm. and then repeats the above experiment. He then replaces the two springs
with three springs, each stretched 10 cm. and repeats the above experiment.

4. The student puts 2000 grams in the cart. He uses one spring, two springs, three springs, four springs, and five springs stretched 10 cm. for each of his five trials.

5. The student puts 10 grams in the cart. He uses one spring, two springs, three springs, four springs, and five springs each stretched 10 cm. for each of his five trials.

In addition, the student has equipment to measure:

A. Distance traveled in a given time, e.g. 1 second.

B. Displacement (from recording timer tape) and time.

Experiments can be performed by selecting a mass-spring combination and a distance-time measurement or a displacement-time measurement. For example, experiment 2A would indicate that the student uses one spring attached to the cart and keeps it stretched 10 cm. He places masses of 500 grams, 1000 grams, 1500 grams, 2000 grams, and 2500 grams respectively in the cart for each trial. (Example 2 from the previous page). He measures the distance the cart travels in a given time for each trial. (Example A from above).

1. Select the experiment from each of the following pairs of experiments that would give you the most information about the relationship between the mass and acceleration. Put the answer on the line at the left of each pair.

   ______ (a) 1A or 2A
   ______ (b) 1A or 3A
   ______ (c) 2A or 4A

2. Select the experiment from each of the following pairs of experiments that would give you the most information about the relationship between the force and acceleration. Put the answer on the line at the left of each pair.

   ______ (a) 1A or 3A
   ______ (b) 2A or 3A
   ______ (c) 2A or 5A
3. Select the single experiment that would give the most information about force, mass, and acceleration. Circle your answer.

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1A</td>
<td>2B</td>
<td>4A</td>
<td>5B</td>
</tr>
<tr>
<td>1B</td>
<td>3A</td>
<td>4B</td>
<td></td>
</tr>
<tr>
<td>2A</td>
<td>3B</td>
<td>5A</td>
<td></td>
</tr>
</tbody>
</table>

4. Select the experiment from each of the following pairs of experiments that would give you the most information about the relationship between force and velocity. Put the answer on the line at the left of each pair.

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) 5A or 5B</td>
<td>(d) 3B or 5A</td>
<td></td>
</tr>
<tr>
<td>(b) 3B or 5B</td>
<td>(e) 2B or 4B</td>
<td></td>
</tr>
<tr>
<td>(c) 2A or 5B</td>
<td>(f) 2B or 3B</td>
<td></td>
</tr>
</tbody>
</table>

5. Select the experiment from each of the following pairs of experiments that would give you the most information about the relationships between mass and velocity. Put the answer on the line at the left of each pair.

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) 1B or 2B</td>
<td>(d) 2B or 5B</td>
<td></td>
</tr>
<tr>
<td>(b) 1B or 3B</td>
<td>(e) 2A or 2B</td>
<td></td>
</tr>
<tr>
<td>(c) 2B or 4B</td>
<td>(f) 2B or 1A</td>
<td></td>
</tr>
</tbody>
</table>

III. From the preceding experiments, students collected data in a variety of ways and prepared the following graphs:

A. Graph showing distance traveled in a given time vs. mass when acted on by one spring.
Graph showing displacement of the cart vs. time when the cart was acted on by one spring and the masses were changed.

\[ m_1 < m_2 < m_3 < m_4 \]

Graph showing distance traveled in a given time vs. number of springs when the mass is kept constant.

Graph showing displacement of the cart vs. time when the cart was acted on by a different number of springs but the mass was kept constant.

\[ F_1 < F_2 < F_3 < F_4 \]

1. Following is a list of hypotheses suggested by graph A. Select three of the hypotheses that could explain the relationship shown in the graph.

A. The acceleration is inversely proportional to the mass.
B. The acceleration is inversely proportional to the square of the mass.
C. As the mass increases, the velocity decreases.
D. The acceleration is directly proportional to the force.
E. As the mass increases, the distance traveled in a given time decreases.
F. As the mass increases, the distance traveled in a given time increases.
Hypotheses?
1. ______
2. ______
3. ______

2. Following is a list of hypotheses suggested by graph B. Select three hypotheses that could explain the relationship shown in the graph.

A. The displacement is directly proportional to the square of the time.
B. As the mass increases, the velocity decreases.
C. The displacement is directly proportional to the square of the mass.
D. As the mass increases, the distance traveled in a given time decreases.
E. The displacement is directly proportional to the mass.
F. The displacement is inversely proportional to the square of the time.

Hypotheses?
1. ______
2. ______
3. ______

3. Following is a list of hypotheses suggested by graph C. Select four hypotheses that could explain the relationship shown in the graph.

A. The displacement is directly proportional to the force.
B. As the force increases, the distance traveled in a given time increases.
C. The acceleration is directly proportional to the force.
D. As the force increases, the velocity increases.
E. As the force increases, the velocity decreases.
F. The displacement is directly proportional to the square of the force.
G. The acceleration is inversely proportional to the force.
H. The acceleration is inversely proportional to the square of the force.

Hypotheses?
1. ______ 3. ______
2. ______ 4. ______
A SPRING EXPERIMENT

I. A student performed an experiment using a spring to investigate the behavior of oscillating bodies. He used a spring with a spring constant of 40 N/meter and hung a 1 kg. mass on the spring. The mass was raised 0.2 meters above the rest position and released. A diagram is shown below.

The student collected and analyzed data from the experiment and prepared the following graphs:

A

Position (meters)

Rest 0.2

-0.2

Time (sec.)

0 0.2 0.6 1.0

B

Velocity (m/sec)

0 1.2

-1.2

Time (sec.)

0 0.2 0.6 1.0

C

Acceleration (m/sec^2)

8.0

0

-8.0

Time (sec.)

0 0.2 0.6 1.0

D

Spring Potential Energy (Joules)

4.0

0

-4.0

Time (sec.)

0 0.2 0.6 1.0
1. A graph of kinetic energy vs. time would have a shape like which of the graphs on the previous page?
   (a) A, (b) B, (c) C, (d) D, (e) None of the graphs.

2. A graph of gravitational potential energy vs. time would have a shape like which of the graphs on the previous page?
   (a) A, (b) B, (c) C, (d) D, (e) None of the graphs.

3. A graph of total energy vs. time would have a shape like which of the graphs on the previous page?
   (a) A, (b) B, (c) C, (d) D, (e) None of the graphs.

4. Using the prepared graphs on the previous page, estimate the value of the following variables at 0.6 seconds.
   (a) Position
   (b) Acceleration
   (c) Kinetic energy

5. Using the prepared graphs on the previous page, estimate the value of the following variables at 1.2 seconds.
   (a) Velocity
   (b) Spring potential energy
   (c) Gravitational potential energy

Shown below are four different graphs of position vs. time that might result from changing either the spring (spring constant) or the mass attached to the spring. The first graph (a) is the graph for a spring constant of 40nt/m, a mass of 1 kg. and a starting position of 0.2 m. above the rest position.
6. If the original spring (spring constant = 40 nt/m) is replaced with a spring having a spring constant of 10 nt/m and all other variables are kept the same as in the original experiment, which graph best represents position vs. time for this experimental arrangement?

(a) A, (b) B, (c) C, (d) D, (e) None of the graphs.

7. If the mass on the spring is replaced with a mass of 4 kg. and all other variables are kept the same as the original experiment, which graph best represents position vs. time for this experimental arrangement?

(a) A, (b) B, (c) C, (d) D, (e) None of the graphs.

II. To investigate the relationships between the spring experiment variables, a student has available a number of different springs having different spring constants, different masses to hang on the springs, meter sticks to measure distance, a stop watch to measure time, and markers to mark the rest position, the release point, and the lowest point of oscillation. The following experiments can be performed:

A. The student places a spring having a spring constant of 40 nt/m on the support stand. He places masses of 1/2 kg., 1 kg., 2 kg., and 3 kg. respectively on the spring for each successive trial. He measures the period of oscillation of each trial.

B. The student places a spring having a spring constant of 40 nt/m on the support stand. He places masses of 1/2 kg., 1 kg., 2kg., and 3 kg. respectively on the spring for each successive trial. He locates the release point, the rest position, and the lowest point of oscillation and measures the distance from the rest position to the high and low point.

C. The student places springs having spring constants of 20 nt/m, 40 nt/m, 80 nt/m, and 100 nt/m respectively on the support stand for each trial. A mass of 1 kg. is placed on each spring. He measures
the period of oscillation of each trial.

D. A student places springs having spring constants of 20 nt/m, 40 nt/m, 80 nt/m, and 100 nt/m respectively on the support stand for each trial. A mass of 1 kg. is placed on each spring. He locates the release point, the rest position, and the lowest point of oscillation and measures the distance from the rest position to the high and low point.

E. The student places a spring having a spring constant of 40 nt/m on the support stand. He places a mass of 1 kg. on the spring. He successively raises the mass 5 cm., 10 cm., 15 cm., and 20 cm. above the rest position and releases it. He measures the period of oscillation for each trial.

F. The student places a spring having a spring constant of 40 nt/m on the support stand. He places a mass of 1 kg. on the spring. He successively raises the mass 5 cm., 10 cm., 15 cm., and 20 cm. above the rest position and releases it. He locates the release point, the rest position and the lowest point of oscillation and measures the distance from the rest position to the high and low point.

Questions

1. Select the experiment from each of the following pairs of experiments that would give you the most information about the relationship between mass and period. The letter of the experiment should be put on the line at the left of each pair.
   _______ (a) A or B _______ (b) A or C _______ (c) A or E

2. Select the experiment from each of the following pairs of experiments that would give you the most information about the relationship between spring constant and period. The letter of the experiment should be put on the line at the left of each pair.
   _______ (a) A or B _______ (b) A or E

3. Select the experiment from the following pair that would give you the most information about the relationship between spring constant and spring potential energy. The letter of the experiment should be put on the line at the left of the pair.
   _______ (a) B or D

4. Select the experiment from each of the following pairs of experiments that would give you the most information about the relationship between mass and gravitational potential energy. The letter of the experiment should be put on the line at the left of each pair.
   _______ (a) B or E _______ (b) B or F
THE COULOMB EXPERIMENT

I. A student performed the Coulomb experiment (the force between two charged spheres) by moving a charged sphere on an insulating stand toward an equally charged sphere suspended from an insulating thread as shown. Both spheres have a mass of 10 grams. You may prepare graphs to answer the questions.

As the experiment was performed, the following data were collected:

<table>
<thead>
<tr>
<th>Position of the Stand Sphere (cm)</th>
<th>Position of the Suspended Sphere (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6.54</td>
</tr>
<tr>
<td>2</td>
<td>6.74</td>
</tr>
<tr>
<td>4</td>
<td>7.43</td>
</tr>
<tr>
<td>6</td>
<td>8.58</td>
</tr>
</tbody>
</table>

1. What would you predict for the position of the suspended sphere when the stand sphere is at 5 cm.?

2. Suppose the mass of the suspended sphere were changed to 20 grams but the charge kept the same. Originally, when the stand sphere was at 2 cm., the suspended sphere was at 6.74 cm. What will the new position of the suspended sphere be?

3. Originally, when the 10 gram stand sphere was at the 2cm. position, the 10 gram suspended sphere was at the 6.74 cm. position. What would happen to the position of the suspended sphere if another charged sphere,
Identical to the original stand sphere, were placed alongside the original stand sphere?

II. A student wants to investigate the relationships between force, charge, and distance. He has available metallic coated styrofoam balls having diameters of 2 mm., 1 cm., 2 cm., and 5 cm., and several hollow aluminum spheres each having a diameter of 5 cm. and a mass of 100 grams. In addition, he has a balance accurate to 0.01 grams and a meter stick. He has a charging device that will provide either a positive or negative charge. The student has no control over the magnitude of the charge. To support the spheres, the student has available an insulated stand and supporting threads. Using the equipment available, the student can perform the following experiments: (See diagram on previous page.)

1. He places a styrofoam sphere having a diameter of 1 cm. on the stand and suspends a styrofoam sphere having a diameter of 1 cm. from an insulating thread. He charges the spheres and touches them together. He measures the distance between the spheres as the stand sphere is brought toward the suspended sphere.

2. He places a styrofoam sphere having a diameter of 1 cm. on the stand and suspends a 2 mm diameter styrofoam sphere from a suspended thread. He charges the spheres and touches them together. He measures the distance between the spheres as the stand sphere is brought toward the suspended sphere.

3. He suspends a styrofoam sphere having a diameter of 1 cm. from the thread and charges it. He then charges several of the 2 mm. diameter spheres with the charging device and touches them together. He places the stand near the suspended sphere and successively places 1, 2, 3, 4, and 5 small spheres of the stand at the same place and measures the distance from the stand spheres to the suspended sphere each time.

4. He places a styrofoam sphere having a diameter of 1 cm. on the stand and charges it. He then charges several of the 2 mm. diameter spheres with the charging device and touches them together. He successively suspends 1, 2, 3, 4, and 5 of the small spheres after placing the stand nearby. He measures the distance from the stand sphere to the suspended spheres each time.

5. He places a 5 cm. diameter styrofoam sphere on the stand. He places the 5 cm. diameter aluminum sphere on the thread. Both spheres are charged and touched. He measures the distance between the spheres as the stand sphere is brought toward the suspended sphere.

6. He places a 5 cm. diameter aluminum sphere on the stand. A 5 cm. diameter styrofoam sphere is suspended from the thread. The spheres are charged and brought together. He measures the distance
between the spheres as the stand sphere is brought toward the suspended sphere.

7. He places a 5 cm. diameter aluminum sphere on the stand. He places a 5 cm aluminum sphere on the thread. Both spheres are charged and touched together. He measures the distance between the spheres as the stand sphere is brought toward the suspended sphere.

8. He places an aluminum sphere having a diameter of 5 cm. on the stand and charges it. He then charges several of the 2 cm diameter styrofoam spheres with the charging device and touches them together. He successively suspends 1, 2, 3, 4, and 5 of the spheres from the thread after placing the stand nearby. He measures the distance from the stand sphere to the suspended spheres each time.

Questions

4. Select the experiment from each of the following pairs of experiments that would give you the most information about the relationship between force and distance. Put the answer on the line at the left of each pair.

- (a) 1 or 2
- (b) 1 or 3
- (c) 1 or 4
- (d) 5 or 6
- (e) 6 or 7
- (f) 5 or 8

5. Select the experiment from each of the following pairs of experiments that would give you the most information about the relationship between force and charge. Put your answer on the line at the left of each pair.

- (a) 1 or 3
- (b) 3 or 4
- (c) 3 or 5
- (d) 3 or 6
- (e) 6 or 8
- (f) 5 or 8

III. From the preceding experiments, students collected data in a variety of ways and prepared the following graphs:

Graph 1

Graph showing force as a function of distance when the charge is kept constant.
Possible hypotheses to describe the relationships shown in the graph are:

A. As distance increases, the force decreases.
B. As the distance increases, the force increases.
C. The distance is inversely proportional to the force.
D. The force is proportional to the square of the distance.
E. The force is inversely proportional to the square of the distance.

1. List the letters of two hypotheses which could describe the relationship shown in the graph.

(a)  
(b)  

2. Select the most complete hypotheses from those selected in (1) above.

Graph 2  
Graph showing force as a function of charge on the suspended sphere when distance is kept constant.

Possible hypotheses to describe the relationships shown in the graph are:

A. As charge increases, the force decreases.
B. As the charge increases, the force increases.
C. The force is directly proportional to the charge.
D. The force is inversely proportional to the square of the charge.
E. The force is proportional to the square of the charge.

3. List the letters of two hypotheses which could describe the relationship shown in the graph.

(a)  
(b)
THE MILLIKAN EXPERIMENT

In this experiment, a student makes measurements of the speeds of a number of small plastic spheres in an electric field. The spheres have a mass of $2.86 \times 10^{-15}$ kg. and freefall at 0.0943 mm/sec. The parallel metal plates which produce the electric field are separated by 5 mm. and are charged to 500 volts. The top plate is always charged positively.

The velocities of 10 different spheres were determined and are shown below. A - velocity is opposite the direction of freefall.

(1) -.0672 mm/sec  (6) .4173 mm/sec
(2) .2558 "        (7) .3096 "
(3) .2100 "        (8) .2100 "
(4) .1483 "        (9) -.4979 "
(5) -.3364 "        (10) -.3910 "

When the effect of the force of gravity (gravitational freefall) is subtracted, the following bar graph of velocities results:

[Bar graph showing the velocities with the values indicated above the bars]
1. Give the probable number of charges on each sphere. Also, tell whether the charges are positive or negative.

(1) _______ (6) _______
(2) _______ (7) _______
(3) _______ (8) _______
(4) _______ (9) _______
(5) _______ (10) _______

2. What velocity, including the velocity due to gravity, would you expect to measure for a particle having:

(a) +5 charges?
(b) -5 charges?

3. What velocity would you expect to measure for a particle having:

(a) +20 charges?
(b) -20 charges?

4. What velocity would you expect to measure for a particle having +3 charges when the applied voltage is changed to 1000 volts?

5. What velocity would you expect to measure for a particle having +3 charges when the voltage is 500 volts and the plate separation is 10 mm.?

6. After the particles reach their terminal velocities, the velocity is proportional to the applied force. The force of gravity (2.86 X 10^{-15} kg. X 9.8 m/sec^2) produces a velocity of 0.0943 mm/sec. What force would you expect to be exerted on a sphere carrying +3 charges?

7. Suppose the speed of the plastic spheres in a Millikan apparatus is measured and found to be three halves of their speed under gravity alone.

(a) What is the electrical force on them if they are moving upward?
(b) What is the electrical force on them if they are moving downward?
Directions: Each of the questions or incomplete statements is followed by five suggested answers or completions. Select the one which is best in each case and write the letter corresponding to the answer on the answer sheet.

Questions 1-2 relate to the following information and diagrams:

Several identical springs and several identical masses are used to perform acceleration experiments on a frictionless surface. It is found that a single spring, when extended by an amount $x_o$, gives an acceleration $a_o$ to a single mass.

Single spring: two springs connected end-to-end:
unextended

extended $x_o$

extended total amount $2x_o$

Two springs connected side-by-side:
unextended

extended $x_o$

1. What acceleration would be produced on a single mass by two springs connected side-by-side and extended by an amount $x_o$?

A. $1/2 a_o$   B. $a_o$   C. $2a_o$   D. $4a_o$   E. Cannot be determined without additional information

2. Two springs are connected side-by-side; this combination is then connected end-to-end to an identical combination. What acceleration would be produced on a single mass if this arrangement of springs is extended by a total amount $2x_o$?
A. $\frac{1}{2} a_o$  B. $a_o$  C. $2a_o$  D. $4a_o$  E. Cannot be determined without additional information

Question 3: A laboratory cart (mass = 1.0 kg.) is connected to a mass of 0.50 kg. by a string which runs over a small pulley, as shown in the diagram. Neglect friction.

![Diagram of a cart and pulley system](image)

3. If the cart is held so that it cannot move, the tension in the string would be most nearly

A. 0.50 nt.  B. 1.5 nt.  C. 5.0 nt.  D. 10.0 nt.  E. 15.0 nt.

4. In each of several trials, a cart was pulled with a different number of equally stretched identical rubber bands. A constant acceleration was observed in each trial. A plot of acceleration versus force exerted by the bands is shown below.

![Graph of acceleration versus force](image)

An extrapolation of the graph would not pass through the origin. What does this indicate?

A. The mass of the cart was neglected.
B. There was a deviation from Newton's Laws.
C. There was another force acting in the direction of motion.
D. There was another force acting opposite to the direction of motion.
E. None of the above.
Questions 5-9 relate to the following diagram and information:

The diagram shows the side view of a roller coaster track. A car of mass m can be placed at various points on the track and be given various velocities. Assume all frictional forces to be negligible. The acceleration due to gravity has a magnitude g and is directed downward, as shown.

5. If the car is placed at C and allowed to slide toward the left, starting from rest, its speed at B will be

A. 0  B. mgh  C. \( \sqrt{2gh_a} \)  D. \( \sqrt{2gh_c} \)
E. \( \sqrt{2g(h_c - h_a)} \)

6. If the car is placed at C and allowed to slide toward the left, its speed at A will be

A. 0  B. mgh  C. \( \sqrt{2gh_a} \)  D. \( \sqrt{2gh_c} \)
E. \( \sqrt{2g(h_c - h_a)} \)

7. If the car is placed at A and given an initial velocity toward the right just sufficient for it to reach point C, this initial velocity must have a magnitude of

A. 0  B. mgh  C. \( \sqrt{2gh_a} \)  D. \( \sqrt{2gh_c} \)
E. \( \sqrt{2g(h_c - h_a)} \)

8. If the car is started from A toward the right and is given a kinetic energy equal to mgh_c, its speed at D will be

A. \( \sqrt{2gh_a} \)  B. \( \sqrt{2gh_c} \)  C. \( \sqrt{2gh_d} \)  D. \( \sqrt{2g(h_a - h_d)} \)
E. \( \sqrt{2gh_c + 2g(h_a - h_d)} \)
9. If the car is started from A toward the right and is given a kinetic energy equal to \( mgh_c \), its speed at E will be the same as its speed at

A. point A  
B. point B  
C. point C  
D. point D  
E. none of the above

Questions 10-11 relate to a Millikan experiment. With no potential difference between the plates, a sphere with a certain charge fell at a constant velocity of 0.2 millimeters per second. With the setup shown below, the sphere was held in balance at rest.

Five other possible experimental arrangements are shown below:

10. In which arrangement would the terminal velocity of the same sphere with the same charge be 0.4 millimeter per second downward?

11. In which arrangement would the terminal velocity of the same sphere with the same charge be 0.6 millimeter per second upward?

Questions 12-16 relate to a system consisting of a spring and an attached object. When the object is attached to the spring, it drops from I to V and then continues to vibrate between I and V. (Neglect the mass of the spring and the effects of friction.
12. At what point would the system's potential energy due to the gravitational field be a maximum?
A. I  B. II  C. III  D. IV  E. V

13. At what point would the system's potential energy due to the tension of the spring be a maximum?
A. I  B. II  C. III  D. IV  E. V

14. At what point would the net force acting on the object be zero?
A. I  B. II  C. III  D. IV  E. V

15. At what point would the object have the most kinetic energy?
A. I  B. II  C. III  D. IV  E. V

16. If the object had had only half as much mass, it would have vibrated up and down about point
A. I  B. II  C. III  D. IV  E. V

Questions 17-18 relate to three identical metal spheres, X, Y, and Z.
X is given a positive charge and placed in a fixed position. Y is touched to X so that the two spheres share the positive charge and then Y is placed 10 cm from X. Z is then touched to Y.

17. If Z is placed midway between X and Y, what will be the value of the ratio \[ \frac{\text{force exerted on } Z \text{ by } X}{\text{force exerted on } Z \text{ by } Y} \]
X, Y, and Z are now placed at the corners of an equilateral triangle. The vectors below represent some of the possible net electric forces on sphere Z as the charges of spheres X and Y are varied. For question 18, assume that sphere Z has a constant positive charge.

18. Which vector may represent the force on Z when X is positive and Y is negative with the magnitude of the charge on X less than that on Y?

A. I  B. II  C. III  D. IV  E. V
STUDENT ATTITUDE QUESTIONNAIRE

ATTITUDE TOWARD COMPUTER SIMULATED EXPERIMENTS

You have just completed an investigation using computer simulated experimentation as a technique for generating data. Following are 15 statements about computer simulated experiments. Consider each statement separately and indicate the extent to which you agree or disagree with it by circling the appropriate symbol to the right of the statement. The symbols are: SA - Strongly Agree; A - Agree; N - No Opinion; D - Disagree; and SD - Strongly Disagree.

1. Getting data from the computer is just like doing a real experiment.

SA A N D SD

2. I had more control over a computer simulated experiment than over an actual laboratory experiment.

SA A N D SD

3. Working with laboratory equipment and taking a sample set of data would aid in understanding computer generated data.

SA A N D SD

4. I get more flustered working with the computer than with laboratory equipment.

SA A N D SD

5. I like to do experiments with laboratory equipment.

SA A N D SD

6. I like to do experiments with laboratory equipment and then collect data using the computer.

SA A N D SD

7. I like to do experiments using computer simulations of experiments alone.

SA A N D SD

8. I become discouraged when a computer terminal isn't immediately available.

SA A N D SD

9. I can work at my own speed while doing a computer simulated experiment.

SA A N D SD

10. I can work at my own speed while doing an actual laboratory experiment.

SA A N D SD

11. The use of computer simulated experiments cause me to feel isolated.

SA A N D SD

12. I feel more involved when doing computer simulated experiments than when doing actual laboratory experiments.

SA A N D SD
13. The use of the computer as a calculator to solve problems is more important than the use of the computer to generate laboratory data.

14. Laboratory problems can be investigated more thoroughly using computer simulated experimentation than by the usual way.

15. Computer simulated experiments will tend to dehumanize the science laboratory.
APPENDIX E

LABORATORY/SIMULATION SHEETS
Newton's Laws

This experiment is designed to provide data that will permit you to develop Newton's Law of motion. The law involves a relationship or relationships between the force acting on a body, the mass of the body, and certain motion variables such as displacement, velocity, and acceleration.

Laboratory

In the laboratory, the experiment will be performed on the air track (2 meters long) using masses hanging over the edge of the track to accelerate the cars on the track. A diagram is shown below.

\[ F = \frac{M_{\text{car}} \times M_2 \times 9.8 \text{ m/sec}^2}{M_{\text{car}} + M_2} \]

The mass of the car can be changed by changing cars. The displacement and time can be measured using the wax tape and the spark timer. A stopwatch can be used to measure the time involved.

Your problem will be to decide what data should be collected, how it should be collected, and how it should be analyzed. See experiment III-2 in the lab manual.

Simulation

The program simulates the action of a body sliding across a frictionless surface. The body starts from rest at the X = 0 meters coordinate and accelerates until it reaches some coordinate selected by you. In addition, you select the mass of the body in kilograms, and the force acting on the body in newtons. A diagram of the experiment is shown below.
The computer will ask you to input the mass of the body, the force acting on it, and the coordinate at which the force stops acting. You should input this data in the form of MASS, FORCE, and LENGTH. The data must be in decimal form and no units are to be used.

The computer will automatically divide the time required for the body to travel the selected distance into ten equal intervals unless you want to use a different time interval. If you do want to use a different time interval, the computer will furnish information for the first 20 intervals or until the body reaches your chosen coordinate. You will be asked if you want to select a time interval. Enter a 1 for yes or a 0 for no. If a 1 is entered, input your selected time interval when the computer asks for it. The input data must be in decimal form.

Various output options are available. These include the time measurements until the body reaches your chosen coordinate and the body's:

1. Displacement
2. Velocity
3. Acceleration
4. Mass
5. Displacement and Velocity
6. Displacement and Acceleration
7. Displacement, Velocity, and Acceleration
8. Displacement, Velocity, Acceleration, and Mass
9. Velocity and Mass
10. Acceleration and Mass

Select the number corresponding to the output variable you want to investigate. When the computer asks for your output variable, input the corresponding number.

The computer then proceeds to generate data like you might collect in a typical laboratory experiment. The laboratory analysis should be done in the usual manner. See experiment III-2 in the lab manual.

Records

From this point on, please keep an accurate record of time spent in:

1. Setting up the apparatus and performing the experiment 

2. Performing the simulation

3. Analyzing the data
Conclusions and Explanations
A SPRING EXPERIMENT

This experiment and/or simulation involves a study of the action of a mass on a spring oscillating in the Earth's gravitational field. You will investigate the relationships between the spring constant, the attached mass, and the release position and the motion of the mass (acceleration, velocity, and displacement) and the energy (gravitational potential energy, kinetic energy, and spring potential energy).

Laboratory

You will work with two different springs to investigate the experimental relationships.

1. Attach a ringstand to the desk top with a C-clamp. Attach a recording timer to the desk drawer below the ringstand. Hang a spring from the ringstand and hang known masses up to a maximum of about 1 kg and find the extension \( x \) in meters as a function of force in newtons. Find the spring constant \( K = F/x \) from the slope. Do the same for the second spring.

2. Determine the period of oscillation of different spring-mass combinations.

3. Hang the brass spring from the ring stand and attach a known mass to it. Locate the coordinate of the rest position. Pull the mass a few centimeters below the rest position, attach the timer tape to it, start the timer, and release the mass. Use the timer tape to determine the displacement, velocity, and acceleration graphs. Use the displacement and velocity graphs to determine the potential energy of the spring, gravitational potential energy, and the total energy. Determine how the variables depend on spring constant, mass attached to the spring, and distance from the rest position.

Simulation

You will work with the 'Spring' simulation to obtain data related to the behavior of oscillating springs. You will select and input data values for the spring constant, the mass attached to the spring, and the height to which the mass is raised above the rest position before it is released. The computer provides the position, velocity, and acceleration of the mass at various intervals for one period.

1. Determine the period of oscillation of different spring-mass combinations.

2. Prepare displacement, velocity, and acceleration graphs.

3. Prepare graphs of spring potential energy, gravitational potential energy, and total energy.

4. Determine how the above variables depend on spring constant, mass attached to the spring, and the distance from the rest position.
Time

Please keep an accurate record of the time spent in performing the experiment, performing the simulation, and analyzing the data collected.

Experiment __________
Simulation __________
Analysis __________
Conclusions and Explanations
THE COULOMB EXPERIMENT

This experiment is designed to provide data that will permit you to develop a relationship or relationships between the force experienced by a charged body from a second charged body, the magnitude of the charges, and their separation. One simple method of performing the experiment involves measuring the force on a charged body by balancing it against a known force, the force of gravity. A small charged sphere is suspended from an insulating thread and another charged sphere is brought close to it. From the deflection of the suspended sphere from the vertical, we can measure the electric force on it in terms of its weight. For a more detailed description of the experiment, see experiment IV-3 in the lab manual.

Laboratory
Perform the experiment as suggested in the lab manual.

Simulation
The program simulates experiment IV-3 as described above. A charged metallic sphere on an insulating stand is brought close to an identical charged metallic sphere on an insulating thread 25 cm. long. A random charge will be placed on the spheres. Your input will include six stand sphere positions and the mass of the suspended sphere.

The computer will ask you to input six stand positions you would like to investigate. These stand positions should be in the form of \( X_1, X_2, X_3, X_4, X_5, \) and \( X_6 \). They must be in decimal form and not greater than 5 centimeters.

The computer will ask you to input the mass of the spheres in grams. To be realistic, the mass must be less than 100 grams. Input the mass in grams in decimal form. Do not use any units.

The computer then calculates the position of the suspended sphere for each of your suspended sphere positions.

At the conclusion of each trial, you may elect to reduce the charge on the stand spheres by \( 1/2 \) to permit you to investigate the relationship between force and charge. This would correspond to touching the stand sphere to an identical uncharged sphere.

The laboratory analysis should be done as described in experiment IV-3.

Records
From this point on, please keep an accurate record of time spent in:

(a) Experiment
(b) Simulation
(c) Analysis
This experiment is designed to provide data that will permit you to determine the magnitude of the elementary charge and the relationships between electric force, plate voltage, plate separation, and number of charges. The experiment involves a study of the motion of small plastic spheres which are acted on by electric forces and by gravity. The electric force is produced by parallel metal plates. The small plastic spheres reach terminal velocity very quickly. The terminal velocity is proportional to the driving force acting on them. Since the net force acting on the spheres is the sum of the electric and gravitational forces, the effect of the electrical force can be found by subtracting the effect of the gravitational force.

**Laboratory**

Perform experiment IV-6 as described in the laboratory manual.

**Simulation**

The program simulates the motion of small plastic spheres in an electric field. The spheres have a mass of $2.86 \times 10^{-15}$ kg. and have a diameter of 1.8 microns. The spheres free-fall at 0.0943 mm/sec. You input the applied voltage and the plate separation. The applied voltage is in volts and the plate separation is in millimeters. The input data must be in decimal form. The computer generates the distance traveled by ten spheres in one second (velocity). The analysis will be done in the manner described in experiment IV-6.

**Records**

From this point on, please keep an accurate record of time spent in:

(a) Experimentation

(b) Simulation

(c) Analysis
Conclusions and Explanations
APPENDIX F

COMPUTER PROGRAMS USED IN THE STUDY
01D: Simple Data Description output includes:
(1) Means
(2) Standard deviations
(3) Standard errors of means
(4) Maximum values
(5) Minimum values
(6) Ranges
(7) Sample sizes

02R: Stepwise Regression output includes:
(1) Multiple R
(2) Standard error of estimate
(3) Analysis-of-variance table
(4) For variables in the equation:
   (a) Regression coefficient
   (b) Standard error
   (c) F to remove

01V: Analysis of Variance for One-Way Design output includes:
(1) Optional listing of the group or treatment means and standard
deviations
(2) An analysis-of-variance table including:
   (a) Within groups, between groups, and total sums of squares
   (b) Within groups, between groups, and total degrees of freedom
   (c) Within groups and between groups mean squares
   (d) F ratio

X69: Multivariate Analysis of Variance and Covariance output includes:
(1) Covariance matrix for each analysis of variance component
(2) Cell means for each variable
(3) For each univariate analysis of covariance:
   (a) Regression coefficients under each hypothesis
   (b) Analysis of variance table including source, sum of squares, mean square, degrees of freedom, and F statistic for each analysis of variance component of the model and each covariate
   (c) Adjusted cell means
The output of the Clyde Program includes:

1. Description of the problem including listing of title, number of variables, criteria, and covariates, and degrees of freedom in the subgroups of each factor.

2. Cell means, unbiased standard deviations and number of observations, identified by cell

3. Reduced model matrix

4. Correlations of effects

5. Test of equality of regression coefficients for all cells in analysis of covariance.

6. For a univariate analysis of variance a single ANOVA table is printed. Each error term is followed by the test of regression if there are covariates, and the hypotheses tested against the error term. These tests are adjusted for any covariates. The estimates of the effects in the complete model and any regression coefficients follow.
BIBLIOGRAPHY


Hansen, Duncan N. *The Role of Computers in Education During the 70's.* Tallahassee: Florida State University, CAI Center, 1970. ED 043 238.


