Evaluation Study of an Innovative Course Design in High School Physics

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EVALUATION STUDY OF AN INNOVATIVE COURSE DESIGN IN HIGH SCHOOL PHYSICS

A DISSERTATION SUBMITTED TO THE FACULTY OF THE GRADUATE SCHOOL OF LOYOLA UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

BY

BETTYJEAN HOULIHAN

CHICAGO, ILLINOIS

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In addition, I would like to express my gratitude to Mr. Daniel Levy and Sr. Mary Agnes Corcoran, O.S.M. for helping me organize the data in its final form. I am also most appreciative of the dedication and efficiency of my typist, Ms. Joan Kubisiak. Mr. James Jackomiec, of Loyola Academy High School's physics department also provided invaluable support throughout this project. Finally, I would like to thank my husband Kevin for his objective advice and understanding sympathy.
VITA

Bettyjean Houlihan was born on May 29, 1944. She attended school in the Chicago area, and graduated from Evanston Township High School. Her participation in an early tryout program of Physical Science Study Committee physics course, during her junior year in high school, awakened her interest in facilitating learning in this subject.

These subject specialties were continued during Mrs. Houlihan's education at Northwestern University, where she received her B.S. degree in Electrical Engineering. She also received her M.S. from Northwestern in this subject, specializing in microwave theory, and was awarded an Amelia Earhart Fellowship for Women in the Aeronautical Sciences. In addition, Mrs. Houlihan chose to do graduate coursework in the French language and literature at Northwestern University, and undergraduate coursework at Loyola's University College leading to teaching certification requirements.

An interest in wave theory and modern physics, and her own experiences teaching mathematics and the physical sciences stimulated Mrs. Houlihan's interest in educational research in this area. She taught Physical Science at Alvernia High School in Chicago, Illinois, and a number of mathematics and general education courses at Northeastern Illinois State College and Loyola University between the years of 1967 and 1974. She has a special interest in facilitating the learning of technical subject matter for the student of average aptitude.
# TABLE OF CONTENTS

ACKNOWLEDGEMENTS ........................................ ii
LIST OF TABLES ............................................. vi

Chapter

I. INTRODUCTION TO THE STUDY ................................. 1
   A. Rationale for Proposed Research ......................... 1
   B. Basis in Educational Psychology ......................... 2
   C. Definition: The Functional Approach ...................... 3
   D. Criteria for Experimental Course ......................... 4
   E. General Statement of Hypotheses ......................... 5
   F. Significance of the Study ............................... 6

II. REVIEW OF THE LITERATURE ................................. 8
   A. Factors Suggesting the Need for Innovation .............. 8
   B. An Assessment of Current Attempts to Innovate ........... 19
   C. Present Responses to These Innovations .................. 26
   D. Evaluation of Existing Physics Curricula ................. 36
   E. Other Problems Specific to the Teaching of High School Physics ....... 41
   F. Conclusion ........................................... 45

III. RESEARCH DESIGN .......................................... 48
   A. Overview ............................................. 48
   B. Measurement Instruments .................................. 48
   C. Description of Textbook ................................ 49
   D. Classroom Program--Specific Teaching Devices .......... 52
   E. Classroom Program--Time Scheduling Considerations ..... 56
   F. Distinguishing Traits of Experimental Course .......... 59
   G. Major Considerations for Administering Experimental Program .... 61
   H. Anticipated Extraneous Variables ......................... 66
   I. Limitations of the Experiment ............................ 68
LIST OF TABLES

1. Reasons for Non-enrollment in Physics .................. 9
2. Curriculum Interactions .................................... 29
3. Weekly Activities of 17 Schools Reporting For An Average of 12 Weeks Per School ...................... 30
4. Significant Variables of Teaching .......................... 39
5. Cognitive Test Scores ....................................... 90-91
6. Classroom Program Ratings: School 1, February ....... 107
7. Classroom Program Ratings: School 2, February ....... 108
8. Classroom Program Ratings: School 1, End of Course .... 109
9. Classroom Program Ratings: School 2, End of Course .... 110
10. Classroom Program Ratings: School 1, January ........ 111
11. Classroom Program Ratings: School 2, March ........ 112
TABLE OF CONTENTS OF APPENDIXES

Appendix

<table>
<thead>
<tr>
<th>Appendix</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Copies of Questionnaires</td>
<td>157</td>
</tr>
<tr>
<td>B</td>
<td>Excerpts from the Basic Concepts of Physics Text</td>
<td>190</td>
</tr>
<tr>
<td>C</td>
<td>Pretest Questionnaire Data, School 1</td>
<td>204</td>
</tr>
<tr>
<td>D</td>
<td>Pretest Questionnaire Data, School 2</td>
<td>238</td>
</tr>
<tr>
<td>E</td>
<td>February Questionnaire Data, School 1</td>
<td>268</td>
</tr>
<tr>
<td>F</td>
<td>February Questionnaire Data, School 2</td>
<td>357</td>
</tr>
<tr>
<td>G</td>
<td>End of Course Questionnaire Data, School 1</td>
<td>446</td>
</tr>
<tr>
<td>H</td>
<td>End of Course Questionnaire Data, School 2</td>
<td>568</td>
</tr>
<tr>
<td>I</td>
<td>January Questionnaire Data, School 1</td>
<td>687</td>
</tr>
<tr>
<td>J</td>
<td>January Questionnaire Data, School 2</td>
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</tr>
<tr>
<td>K</td>
<td>March Questionnaire Data, School 2</td>
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</tr>
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</table>
Chapter I

Introduction to the Study

Rationale for Proposed Research

The purpose of this study is to apply current insights in instruction to the high school physics course. The experimental course which is to be evaluated in this research project was designed by the investigator; it is designated the "functional approach" to teaching high school physics. The Basic Concepts of Physics textbook utilized here incorporates a structured outline format organized around the major conceptual categories of "Newtonian Physics," "Energy," "The Field," "The Wave," and "Modern Physics." Inessential and anecdotal learning materials have been eliminated from the textbook format.

The teaching methodologies utilized in this experimental course have been chosen for the purpose of adapting the subject matter to the capabilities of the mathematically inexperienced, beginning physics student. Basic classroom strategies include an emphasis on problem-solving instruction, an advance organizer lecture plan for introducing new learning material, and the use of summary charts and planned review sessions. The appropriateness of the textbook format and classroom approach as learning facilitators has been substantiated by research in educational psychology.
Results of this study have been evaluated in the affective as well as the cognitive domain. In this study, it is considered to be of prime importance that the student attain the personal self-confidence as well as the technical know-how to continue his studies in physics. It will be of interest to the investigator specifically to evaluate a number of different innovations comprising the classroom program and textbook format. Insofar as possible, these findings will be interpreted and generalizations derived regarding the appropriateness of particular facets of the experimental course to students with different interest areas and ability levels.

Basis in Educational Psychology

Specific teaching techniques utilized in this course have been chosen in accordance with the learning theories of Ausubel. Ausubel and Robinson (1969) state that classroom teaching will be more effective if a number of special learning devices are utilized; these devices include the provision in the classroom for early review, student self assessment, repeated practice, explicit problem-solving instruction, and the reformulation of major concepts in the student's own words.

Also included in the format of the textbook designed for this course, and substantiated by the learning theories of Ausubel, are the following emphases:

(a) The use of advance and perceptual organizers;
(b) Provision for the overlearning of essentials;
(c) An organization based on the underlying concepts of
physics;
(d) An emphasis on clarifying interrelationships.
The specific applications of the methodologies to the course design are described in chapter three, "Classroom Program--Specific Teaching Devices."

Rejected in this course design (in accordance with the same learning theories) are these emphases:
(a) Student discovery of intuitive type insights;
(b) A historical perspective on the science of physics.

It can be noted that the nationally recognized Physical Science Study Committee course is geared to student discovery of intuitive type insights, and the more current Harvard Project course is based on a historical perspective of the science. These techniques seem more suitable for motivating certain types of students than for assuring that all students gain technical competency in high school physics.

Definition: The Functional Approach

The functional approach embodied in this course is designed to facilitate learning by emphasizing the use or application of new learnings, as opposed to memorizing or describing factual material. This is simply a common sense, or utilitarian approach to learning. It is especially necessary for the introduction of a technical discipline. In accordance with this emphasis, the text describes (a) how each physical concept relates to other theoretical material; (b) how each concept is applied in problem solving situations; (c) and, where applicable, how each
new theoretical formulation is regarded by modern physicists in terms of completeness and accuracy. Significant in this innovation is the effort to demythologize the science. Emphasis is placed on the logic, coherence, and significance of physics formulations, rather than on the exceptional or intuitive insights or the "greatness" of such learnings.

Criteria for Experimental Course

The textbook and classroom instructional format of the experimental course were designed with these criteria in mind:

1. Flexibility: The experimental course should be adaptable to the learning characteristics of the students, as well as to the backgrounds and biases of the teachers.

2. Maximal use of learning aids: These include planned review, classroom problem-solving practice, classroom practice in the verbal expression of physics concepts, and feedback from students in the planning of instruction.

3. Realistic time scheduling: The text is sufficiently condensed and the time schedule sufficiently flexible, so that the experimental course can reasonably be completed in the time available.

4. Inclusion of modern physics material: The inclusion of learning material in modern physics is to be made possible by realistic time allotments and a more condensed and adaptable textbook format; it has been noted by the investigator that the high school physics teacher habitually devotes the entire first semester to the study of mechanics and seldom touches upon the
modern physics material in the last section of the text.

5. Use of charts and organizers: The use of these learning facilitators is in accordance with the instructional theories of Ausubel.

6. Incorporation of feedback from teachers in classroom planning: Revision of the classroom instructional plan has been anticipated, based on feedback from the participating teachers.

7. Basis in educational psychology: Though the two major innovative physics courses (Project Physics and PSSC) were designed to be motivating, they are not based on premises of educational psychology that deal with facilitating the learning process. This experimental text and classroom plan are based on a systematic application of current insights on learning technical subjects. This is considered to be especially necessary in an introductory physics course.

General Statement of Hypotheses

Three major areas for evaluation have been chosen in this study: cognitive achievement of students; affective reaction of students toward course materials and classroom program; and reactions of participating students to the experimental course. The experimental course (as designed by the researcher) is compared to the so-called "traditional" or control course, which will be taught as usual by the participating teachers.

In the early units of this course, feedback on the classroom program was requested from the teachers, so as to be in-
corporated into future units. In the early units, this experiment also included a formative evaluation process.

The null hypothesis is that of no difference in scores or distributions between experimental and control courses. This was tested against these alternative hypotheses:

1. Superior cognitive achievement in each of four subject areas in the experimental course as measured by the Harvard Project Achievement Test series; superior achievement in the experimental course in the comprehensive Dunning Physics Test;

2. More favorable affective reaction of students toward the experimental course measured by questionnaires constructed by the investigator. Emphasized here will be student evaluation of subject matter selection and classroom program in terms of the previous expectations of students, the general interest and difficulty level of learning material, the student's anticipated success in the course, and the course's applicability to, and effect on students' future career plans;

3. A favorable reaction of the participating teachers toward the textbook materials developed by the investigator;

4. A favorable reaction of the participating teachers toward the classroom program developed by the investigator with the help of feedback from these teachers.

Significance of the Study

It is hoped that the recent attrition in enrollment for high school physics courses\(^1\) can be countered by the development of a course that is realistically geared to the capabilities of
the usual high school physics student. Simultaneously, this course would provide motivation through emphasis on current research material, and competent preparation for future studies.

Though it is recognized by the investigator that this attrition in enrollment is in part a reflection of increased emphasis on the humanities and social sciences in current priorities among our students, it is felt that the reputation which precedes so many high school physics courses is also partly responsible for this attrition. Also, if indications are forthcoming that this experimental course is indeed effective, a complementary laboratory program emphasizing humanitarian applications of the science in environmental and bio-medical engineering is recommended.
Chapter II

Review of the Literature

Factors Suggesting the Need for Innovation

The need for innovation and revitalization in the high school physics curriculum has been cited in much of the literature. The attrition in student enrollment of which educators have been aware since the early sixties has been labeled the "Physics Education Crisis" (School and Society, 1964).

Abegg and Crumb (1966) undertook a questionnaire research project on this problem. A questionnaire was distributed to the chemistry classes of four selected high schools, since normally physics follows chemistry in the high school science sequence. Although only 50 of the 1049 students who responded had not and would not take the high school biology course, it was found that 467 would not enroll for physics. Reasons given for non-enrollment are shown in Table 1.
TABLE 1

Reasons for Non-enrollment in Physics

<table>
<thead>
<tr>
<th>Reasons</th>
<th>Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Graduating 12th graders</td>
<td>50</td>
<td>10.57</td>
</tr>
<tr>
<td>Scheduling problem</td>
<td>56</td>
<td>11.83</td>
</tr>
<tr>
<td>No interest in physics</td>
<td>121</td>
<td>25.58</td>
</tr>
<tr>
<td>Not necessary for future vocation</td>
<td>135</td>
<td>28.54</td>
</tr>
<tr>
<td>No reason stated</td>
<td>50</td>
<td>10.57</td>
</tr>
<tr>
<td>Poor background for physics</td>
<td>61</td>
<td>12.89</td>
</tr>
</tbody>
</table>

It is indicated here that the high school physics course fails to evoke interest in, and/or appears as though it would be too difficult for a large number of students. Milson (1972) deals with physical science curriculum materials designed to improve the attitudes of below average students toward the subject. Bridgham (1969) attempts to correlate physics enrollments and grading practices, which are reputed to be and actually often are more severe for physics than for other high school electives. "It is ironic," states Bridgham, "that vast sums of money have been spent on the improvement of instruction in physics and the result appears to be a relative loss in the percentage of students enrolled in physics (p. 44)." The results of Bridgham's study were inconclusive. An exception was a $p < .02$ correlation between the questionnaire item "If it were possible I would take another physics course next year (p. 44)," and an adjusted mean
Jordan (1971) conducted a survey of seniors taking physics and seniors not taking physics in four high schools in the Toledo, Ohio, area. He found the following:

(a) "Apparently 80% or more of the high schools have students taking physics that are better achievers than the average non-physics student in that school (p. 697)."

(b) A "nearly direct proportionality that exists between socio-economic level and enrollments in physics courses (p. 698)."

(c) "The students taking physics are in most cases college bound and when compared with fellow non-physics, college bound students' interest in science ranks higher (p. 699)."

From his data, Jordan concludes that the "present physics course is undesirable for non-science majors (pp. 699-701)."

Dietrich and Pella (1974) conducted a comparative study of student and teacher characteristics in Wisconsin secondary schools. They surveyed those with a relatively high student population enrolled in physics, as contrasted with low enrollment schools. The researchers found that 65% of the high enrollment schools offered a choice of physics courses, whereas none of the low enrollment schools offered more than one course. The guidelines offered by this result, however, may not be useful in those cases where the student enrollment is too low to permit differentiated course offerings.

There were a large number of no difference results found
Dietrich and Pella in this study -- specifically, in terms of academic preparation of teachers, teaching load, etc., and student IQ and grade point averages. The researchers do conclude that "there seems to be some evidence that the students who plan to go to college take courses in physics (p. 11)," though this decision may be more relevant to the past, "rather than present and future requirements of colleges and universities (p. 12)." Dietrich and Pella conclude this report by recommending further research in the area of "student's personal interests and fears (p. 12)."

It is reported (School and Society, 1964) that "America is facing a severe crisis in its physics education (p. 301)." In a report prepared in 1964 under a National Science Foundation grant, projective statistics were utilized to indicate a trend toward a shortage of trained physicists. Also in this source it is stated that "there is an extremely serious shortage of adequately trained elementary and high school physics teachers, and if present trends continue, no relief from the shortage is in sight (p. 301)." The accuracy of this prediction is supported in the Harvard Project Physics Newsletter (1971), which states "the number of students in public senior high schools taking any variety of introductory physics course was, according to the most recent available statistics of the U.S. Office of Education, only 485,000, less than 20% of the total number of seniors in high schools (p. 4)." It follows that a shortage of physicists and of physics teachers will be joint results of a long term
attrition in student enrollment in this subject.

Current efforts to revitalize the curriculum are being made by the CPPE (Committee on Physics in Pre-College Education). Formed from the Committee on Physics in Secondary Education in 1972, the CPPE describes its function as follows:

The long term, all inclusive goal of the Committee on Physics in Pre-College Education is to greatly improve the pre-college environment for education in science for all the people and to find many ways to implement significant increases in physics literacy (p. 272).

The CPPE is also involved with teacher preparation programs, coordination of physics education in elementary and high schools, encouraging the development of curriculum materials, providing input on physics education to administrators and school boards, and developing materials for guidance counselors on the role of physics in society. (The Physics Teacher, 1973)

A problem specific to the physics curriculum is the advisability of developing a college-preparatory versus a terminal course, or a course adaptable to either type of preparation. Even amidst the space age push of the late fifties, Swales (1957) recommended that "administrators and school boards would be doing a real service to their community in re-evaluating their science needs and placing in their curriculum an additional course in physics for the non-college-preparatory students (p. 222)." And there is the difficulty inherent in developing a
course that fulfills the dual role of motivating students and giving them adequate technical preparation in the subject. Welch (1969) conducted a course satisfaction study with Harvard Project physics students. This study utilized a course satisfaction scale (students agree or disagree with statements made by their peers), a semantic differential, and various cognitive achievement measures. It was concluded that "satisfaction is related to achievement gains, greater participation in science activities, and course grades. It is negatively related to perceived course difficulty (p. 58)."

The difficulties inherent in motivating and communicating this technical subject on a high school level lead to the consideration of a number of aspects of the learning situation. Specifically, teacher behavior is considered in terms of verbal explanation (lecturing/soliciting response; construct/system/meaning) (Ivany and Oguntonade, 1972), teaching duration (time spent on one unit of material) (Welch and Bridgham, 1968), and teacher personality attributes (Walberg and Welch, 1967-68; Rothman, Welch, and Walberg, 1969). Also attitude and personality factors pertaining to the student of physics have been considered (Congdon, 1964; Walberg, 1969). In their study of "Verbal Explanation in Physics Classes," Ivany and Oguntonade conclude that "constructs are the most frequently used explanatory tool, while lecturing is the most prevalent mode of verbal explanation in our sample of high school physics teachers (p. 358)." They recommend that "teachers need specific training
in (1) the purposive use of verbal strategies to probe students' cognitive maps; (2) the use of appropriate and realistic analogies and (3) the use of historical accounts of scientific investigations to illustrate the epistemological foundations of physics (p. 358)."

Welch and Bridgham (1968) consider "Physics Achievement as a Function of Teaching Duration" in a study related to suggested scheduling of the Harvard Project course. They found that extra time spent on a unit was neither a function of student ability, nor did it necessarily lead to increased (cognitive) test scores on the unit test for that material.

Walberg and Welch (1967-68), and Rothman, Welch, and Walberg (1969) studied personality characteristics in physics teaching and attempted to correlate these characteristics with student learning. Owing to the small sample size (35 male teachers) and the difficulty of interpreting results dealing with such personality characteristics as altruism and friendliness (Walberg and Welch, 1967-68) or dominance and heterosexuality (Rothman, Welch, and Walberg, 1969), the results of these studies seem only minimally applicable to the improvement of instruction.

Congdon (1964) studied personality factors of students and their parents, seeking correlation with completion versus dropout in an introductory physics course at a state technical college. His study is difficult to interpret since his overall tendency to equate such personality traits as maturity, seriousness, responsibility, self-control, and self-acceptance
with the success index of completion of introductory physics must be questioned.

Walberg's attempts to correlate preferred seating positions with students' attitudes toward the high school physics course may be more useable for the teacher. Walberg (1969) suggests that "astute teachers may consciously or unconsciously induce the relationship between physical and psychological distance and make probable inferences about student characteristics (p. 70)." These previously cited studies represent an attempt to quantify variables of teacher and student behavior that are significant to the teaching of physics.

A dissertation study of the Nebraska Physical Science Project (Douglas, 1973) dealt with the effect of teacher variables such as directiveness, motivator role, and disciplinarian role on student achievement. The Nebraska Physical Science Project is an integrated two-year physics/chemistry course with instructional materials sequenced around behavioral objectives and geared for individualized study. One significant result of the study was the suggestion that increased teacher directiveness is associated with a higher level of student confidence as indicated by the "Test on Understanding Science." Also, the researchers concluded with the advocacy of the motivator-role as most appropriate for the teacher. Owing to the large number of nonsignificant results in this study, the final recommendation was that teachers were to feel free to adopt a variety of instructional approaches.
The difficulties being faced at present by our high schools in making the best usage of available course materials are typified by efforts to:

1. Offer as many different physics courses as possible.

One large suburban high school in the Chicago area gives courses in Project Physics, 2 Chem-Phyx, 3 Chem-Phyx, 4 Chem-Phyx Honors, 4 Chem-Phyx AP (advanced placement), 4 Physics and Honors Physics. Another suburban school in this area offers Project Physics, Physics, and Physics AP.

2. Combine material from a number of course curricula, or utilize a number of textbooks, in attempting to develop a course that is tailored to an average class comprising terminal and non-terminal students. At one Chicago public high school, the Physical Science Study Committee and Harvard Project curriculum materials are combined so as to provide, in the opinion of the instructor, a more optimal curriculum than either course alone would offer. Two teachers from another city school have developed much of their own teaching material, including a repertoire of classroom demonstrations. They find the current textbooks to be useful for assigning problems, but inadequate for other teaching purposes.

3. Adopt a different type of alternative plan as suggested by Euller and Smith (1973). At Eastridge High School in New York, the researchers have abandoned the previous differentiated course offerings and now offer only a single, individualized physics course. A student can follow any one of the three available
content streams: PSSC, Project Physics, or New York State Regents' Physics. Students have some choice of supplementary learning activities. They are graded both on the basis of test scores and optional projects undertaken according to the designated grade option plan. Available for reference are the texts by Taffel, White, Genzer, Lehrman, and Marantz, as well as the PSSC and Project texts. The major portion of the teacher's preparation time is devoted to preparing and revising study guides; it would seem that an individualized project on this level of sophistication can be best accommodated by the larger high schools. Students are responsible for completing each six week block of learning material within fixed deadlines; options such as retakes on examinations for failing and low-scoring students are also offered.

Euller and Smith report pros and cons of this alternative plan. A pro is that "The majority of students show a definite preference for the freedom of choice in content, time, movement, and tasks that the course provides (p. 102)." A con is that "many pupils who are accustomed to blaming the teacher or the school for their failure are uncomfortable in the new role. The negative effect is compounded when habitually passive pupils see the teacher steadfastly refuse to go through the motions the pupil identifies as 'teaching' (i.e., telling the class what to do) (p. 102)." But the researchers are optimistic about this classroom plan, "As teachers, we are aware of a profound change in the psychology of the classroom. The role and strategy of the
Student have changed from passive receiver of information to active participant in the planning and process of his own learning (p. 102).

4. Offer special types of more motivating courses for non-physics majors. Gerson (1973) describes Physics III, a course titled "The Laws of Physics and Man's Environment" which was offered at the University of Missouri. The course outline was divided into these major topics: "Introduction," "Large-Scale Physics," "The Physics of Man," and "The Physics of Civilization." States Gerson, "No attempt was made to teach the usual first-course topics of vectors, center of gravity, Archimedes principle, momentum, projectile motion, etc. (p. 237)."

This solution of changing the typical orientation of the physics course should, perhaps, receive more attention than it has. But this type of course is considered acceptable only for non-science majors. And, concludes Gerson "on the question of whether a course modeled on Physics III can be maintained as part of the curriculum, I do not believe that this can be done for the small number of humanistic-social science students at our school (p. 237)." In other words, special courses are considered to be best suited to larger schools.

It can be concluded that the problems enumerated above (specific to the development of an appropriate high school physics curriculum) include these: (a) attrition in student enrollment, (b) lack of adequately trained teachers, and (c) the confusion associated with the selection and combination of course content, textbooks, and demonstration, laboratory and other
appropriate materials for the mathematically sophisticated and unsophisticated, terminal and non-terminal student.

The first current attempt to solve these problems was launched in 1957 with the development of the Physical Science Study Committee course program. This and subsequent attempts at solution will be discussed in the following pages.

An Assessment of Current Attempts to Innovate

The PSSC (Physical Science Study Committee) curriculum was developed in the 1950's by collaboration among high school and college personnel. It was said by Sawyer (1965) that, "the program stresses development of the ability to reason and makes many provisions for reinforcement of learning. Deeper treatment of fewer topics is provided. Emphasis is on laboratory work which, with relatively simple materials, is made a learning experience. It is a complete course, with special texts, laboratory materials, films, apparatus, and teacher guides. The PSSC program was designed to appeal to the able student who often plans to take physics in college. It is a challenging course for both students and teachers (p. 391)." The achievement of this college preparatory objective was disputed by Finger, Dillon, and Corbin (1965). They found that among students studying introductory physics during the 1963-64 school year at Brown University that, "If PSSC produces an advantage in the study of college physics, it cannot be detected in the differences among these (PSSC and non-PSSC) groups (p. 65)." The PSSC course was, however, widely adopted in the early sixties owing perhaps to the results of the
tryout year and to the space-age impetus of that time period.

During the tryout year of 1958-59, approximately 300 volunteer, institute trained teachers introduced this course to their students. These students were examined with PSSC achievement tests; Finlay (1962) reported it was decided that "an average performance of answering half the questions correctly would be regarded as a satisfactory achievement (p. 76)." This minimal criterion was met and the PSSC course materials were widely publicized. Thus, the PSSC text is now in its third revision.

The space age impetus of the late 1950's stressed technical proficiency; and Tomer (1958) states that "one of the assumptions of PSSC is that the high school student is better prepared to accept a high level physics course than is generally thought... (p. 494)." Learning material utilized in this course does, in fact, demand a high degree of mathematical and scientific sophistication, according to the results of a study conducted by Rathe (1965). In this study, an attempt was made to define the problem of student readiness for the PSSC course. Rathe compiled a list of 294 scientific generalizations, such as, "The force of attraction or repulsion between charged objects varies inversely as the square of their distance apart (p. 134)." He surveyed the opinions of 21 instructors as to whether the knowledge of each of these generalizations was necessary for students as a prerequisite to the PSSC course. He concluded that, "Two hundred twenty-three generalizations were identified as preliminary to and basic for those found in PSSC physics (p. 137)."
On the basis of this study, Rathe recommended that an integrated science program, involving preparation on the junior high level for the PSSC course, would be desirable.

The PSSC course has achieved only minimal acceptance among the nine Chicago area high school teachers interviewed by the investigator. Among these teachers, one uses the PSSC text for honors students, one uses it in conjunction with other texts, and none of the others utilize it at all. Welch (1968) states, "We have seen that the available information on the acceptance of the PSSC physics course is incomplete; figures are contradictory and without sound statistical basis (p. 233)."

In summary, the objectives of the PSSC program were to include in the curriculum:

(a) The cultural-historical background of physics;
(b) An experimental approach utilizing inductive and deductive reasoning;
(c) Discovery-oriented laboratory work;
(d) A realistic picture of current developments in high level physics;
(e) The use of simpler theories or models, which would later be proved incorrect, to build more complex theories;
(f) High level work in mathematical-physics problem-solving techniques.

In a doctoral dissertation, entitled "The Measurement of Concept Attainment: A Comparative Study of Modern and Traditional
High School Physics Courses (Barrett, 1970)," students enrolled in the PSSC course were compared with students enrolled in the traditional physics course (textbook: Physics: Its Methods and Meanings by Alexander Taffel). This comparison was based on a number of indices of concept attainment. These indices were constructed by Barrett and based on the determination of the cognitive level indicated in a problem-solving situation according to the classifications of Bloom's taxonomy. In his analysis of results, Barrett found interaction effects indicative of a differential effect of PSSC versus the traditional course; these effects were evidenced over the range of student intelligence quotients and concept knowledge scores. The concept knowledge score dealt with the memorization of factual information.

The sophistication of the statistical analyses utilized in this study helps to provide insights into the justification for individualized course offerings. But Barrett's decision to drop the student intelligence factor from his final analysis (in favor of the concept knowledge factor as the significant covariate) does not seem to be adequately substantiated. It would seem that a more in-depth battery of tests associated with the factor analysis procedure would be needed in order to justify Barrett's dropping of the intelligence factor. For this reason, the conclusion of this study, that greater concept attainment is achieved by high and average students and equal concept attainment by low students in the PSSC course, seems questionable.

The PSSC course is considered to be superior in technical
quality. It figured conspicuously among those course programs recognized by the High School Awards Committee of the American Association of Physics Teachers (Reitz, 1969). It is often used in combination with other curriculum materials, especially the Project Physics materials. Its primary drawback seems to be the over-inclusiveness of its aims and objectives, and as a result, the difficulty that this learning material poses for students. Tansey (1974) found that a contract teaching approach was considerably more effective than the "usual lecture-lab method (p. 213)" for utilization of PSSC materials with his 12 student honors class. And Reitz praises the Omaha Benson High School which directs its PSSC course to "those with particular mathematical strengths (p. 487)," but also offers an alternative course "directed at students with diverse interests and a wider range of capabilities (p. 487)."

The Harvard Project Physics course materials, published by Holt, Rinehart, and Winston, are an innovation of the early sixties. These materials represent an attempt to stress the humanitarian aspects of the science--historical and literary ramifications. As was stated in the New York Times Education Review (1973), "this innovative approach attempts to translate the wonders of the physical world into 'humanistic' and practical terms--to make them accessible and meaningful to the student, whether college-bound or not, who may never take another science course in his life." This innovation is marked by the variety of course materials available, which include student text and student handbook, readers, test booklets, programmed instruction
booklets, supplemental units, teacher guides, film loops, 16 mm sound films, and teacher training films. The Project Physics text itself includes reproductions of hand drawn graphs and diagrams which represent, again, the attempt to humanize the learning material.

The Project Physics course has been considered effective, based on data from a poll carried out in 1970 at Knox College, in increasing physics enrollment at 35 schools with "newly found" students (Harvard Project Physics Newsletter, 1971). This study confirmed the hope of the staff of Harvard Project Physics that, "this course will help stem the tide running against the study of introductory physics in secondary schools in the U.S. (p. 4)."

Questionnaires sent to teachers using the Project materials were assessed on the basis of 222 replies. Again, it was confirmed that students registering for the Project Physics course do not simply constitute "switch-overs" from regular physics or PSSC, but are students taking physics only because a different kind of course was offered.

Teachers who attended training institutes at San Diego State College reported that whereas 124 students registered for their Project Physics classes in 1967-68, there were 399 students taking Project Physics in 1968-69, and 1,231 students in 1969-70. It was concluded (Harvard Project Physics Newsletter, 1971) that, "A good portion of these increases can be attributed to the growing enrollment of girls (p. 6)." Jordan (1971) confirms this finding from his "Investigation into the Cause for Decreasing
Enrollments in High School Physics." He concludes, on the basis of a 14 item questionnaire distributed to students in four high schools, that, "Between 16% and 59% of those seniors not taking physics would have taken this (Harvard Project) physics course had it been offered (p. 701)." Walberg (1967) surveys boys and girls taking physics to determine sex differentiated interests in academic, nature study, tinkering, cosmology, and applied life aspects of physics. Girls scored higher on applied life and boys scored higher interest in cosmology; both these areas are given unusual emphasis in the Project course.

The development of Project Physics included a five year testing program (1964-69). The formative evaluation program was designed to revise course materials leading to the presently utilized editions. For the final phase of this evaluation program, Welch and Walberg (1968) suggested that these questions also be considered:

(a) "Is the average or below average student penalized in any way for electing to take physics his senior year?

(b) What factors are related to gains in understanding science as a result of a one-year study of Project Physics?

(c) What growth is experienced by students who are recruited into the study of high school physics? (p. 15)."

The summative evaluation phase utilized feedback from volunteer institute trained teachers. Welch, Walberg, and Ahlgren (1969) describe the attempt to offer teachers the option of volunteering for this program on a random sampling basis from
the population of teachers on the 1966 National Science Teachers Association list. Other research included a comparison of scores on the College Entrance Examination Board's physics achievement tests in 1969 and 1970 (Harvard Project Physics Newsletter, 1971) on which Project students scores were seen to be approximately the same as the total group average.

It can be noted that the Project Physics materials are also being used in some junior college introductory physical science courses. Also, in the larger Chicago area high schools where enrollment is sufficiently high as to justify a special Project Physics course, the Project materials are being used without being supplemented by more mathematically-oriented texts. However, the teachers interviewed by the investigator generally considered Project Physics to be a terminal course.

Present Responses to These Innovations

It was found by the investigator that textbooks being utilized at present in three Chicago area high schools (among which a total of 12 differentiated course offerings are available) include the Harvard Project text, Genzer and Youngner, Resnick and Halliday, Taffel, Richards, the PSSC text and Lehrman and Swartz. In two schools, the Project text is used only in a special course entitled Project Physics. Genzer and Youngner, Taffel, and Lehrman and Swartz are used in the regular physics courses; Resnick and Halliday (a college level book), and Richards are used in advanced placement physics; the PSSC text is used in the Honors Physics course, in one school only among those
The question of whether teachers prefer textbooks produced by one or two authors over the major Harvard Project and PSSC curriculum projects can be raised—certainly, the curriculum projects have not supplanted the use of other textbooks. This may indicate the need for a less specialized curriculum program—one that is neither predominantly historical, nor mathematical-technical, nor discovery oriented. Among those teachers interviewed, it was generally accepted that the reputation received by the course one year has a major bearing (20% to 30% of the total enrollment) on the number of students signing up for the course the following year.

It can be suggested that, in order to achieve widespread utilization, the high school physics text must be adaptable to a number of student learning styles and teacher-classroom methodologies. Andrews (1964) conducted a questionnaire study seeking correlation and interaction among college level and honors students and their preferred method of instruction. The pilot study conducted in 1964 comprised 76 students; a later study in 1970 included 100 students. She considered laboratory experiments, classroom demonstrations, classroom discussions, films, problems in text, summarizing review, questions in text, reports by pupils, projects done outside school, tests, work-sheets. She concluded that, "with an occasional exception, each method of instruction was considered by a least a few pupils to best attain the five goals of (1) preparation for the future;
(2) enjoyment; (3) learning; (4) interest; and (5) powers of thought. In short, one method of instruction appeared to one pupil to best attain a certain goal and another method of instruction appeared to another pupil to best attain the same goal (p. 156).

A more current attempt to assess practices in physics teaching was made by Ivany, Mullaney, Huegel, Faust, and Strassenburg (1973). This study involved a week long visit by a researcher to each of 42 high schools in the Northeast states, plus the collection of questionnaire data (including records of daily classroom activities) for each of these schools. These schools were initially drawn from a randomly selected list; in these schools a maximal diversity of physics teaching facilities was represented, with total physics enrollments varying from eight to 172. Also, annual outlay for the physics capital equipment varied from less than $5.00 per student to more than $15.00 per student. The following tables summarize their findings regarding course offerings and types of classroom activities utilized.
### TABLE 2.3

**Curriculum Interactions**

<table>
<thead>
<tr>
<th>Traditional (23):</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>&quot;Pure&quot; traditional,</td>
</tr>
<tr>
<td>10</td>
<td>Traditional with PSSC influence;</td>
</tr>
<tr>
<td>6</td>
<td>Traditional with PSSC and Project Physics influence.</td>
</tr>
<tr>
<td><strong>PSSC (14):</strong></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>&quot;Pure&quot; PSSC,</td>
</tr>
<tr>
<td>4</td>
<td>PSSC with traditional influence,</td>
</tr>
<tr>
<td>1</td>
<td>PSSC with Project Physics influence;</td>
</tr>
<tr>
<td>2</td>
<td>PSSC with traditional and Project Physics influence.</td>
</tr>
<tr>
<td><strong>Project Physics (5):</strong></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>&quot;Pure&quot; Project Physics;</td>
</tr>
<tr>
<td>1</td>
<td>Project Physics with some PSSC influence.</td>
</tr>
</tbody>
</table>
### TABLE 3
Weekly Activities of 17 Schools Reporting
For An Average of 12 Weeks Per School

<table>
<thead>
<tr>
<th>Activities</th>
<th>Percent of time per week devoted to respective activities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lo</td>
</tr>
<tr>
<td>Lecture</td>
<td>5%</td>
</tr>
<tr>
<td>Discussion</td>
<td>8</td>
</tr>
<tr>
<td>Problems by teacher</td>
<td>0</td>
</tr>
<tr>
<td>Demonstrations by teacher</td>
<td>0</td>
</tr>
<tr>
<td>Laboratory</td>
<td>11</td>
</tr>
<tr>
<td>Demonstrations by student</td>
<td>0</td>
</tr>
<tr>
<td>Problem by student</td>
<td>0</td>
</tr>
<tr>
<td>Films and Other A.V.</td>
<td>0</td>
</tr>
<tr>
<td>Tests and quizzes</td>
<td>5</td>
</tr>
<tr>
<td>Other</td>
<td>0</td>
</tr>
</tbody>
</table>

100%

Other interesting findings of this study were these:

1. "With only minor variations the science curriculum sequence available in the sample schools is the traditional biology-chemistry-physics pattern (p. 223,April)."

2. "No matter what the size or location of the school,
the general type and level of physics taught and the role physics plays in the curriculum is an invariant. A high school physics course almost always covers the major areas of classical physics in a quantitative way that includes laboratory measurement and data analysis, the development of theoretical models and theories, and applications and problem solving using algebra (p. 293, May)."

3. "Nineteen of the forty-two teachers mentioned that recent innovations in their physics program had been a factor in attracting students to their classes. However, eight teachers thought that the general economic condition of the country was a factor which influenced some students to stay away. More importantly, eighteen teachers mentioned that the general alienation of some youths toward modern society was a factor which kept some students from choosing to take physics classes (p. 225, April)."

4. "The percentage of twelfth graders enrolled in physics does vary significantly from school to school, with urban schools on the low end of the spectrum. Despite the variation, it is true that very few students who are not intending to enter college enroll in the course (p. 293, May)."

5. "The difficulty of doing science, and perhaps the appeal of other fields, appears to discourage about half (of the physics students) from wanting to pursue science as a career (p. 294, April)." The researchers also noted that students included the possibility of a poor job market for physicists as a reason for discontinuing studies in this subject.
6. Laboratory work and lecture are most prevalent in the classroom. "Relatively little time is devoted to learning through the use of audio-visual aids or other modern teaching devices. Independent study time is still relatively rare but not unknown (p. 294, April)."

7. A major difference in classroom activities, and students' perceptions of classroom activities, was noted in comparing the Project Physics course to other courses. "Project Physics students indicated that lecturing is not a common activity in their classes..., and that films shown in classes are well integrated with discussion topics." "Project Physics classrooms are ... apparently not quiet places; rather, they are active places with no obvious prescribed goals." "Project Physics teachers ... are far above average in allowing students freedom in the lab (p. 290, May)." And, the researchers conclude that, "The Project Physics course teachers have been unusually adept at conveying the impressions that students direct their own learning (p. 294, May)."

This research generally gives the impression of a fixed curriculum with, however, a wide divergence in preferred textbooks and textbook combinations. If student rating of teacher behavior can be taken as a criterion of innovation, it would seem that the Project Physics course most closely reflects modern trends toward student self-direction.

The current physics program at Northwestern High School in Flint, Michigan, as described by Collins and Madden (1974),
also suggests that the Harvard Project course is considered to be geared more toward current motivational priorities than the previous PSSC curriculum. State the authors,

Physics courses at Northwestern High School began several years ago with a philosophy and teaching style consistent with those traditionally found in physics departments. Physics was taught as if everyone who took it intended to become a scientist or an engineer. The entire class progressed through the course at a pace prescribed by the teacher, grading was competitive, and everyone finished the book.

Concurrent with the adoption of a curriculum change from PSSC to Project Physics, an evolution began in the physics program at Northwestern, which led to the development of individualized Project Physics. For the first time, learning was viewed from the student's perspective rather than from the teacher's perspective (p. 465).

The main priority in Collins and Madden's individualized Project Physics is "to provide every student with an honest opportunity to succeed (p. 465)." The course is individualized by means of behavioral objectives, flowcharts of required and optional assignments, and differentiated assignments to fulfill the requirements for the A, B, or C grade. Collins and Madden consider their approach to be successful, "judging from student enthusiasm and continued increases in enrollments (p. 469)."

These authors specifically suggest that the following aspects of the individualized Project Physics course are the most
significant advantages to the student:

"(1) choice of level and pace
(2) day to day active learning
(3) individual or group work
(4) facilities and assistance available from 7:30 a.m. to 5:30 p.m. daily
(5) competition only with oneself
(6) opportunity to develop a sense of responsibility
(7) computer assistance in performing mathematical computations, in self-evaluating, and in obtaining a record of completed work (p. 469)."

If recommendations are to be made on the basis of the experience of Collins and Madden, one must question to what extent the success of this program is due to the excellence of the Harvard Project materials, and to what extent this success is due to the individualized nature of the course, or to other efforts put forth by Collins and Madden. The authors admit that, in a program such as theirs, "the demands on (the teacher) during class are tenfold, the hours put into preparation are at least tripled, and the extra time and effort put forth are strictly voluntary (p. 469)." It might also be suggested that Collins and Madden were especially successful in their individualization attempt because of their realization that "the success of this type of program depends upon the teacher's ability to understand the particular needs of his students (p. 469)." These authors suggest that teachers take into account factors such as the
socio-economic level, ethnic and cultural background, and the intellectual level of students, for planning purposes. Therefore, in order to achieve a successful individualized program, physics teachers should write their own behavioral objectives and learning activities, "rather than depend on materials written by other teachers (p. 270)."

The need for staff-written materials was also pointed out by Mr. Eugene Miller of the DeVry Institute of Technology of Chicago in his address to the October 26, 1974 meeting of the American Association of Physics Teachers. Mr. Miller described the present "Preparatory Program" operated by DeVry in conjunction with the open-admissions policy that has been in effect for approximately the last three years. Study sessions utilizing staff-written workbooks, individualized tutorials in remedial mathematics, and an introductory physics course stressing concepts of the science and eliminating mathematical calculations constitute the basis of the "Preparatory Program." It is also interesting to note that the total elimination of mathematics from the introductory physics course which enrolls students whose initial deficiencies prohibit the standard course, would seem to be a more realistic educational approach than that followed by many high schools. High school juniors and seniors are often expected to apply algebraic and trigonometric formul­ations, which they are simultaneously learning for the first time in their mathematics course to the more complex problem-solving operations of physics.
Evaluation of Existing Physics Curricula

The following points help to summarize the current status of available high school physics curriculum materials, and reactions of individual teachers to their own curriculum problems.

1. Both major curriculum projects (PSSC and Project) depended on volunteer teachers with special institute training for their systematic evaluation programs. Welch and Walberg (1968) attempted to evaluate the effectiveness of these summer institute programs for physics teachers. From this evaluation study, based on a pre-test/post-test design using the t-statistic, they found that significant gains $p < .005$ occurred in teacher performances on the "Test on Selected Topics in Physics" for each of the institutes. This study generally showed the summer institute to be effective; it is also clearly stated (Ferris, 1959); (Welch, Walberg, and Ahlgren, 1969) that teachers participating in the PSSC and Project curriculum projects were institute trained, whereas the control group teachers were not. It is, therefore, difficult to understand why such comparative evaluations utilizing specially trained teachers in the experimental group only were considered to be statistically valid.

2. PSSC and Harvard Project Physics are intended for very different types of students; neither the mathematically sophisticated PSSC student nor the historically oriented Project Physics student necessarily represents the average or regular course student. As was mentioned on page 26, among the three schools surveyed, the PSSC text was used only for one honors
course. The Project Physics text was used only in specifically labeled "Project Physics" courses.

3. The tryout criterion for the PSSC course was based on an average score of 50% on PSSC tests. The question must be raised as to whether most teachers and students consider 50% to be a satisfactory score.

4. A major objective of the Project course curriculum is to increase enrollment by recruiting students. Welch and Rothman (1968) made a study contrasting gains made by recruits to the Project course with gains of students who voluntarily planned to enroll. This study utilized pre-test/post-test difference scores on the Test On Understanding Science, and the Welch Science Process Inventory. It was concluded that, "Students recruited in the Project Physics course gained as much or better than students who signed up of their own volition (p. 272)." It would seem that most administrators and teachers schedule the Project course as a supplement to the regular and/or honors courses; and the purpose of this Project Physics course offering is to attract the non-mathematically inclined student-recruit to physics.

5. Among the three Chicago area high schools surveyed by the investigator (see page 26), six different texts are used for eight types of courses. Ivany, Mullaney, Huegel, Faust, and Strassenberg (1973) in studying a sample of 42 schools, confirm this diversity, stating that, "Among the textbooks written privately, none stands out as a clear choice of a large fraction
of the high school physics teachers (p. 294)." There were 14 PSSC courses and five Project courses offered among the schools studied; seven of the 14 PSSC courses used PSSC materials combined with Project or other texts and materials. This diversity indicates that there has been no final solution to the physics education crisis.

From the results of a study conducted using student interest measures (The Kuder Preference Record), Wynn and Bledsoe (1967) conclude that "The findings of this study suggest that the extreme emphasis which has been placed upon science and science education during recent years has not resulted in greater interest in science among high school students (p. 74)." This conclusion was based on the pre-test/post-test scores for 325 students. The study was designed to answer the questions:

"(1) Are high school freshmen particularly interested in science?

(2) Is there a present trend of increasing science interest among high school freshmen?

(3) How much change do students' science interests undergo during the high school years? and

(4) What factors seem to be related to changes in the science interests of high school students? (p. 67)."

Bauman (1974) attempts to derive "A Preliminary Model for Effective Teaching (p. 287)" by means of a literature review. He summarizes his premises by charting those variables traditionally considered to affect the teaching/learning process significantly,
and re-evaluates the significance of each variable under the codings of: yes (definitely significant), probably yes, probably no, and no (not significant).

TABLE 45

Significant Variables Of Teaching

<table>
<thead>
<tr>
<th>Variables</th>
<th>Probably</th>
<th>Probably</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>1. Course Syllabus</td>
<td>(X)</td>
<td></td>
</tr>
<tr>
<td>a. Textbook</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>b. Examinations</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>c. Instructor Input and</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Handouts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Teaching Format</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>3. Instructor</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>4. Students</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Level of Ability</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>b. Individual Attitude</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>c. Collective Attitude</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>d. Group Dynamics</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>e. Study Effort</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

Bauman's study seems to represent a genuinely necessary effort to synthesize a number of research findings. But this review does seem to suffer the same difficulties in interpretability as the
research upon which it is based. That is, can one conclude as does Bauman that, "taken collectively and evaluated objectively, their message (the message of a number of studies) seems quite clear--that the choice of (teaching) format is not important for student learning ... as measured by final examinations (p. 289)."

Here Bauman chose to minimize his own statement that, "there are differences in student attitude engendered (p. 289)" by the various teaching formats--and to maximize the so-called hard evidence of the cognitive test score. It would seem that in his attempt to simplify and categorize the significant variables of teaching, the researcher may have been forced to minimize the importance of long range affective considerations in favor of immediate cognitive results.

Bauman also has some difficulty in substantiating his final conclusions or model and criticized his own hypotheses as being unsubstantiable. These hypotheses include the suggestion that learning single concepts "cannot be accelerated but it can be initiated (p. 290)," which leads the researcher to suggest that "proper scheduling of experiences" can lead to a significant increase in "macroscopic learning rate (p. 290)."

Perhaps a serious consideration is needed of Bauman's suggestion that, "Good research on teaching and learning will require a separation from the standard educational process .... More research is called for that is free of predetermined time schedules (p. 290)." So although this preliminary model seems poorly substantiated in its present form, Bauman is one of the
few authors who suggests that the inadequacy of our present research data can be corrected only by advocating the priority of obtaining accurate research results over the instructor's conviction that each course he teaches must be a "best possible" course. States Bauman, "we feel too deeply a responsibility to teach and not enough responsibility to conduct research (p. 290)."

**Other Problems Specific to the Teaching of High School Physics**

Other problems, noted in the literature, that are specific to the high school physics course, are the following:

1. The need to update the course constantly so as to include modern developments in the science; and, alternatively, the danger of so overloading the course with learning material so as to make it unteachable during a single school year (Hammond, 1958; Schulz, 1960; Little, 1959).

2. The inadequate mathematical background of many high school students which makes it very difficult for them to master the physics learning material (Schulz, 1960).

3. The need to produce learning materials adaptable for individualization in the high school physics course. Here, the term individualization is applied to gearing the course to the school and the class rather than to each student. It is pointed out (Schulz, 1960) that, "Even though the physics course of study is adapted to the problems and resources of a specific school, there is no assurance that the classroom instruction will be equally well individualized with respect to the students (p. 131)."
4. The need to include a variety of types of learning activities in the course. States Schulz, "Reading and listening need to be enriched by demonstrations, laboratories, films, monographs, reference volumes ... (p. 131)." Here it might be pointed out that there is some confusion between the concept of providing different types of course materials, and that of providing different types of learning activities. Whether the student is reading a textbook, or a supplementary reader--or attending a lecture/demonstration versus a film showing--he is still engaged in the same type of learning activity, even though a variety of course materials is being utilized.

5. The need to include motivational learning experiences in the classroom repertoire. One teacher interviewed by the investigator found classroom demonstrations to be especially motivating for students. The favorable student response to laboratory experiments and classroom demonstrations was also indicated by Andrews (1964) research on methods of instruction. She found the most generalizeable result of the study to be that, "In both 1955 and 1960 pupils ranked laboratory experiments and classroom demonstrations as highest for enjoyment and the development of interest (p. 154)." Verduin (1965) also found his students to be especially interested in performing laboratory demonstrations in an experiment on democratic pupil-teacher course planning.

6. The need to attract more girls to the physics course. Pollack and Little (1973) of the University of Oklahoma initiated
during the 1971-72 school year a special physics course for girls. In this course, group meetings with a clinical psychologist were provided to obtain student feedback. It was found that the girls "wanted a real physics course (p. 391)" not a watered down version of the subject. Provided for the students were "(1) counseling (both academic and personal if needed); (2) extensive laboratory experience; (3) informal seminars where they heard talks by ten scientists who were not directly connected with the project; (4) informal seminars with visiting women physicists; (5) participation in social affairs (for visiting women physicists) with faculty and graduate students from the physics department; and (6) striking group identity (p. 392)."

Procedures taken, in this course, to insure careful handling of students in the affective domain would appear to be an educator's ideal; but the question must be raised as to whether these procedures were more effective and/or necessary with girls than they would be with a randomly assigned class of students.

7. The need to insure that adequate content learning accompanies the acquisition of scientific thought processes.

Iona in his Letter to the Editor (The Physics Teacher, 1974), states "Although, of course, the processes of scientific investigation are an important part of science activities, frequently the promoters of curricula emphasizing the process approach get so involved in the processes themselves that there is little approach to the understanding of the physical world (p. 197)."

Iona cautions that the presently advocated learning "activities emphasizing processes or computers" would be enhanced in value
if these problems were more manifestly "related to the natural phenomena rather than exercises in manipulation (p. 247)."

8. The need to exchange information on successful classroom innovations; information on new types of physics courses being offered throughout the country should be made widely available to teachers. Ayers (1974) conducted an "Analysis of the Current Literature of Science Education (p. 309)" and concluded by recommending that teachers on the K-12 levels should be encouraged to publish "first hand information from the classrooms (p. 314)." There is a particular shortage of literature on teaching junior high science. Also, "there is a definite need to make the articles related to research in teaching science education of interest and value to the practicing teacher (p. 314)."

Some such information is presently being published on the "Physics in Pre-College Education" page of The Physics Teacher. Many ideas from this feature should be adaptable to physics programs throughout the country; such possibilities include a "Design Your Own Experiments" sequence from Cubberley High School in California, a feature involving the relation of traffic laws to the laws of physics (October, 1973) or a personalized learning packet series utilized at Bloomington Lincoln High School in Minnesota (April, 1973).

9. The need to be critical in evaluating research results and curriculum changes. Keller (1974) proposes these guidelines:

"(1) Experiments to learn which method is most effective for teaching a particular skill or concept to all students should
be abandoned.

(2) Many of the changes in curricula and methods that have been tried in the past are constantly being revived and recommended without any empirical evidence to establish that the proposed reforms have any more merit for all students than those they are replacing.

(3) All too frequently, as self-appointed "leaders" proclaim they have "the answer" for improving the quality and/or quantity of education, teachers and school systems quickly adopt neatly packaged old remedies to establish they are progressive and in the vanguard of progress with the latest innovations without a look for any convincing evidence as to its success in pilot runs. Change is made synonymous with progress and better education.

(4) The time is long past for getting off this merry-go-round. To learn, before introducing any innovation in method or curriculum, whether there is any reasonable evidence that the proposed change will produce better trained or educated individuals before time, effort and money are expended to no avail (p. 591)."

And Keller concludes by advising the prospective teacher, "Don't join every reform and innovation parade as history suggests they are only going in circles (p. 592)."

**Conclusion**

Although there is widespread agreement on the difficulty of maintaining enrollment in high school physics classes and on the
problems specific to the teaching of this subject, there has been no generally accepted solution to these problems. It can be inferred that teachers need textbook materials that fulfill the following criteria:

(a) Suitability to the level of conceptual and mathematical sophistication of their students;

(b) Adaptability to school, class, and teaching style; textbooks should be sufficiently brief to permit time for the inclusion of demonstrations and other special learning activities, and practice and review;

(c) Inclusion of modern developments in the science, and reflection of our current outlook on physics phenomena;

(d) Ease of utilization by most physics teachers, who will not have attended special institute or training sessions;

(e) Capacity to interest and motivate the student;

(f) Suitability for college-preparatory courses; an exception here is that some types of non-college preparatory materials can be utilized in the larger high schools where additional "terminal" courses can be scheduled.

The effect of each course on the subsequent year's enrollment is often the criterion by which teachers evaluate their own selection of textbook and other materials. If a course curriculum is geared only to a special or unusual type of student, or alternatively if an excess of learning material provided for that course makes the one-year time scheduling impossible, then the necessary criteria for widespread acceptance of the course are
not met. Though it would seem that a number of adequate textbooks are on the market and are being utilized by Chicago area high school teachers (see page 26), there is little consensus on the merits of these books. And comments by teachers who combine two textbooks or who are "better off without a textbook, except for assigning problems" (as suggests one of the teachers interviewed by the investigator) indicate a need for a different kind of text. Also, little consensus has been reached on a classroom program that provides a solution to the problems of individualizing, including course content on modern physics, and leaving enough time for practice and review. It is thus indicated that further research on the high school physics curriculum is needed.
Chapter III

Research Design

Overview

The experimental research for this study was conducted at two Chicago area high schools. One teacher from each of these schools taught one experimental and one control class, each comprising about 32 students. The classroom programs and subject areas covered in each of these courses are described under Classroom Programs in Effect (pp. 75-77). Pre-test data (cognitive and affective) is utilized as needed in comparing experimental and control classes.

Students in the experimental classes received the 300 page text Basic Concepts of Physics, which was written by the investigator to demonstrate the functional approach to teaching high school physics and is at present submitted for publication. Other materials developed by the investigator include questionnaires used in evaluating students' affective (non-cognitive) responses to experimental and control courses. These questionnaires are included in Appendix A.

Measurement Instruments

Measurement instruments utilized in evaluating the results of this study include the following:

(a) Three questionnaires to be distributed to students in
both the control and the experimental classes;

(b) Three additional questionnaires pertaining to specific aspects of the experimental course, to be distributed to the students in these classes only;

(c) Three teacher attitude questionnaires, designed to be administered at the beginning of the school year, at some point during the year, and at the end of the experimental program; these questionnaires are to be administered in the form of a taped interview.

Printed test materials to be purchased and utilized in this program include:

(a) The Engineering and Physical Science Ability Test, to be given to all students (experimental and control classes) as a pre-test;

(b) The Harvard Project Physics Test, Units One, Three, Four, Five, and Six; selected multiple choice and essay questions were chosen from these test booklets, and administered to experimental and control classes upon completion of the appropriate units;

(c) The Dunning Physics Test, administered to experimental and control classes as a post-test.

Description of Textbook

The text to be utilized in this study was designed on the basis of a two part division of learning material into basic concepts and applications. The Basic Concepts text is organized around the division of course material into five major conceptual
areas: "Newtonian Physics," "Energy," "The Field," "The Wave," and "Modern Physics" (atomic and Einsteinian). This organization differs from that of the traditional course. Though the objective of most physics courses is to teach underlying concepts, the organization is nevertheless based on specifics such as mechanics, light, or electricity.

The Basic Concepts text comprises approximately 300 pages; all learning material that is included here is specifically applicable to more advanced study in physics. The participating teachers were instructed to coordinate their own laboratory program with the presentation of learning material in the text. This laboratory program includes instruction on some technological applications of the theoretical learning material. Ideally some individualization is possible in choosing this applications study material, since the Basic Concepts text includes all learnings essential for the development of the conceptual framework of the subject.

The division of course material into the Basic Concepts text and the applications laboratory program can be illustrated with this example on the three wave characteristics of reflection, refraction, and diffraction. Material on the refraction characteristic is eliminated from the Basic Concepts text and taught through laboratory experiments. The theoretical basis of refraction is irrelevant for subsequent modern physics understandings. In contrast, the related wave phenomena of reflection (the basis of the standing wave), and diffraction (as applicable to spectral analysis) do apply to future understandings, as in
current research on the atomic electron. So reflection and dif-
fraction are included in Basic Concepts.

In preparing the Basic Concepts material, the researcher
attempted to prevent the most common misconceptions of beginning
physics students. Thus the student is told why his "intuitive"
conception of motion often misleads him in Newtonian physics; he
is presented with Newton's third law of motion as a result of the
conservation of energy rather than as an actual motion equation;
he is told that electrons do not move in a straight line in a
conducting wire, and that the sine wave equation for alternating
current represents a cumulative effect. Though conceptual dis-
tinctions such as these may seem unnecessarily explicit, this type
of clarification is designed to introduce the student to logical
and rigorous thinking, as well as to prevent confusion or incom-
plete understanding.

Also within the organizational format of each sub-section
of this text, areas of special emphasis are designed to give the
student insight on how his present learnings will relate to
future work in physics. Thus it is hoped that the student is not
confused, distracted, or misled as to which learnings are most
important. In the point by point listing of information relevant
to each physics concept, the following (where applicable) is
included:

(a) The customary usage of each concept in problem
solving;

(b) The projected place of the concept in future physics
learnings;
(c) The present state of research in the area;
(d) Some suggestion of the importance of each formulation in technological applications (however, detailed technological information is relegated to the laboratory portion of the course);
(e) Descriptions of mathematical formulations that clarify future usages of the physics concepts;
(f) Appropriate analogies to make each theoretical formulation understandable on the cognitive level of the high school student.

Classroom Program--Specific Teaching Devices

The following is a listing of specific teaching devices that are incorporated into the experimental course design. Included are examples of how these devices or procedures are applied through the textbook format or the classroom procedures of this study.

1. Organization through underlying concepts. Theoretical learning material is classified under five conceptual categories. This device permits students automatically to generalize all instances of a physical phenomenon into its dominant category.

2. Progression from the familiar to the unfamiliar. This progression is evidenced in the order of the five major sections of Basic Concepts. "Newtonian Physics" includes the familiar laws of motion. "Energy" deals with mechanical, heat, and electrical energy which are familiar to us. "The Field" is familiar to us through the magnet, yet the mathematical implications,
which introduce "The Wave," almost entirely constitute new learning material. Other material, dealing with the probability wave, is directly contrary to our everyday experience. The learning material introduced in "Modern Physics" deals with subatomic particles and an entirely different perspective on previously studied formulations such as velocity, energy, and the conservation laws.

This progression, from the familiar to the unfamiliar, aids the student in dealing with physics "facts" that seem directly contrary to his own experience. Also, the importance of cumulative learnings is emphasized, with retention facilitated through review procedures.

3. Teaching the "whole" versus its "parts." Classroom procedure provides for student's exposure to each of the five major, or "whole" sections in the Basic Concepts section before concentrating on points of difficulty. This is most important in a beginning course where students must be given enough information to understand the significance of each formulation that they are studying; motivation is increased when students do not spend large amounts of time on detailed learning until they "see the point of it."

4. Factual selection of subject matter. This course is geared toward the learning and over-learning of essentials. The structured outline format permits the inclusion of relevant information only. Superfluous details often obscure underlying concepts, as does "discovery" or intuitively based learning. It is necessary that the students' retention of learned material be
maximized through factual emphasis in this college preparatory course.

5. Self-assessment procedures. It is considered essential that the beginning physics student have some means of assessing the extent and accuracy of his current understandings in the subject. Students inexperienced in a technical field often fail because they are unable to estimate the necessary amount of study for problem-solving examinations. Explicit classroom instruction in problem-solving and the use of study questions leading to directed problem-solving practice in student groups are designed to compensate for the students' initial lack of experience here.

6. Restatement of concepts in the student's own words. After a two week introductory period spent on one of the five conceptual areas comprising the Basic Concepts section, students formulate study questions. These study questions are based on points of knowledge that confuse the student. Student groups are formed on the basis of similar study questions that have been posed by group members. These groups are instructed to reword their questions together until such questions are adequately precise (scientifically formulated). It is found that in a technical discipline, an accurately worded question often answers itself. Correctly worded, such questions clarify important conceptions and misconceptions. These question formulations can be referred to the appropriate subsection in the structured learning material. Then both teacher and student directed reference work can provide appropriate clarifications on these
points.

7. Early and repeated review. Early review is provided in class. After student groups spend one double period rewriting study questions in accurate form and logical order, the teacher will assign related problems. Students are to spend a double period on this directed problem-solving activity, then a single period on pinpointing their difficulties and evaluating their general comprehension of the material. When these group-oriented review and assessment procedures are completed, an additional one and one half weeks of class time will remain for each of the five major areas of the Basic Concepts. This classroom time is to be spent on a teacher directed, problem-solving review. (An outline of time to be devoted to each classroom activity is provided at the end of this section.)

8. Focus on current research. In Basic Concepts, special emphasis is placed on relating each newly introduced formulation to current research or to understandings in modern physics. The theoretical basis of many high level physics concepts has been simplified and explained in this text. For example, Einstein's relativity formulation is introduced with simple analogies to "frames of reference" in Newtonian physics. Though most physics courses include the basis for such understandings, concepts such as relativity are described in a manner more suitable for stimulating the student's imagination than for facilitating his understanding of the theory.
Classroom Program--Time Scheduling Considerations

The classroom program has been designed to allow seven to eight weeks for each of the five units. The time-schedule below applies to one unit. Directions given to teachers of experimental classes were as follows:

First four weeks: Divide up the section ("Energy" for example) into five parts. Give about two days of lecture-introduction that completely covers each of these five parts, and two days of explanation and problem-solving examples, immediately following the lecture-introduction. Thus the schedule will be two days of lecture, two days of explanation and examples, and then two days of lecture on the next of the five parts, etc.

During the problem-solving example period, the students are to be given sample problems to work individually at their desks. These problems are not to be too difficult, that is, they are to be on the order of the examples that have just been demonstrated at the blackboard. Student homework is to consist of problems to solve, on the level of difficulty of the sample problems or one level more difficult. (Problem sheets are arranged in order of difficulty, with group one problems the easiest, and group four the most difficult. Finding the right level of difficulty for the students at this time will be a matter of trial and error. It is most likely that these sample problems will be from groups one and two.)

One two-hour period per two weeks or one one-hour period per week: This time period is to be scheduled for a problem-solving lab. The first of these problem-solving periods should
be scheduled two to three weeks after the beginning of the unit. A problem sheet will be made up of some of the more difficult examples that relate to the previous week's lecture. A majority of examples from group three may be appropriate since these problems are to be challenging. Students will work individually on their problems, with some discussion among students and direction from the teacher, if necessary. (The appropriate level of difficulty for these problem sets will vary with the class.) Students are to be graded on these problem sets, which are to be turned in at the end of the problem-lab period. This grade can be weighted the same amount as a regular laboratory experiment grade.

The fifth and/or sixth week of the unit: For this time period, two exercises are scheduled. Students, in groups, are to make up both a non-mathematical (conceptual) question on the unit and a problem demanding a mathematical solution. These questions and problems can be either:

(a) Discussed and solved by the group that originated them, with the solution demonstrated on the blackboard for the whole class; or,

(b) Assigned by the originators to another group, the members of which must solve the problem in front of the class; or,

(c) Given to the teacher to solve for the class.

The sixth and/or seventh week of the unit: A planned review will be scheduled for this one or two week time period. Student performance on problem-lab work can be used to diagnose
which areas need stressing. The sample problem procedure, where students work sample problems at their desks similar to those demonstrated by the teacher at the blackboard, should be useful here. Homework problems assigned during this review should reflect the maximum level of achievement that students are expected to reach during the unit (group three problems, for example).

Laboratory schedule: Regular laboratory experiments are to be scheduled as convenient.

Selected tests from the Harvard Project Physics course exam booklets are to be given to both the experimental and control classes. For the experimental classes, these tests are scheduled for the end of each seven to eight week unit. For the control classes, the tests can be given just after the appropriate subject matter has been covered. The tests for each unit will take 60 to 70 minutes.

The rationale for the classroom program is as follows:

The first four weeks of the unit: This time period has been scheduled with two days of introductory lecture prior to the problem-solving practice. This was done under the assumption that the high school student often ignores concepts once he begins to concentrate on numbers. On the other hand, two days spent on concepts without showing concrete applications seems to be as much as is desirable considering the attention span of the high school student. The two days of introductory lecture are to serve as an advance organizer. The problem-solving examples
introduced in class are to provide material for homework assignments during the first four weeks of the unit.

Problem-solving lab periods: These problem-lab periods are used here as a device to raise the level of the students' problem-solving abilities. For example, students can be introduced to group three problems during this lab period, after having practiced solving group two problems as sample problems in class and for homework.

Group exercise in making up questions and problems: This activity will probably be carried out in a competitive manner, with one group challenging another. It is felt that by means of this procedure, students will be encouraged to state conceptual questions and to make up problems that are on as high a level as possible. One of the objectives of this course is to provide students with some practice at stating physics concepts in their own words.

Planned review: The time interval suggested for the planned review is stated very approximately, to be adaptable to student needs and general scheduling considerations.

Distinguishing Traits of Experimental Course

It is not really accurate to give a generalized description of the "traditional" physics course, owing to the variety of course materials and teaching methodologies that are utilized. Recent innovations such as the Harvard Project Physics course incorporate modern educational practices by providing the student with a variety of resource materials. But in general, many
aspects of this experimental course differ significantly from the usual teaching practices. Even the most elaborate of the previous innovations fail to suggest a teaching methodology that is based on current educational practices and is designed to accompany the proliferation of course materials.

The classroom program that is planned for this course and described in the previous section is significantly more up to date than the usual "lecture, text, and homework" teaching method. This classroom program focusses on learning activities for the student (rather than lecturing by the teacher) so as to render the learning process both more effective and more enjoyable. Independent study, as utilized here, is not unstructured; rather this classroom program is designed to insure each student's overlearning of the essential Basic Concepts.

Some learning material included in Basic Concepts is presented in greater depth than is usual in a high school course. This includes current material on relativity and nuclear physics. This material is presented in a straightforward, factually-oriented manner so as to render it more accessible to the student; this is in contrast to the usual textbook approach of emphasizing the "greatness" and "complexity" of these learnings. The subject matter that is included in "Modern Physics" is seldom arrived at in the last chapter of the traditional course. Most high school physics courses devote considerably more time to Newton's seventeenth century findings.
Major Considerations for Administering Experimental Program

The data collected during this study is described in the following pages. In the interpretation of these findings, special attention is given to the following concerns.

1. Comparison of time-schedules for experimental and control classes. If, for example, there is no statistical difference between cognitive test scores on mechanics and electricity in experimental and control classes, but the subject area of modern physics has been taught in the experimental class in addition to the learning material covered in the control class, the investigator will make note of this.

2. Student affective indices. A particular concern with students' reactions to this course is in order in view of current enrollment problems in physics. Consecutively administered affective questionnaires were designed to indicate changes in attitude as well as to obtain student evaluations of the courses.

3. Curriculum selection decision-making. The investigator is attempting to evaluate the choice of subject matter included in the curriculum of the experimental course. In the questionnaires (Appendix A) students are asked to indicate whether they would have preferred to spend more, less, or the same amount of time on each subject area, as well as to indicate perceived interest and difficulty levels of these areas.

4. Teacher considerations. Although the teachers volunteered for this experiment, it can be expected that they will to some extent be reluctant to change previous teaching patterns.
The extent to which this experimental course motivates teachers to do things differently (such as spending less time on mechanics and more on modern physics) and the carry-over of techniques from the experimental course to next year's classes will provide a valuable index of teacher reaction.

It is felt that it is only when considerations such as these are taken into account that innovation can be meaningful. There is no "standard" physics course that is universally accepted. The acceptance of any attempt to innovate in this curriculum is contingent upon the teacher's willingness to change in that direction, as well as upon the reputation that the course receives from the students.

The findings in this study will consist of the data described below; of the results of hypothesis testing for significant differences between experimental and control classes; and of conclusions based on these findings in view of the practical considerations described above.

The data to be gathered during the process of this study consists of the following:

1. Student ability pre-test data. This data will initially be in the form of raw scores of students in experimental and control classes on the Engineering and Physical Science Ability Test.

2. Teacher affective pre-test data. The main purpose of the teacher affective pre-test is to identify bias on the part of the participating teachers. Other points of information to be
obtained from this taped interview include:

(a) Teacher preferences in type of textbook used;
(b) Teacher self-image in terms of previous success with the course;
(c) Teacher reliance on laboratory and other visual aids;
(d) Other types of teacher bias; for example, a preference for spending an entire semester on mechanics;
(e) Teacher reactions to the functional approach.

This interview also serves to ascertain that the participating teachers have adequately familiarized themselves with the experimental text and classroom plan.

3. Two additional affective tests (Appendix A) to be administered at mid-year and as a post-test to experimental and control classes; these tests will be quantified to provide indices of:

(a) The student's perception of his present success in the course;
(b) The student's evaluation of all aspects of the teaching program (text, classroom program, problem-solving, amount of homework, laboratory, examinations, and time allotments). This evaluation is to utilize as criteria the student's perception of interest levels, difficulty, effectiveness, and utility of subject matter and learning materials;
(c) The effect of this course on students' future study and career plans, if any.

A few open-ended questions are provided in various forms of the
affective questionnaire to insure obtaining unanticipated but relevant student comments.

4. Three affective questionnaires (Appendix A) to be administered in January, March, and May to the experimental group only. These tests are designed to obtain students' evaluations of specific aspects of the experimental course. These aspects include:

(a) Textbook: Conceptual clarity, organization format, and choice of subject matter;

(b) Classroom program: Perceived utility and appropriateness of time allotments for learning activities.

Questions about the laboratory program are also included to insure that students evaluate the experimental text and classroom program separately from the (non-experimental teacher designed) laboratory work. Additional questions dealing with students' perceived success in this course and future career expectations serve to replicate data obtained from other affective questionnaires. The investigator considers it of primary importance to obtain affective indices throughout the experimental course, so as to minimize the effect of a student's reaction to a particular subject area being taught at the time, a particular aspect of the course, or a "bad day, bad test" reaction.

5. Harvard Project test data. These cognitive multiple choice tests are to be administered at the end of each of four units to the experimental classes, and upon completion of similar study material to control classes. These tests are to
provide comparative data on cognitive learning for the four units.

6. Dunning Physics Test data. This standardized test is suitable for administration to experimental and control classes at the end of the school year. It is a multiple choice test dealing with the full year's curriculum and is considered to be an exceptionally valid and reliable instrument.

7. Two additional teacher-opinion interviews. These taped interviews are similar in form to the teacher affective pre-test. Information to be obtained here includes:

(a) Teacher reaction to experimental text;
(b) Teacher reaction to classroom program;
(c) Teacher reaction to the general (functional) approach of the experimental course;
(d) Teacher reactions to the particular groups of students in their experimental and control classes (to check for bias and for confirmation with test data on students);
(e) Teacher's overall comparison of experimental and control courses (to check for bias, give additional information on teacher reaction to experimental course materials, and compare with teacher affective pre-test data).

Also, the investigator will attempt to assess how closely the teachers have been following the classroom instruction plan and time schedule for the experimental course; this will be done through the medium of these taped questionnaires, as well as through more frequent, informal conversations.
Anticipated Extraneous Variables

The independent variable in the study is method of teaching physics. Dependent variables are student cognitive achievement, student affective response, and teacher reaction to the experimental course. Anticipated extraneous variables and possible methods to control for them are these:

1. Teacher personality/effectiveness variable. This is compensated for by means of assigning to each teacher one experimental and one control class.

2. Student aptitude variable. Initial differences in aptitude of students in experimental and control courses will be determined by an index derived from scores on the Engineering and Physical Science Ability Test (administered as a pre-test). These initial differences in aptitude will be accounted for in the analysis and interpretation of results, if necessary.

3. Student attitude variable. Initial differences in students' attitudes toward physics is to be assessed by an affective pre-test designed by the investigator. The test elicits a measure of students' attitudes by quantifying responses on a multiple-choice questionnaire dealing with students' reasons for taking the course and their expectations of the course in terms of type of subject matter, applicability of subject matter, and the students' anticipated success in the course. Attitudes dealing with students' learning styles and teacher expectations are also elicited. Again, differences in attitude between experimental and control classes will be accounted for statistically,
if significant.

4. Teacher attitude variable. Initial bias toward the experimental class on the part of the teachers involved is elicited by an interview questionnaire, recorded on tape.

5. Teacher performance variable. It has been anticipated that one teacher may have been more precisely following the proscribed classroom program than the other. By maintaining close communication with teachers, eliciting feedback, and keeping a log, the researcher can estimate the performance of teachers in this respect.

6. Student socio-economic class. The two schools selected for this study represent widely different socio-economic levels. Although this difference is somewhat offset by the fact that it is not a random sampling of School 1 students who choose physics as an elective, it is felt that the divergence between these schools should yield interesting information as to the relative appropriateness of this course for different types of student populations.

7. Teacher grading/student success variable. It is recognized as inevitable that student response to a course will be related to the grades received. These attitudes will be assessed and accounted for in the construction and evaluation of attitude questionnaires, to be periodically administered to the experimental and control classes.

8. Laboratory program variable. In order that student ratings of the experimental and control courses be meaningful
for evaluation purposes, it is necessary that students rate the
textbook plus classroom program separately from the laboratory
program. Questionnaires have been constructed to make this
distinction clear.

The basic hypotheses to be tested involve significant dif­
ferences in the dependent variables (affective and cognitive
examination indices) between experimental and control classes of
each teacher. The method of analysis that will best control for
extraneous variables and indicate significance in the hypotheses
to be tested will be contingent upon the nature of the data.
Considerable variation is possible in the manipulation of the
data; for example, dependent variable cognitive test scores can
be pooled or utilized as separate dependent variables.

Limitations of the Experiment

The experimental course material developed by the investi­
gator does not include a complementary laboratory program.
Teachers have been instructed to utilize the same laboratory
exercises in experimental and control classes, adapting their
usual laboratory assignments to correspond with the organization
of the textbook. So in this experiment, the comparison of
experimental and control courses refers to textbook and class­
room program, rather than to textbook and classroom program plus
laboratory program.

Another limitation of this experiment is that there is no
formal provision for observing the participating teachers in
their classrooms. This is conceded as a professional courtesy
to these teachers, who have voluntarily committed their time and effort to this project. Information as to the classroom performance of these teachers has been obtained through informal visits to the schools, conversations, taped interviews, and student questionnaire data. Student questionnaires have been constructed to elicit information on subject areas covered to date, and classroom activities incorporated into the course.

During the 1973-74 school year, the experiment was limited to the two participating teachers. The investigator was able to maintain close communications with these teachers to elicit feedback and attempt to maintain classroom practices reflective of the rationale of the experimental course.
Chapter IV

Findings and Interpretations

Description of Specific School Situations

Due to the extreme teacher and school differences between the classrooms of Teacher 1 and Teacher 2, it was decided that the pooling of data between the two sets of experimental and control classes would be unjustified. These classroom situations will be described on the following pages and can be contrasted on a number of points.

School 2 is an academically superior boys Catholic high school located in a prestigious suburban area. Because of the high percentage of these college bound students who sign up for physics, there are two full time physics teachers and three levels of tracked physics classes; students entering the Honors physics classes taught by Teacher 2 (experimental and control were both honors classes and exceptionally well-matched as to student populations) are motivated and well prepared. The honors classes as well as the college level class are almost entirely directed toward college preparatory work. The regular class is based on the Harvard Project textbook and is the only terminal physics course offered at School 2.

School 1 is a Chicago public high school located in a changing neighborhood with a mixed student population. The
students who sign up for physics constitute a relatively small portion of the School 1 students and are not generally typical of the school population as a whole. There are two physical science teachers at this school who have initiated a strong recruitment program. Despite this, the non-participating teacher was assigned only one class of physics students during the 1973-74 school year and, for this reason, was unable to provide data for this experiment since no control class would have been available. Teacher 1 taught two regular classes which constituted the experimental and control classes evaluated.

The strong emphasis placed on recruitment of students for the physics classes at School 1 has affected the teaching approach. Teacher 1 offers as an incentive the promise that the final grade each student receives in physics will be no lower than his lowest grade for his other courses. He also teaches a strongly laboratory-oriented course, with his own demonstrations chosen for humor and student appeal; he characteristically describes his monkey gun experiment, "you shoot a banana at a monkey ..." which demonstrates laws of motion and free fall. A considerable amount of classroom time is directed to school wide recruitment projects where students, for example, engage in a bridge building competition wearing "Physics is Fun" buttons. Teacher 1 habitually devotes a semester or more to mechanics and is reluctant to teach modern physics in his classes since fewer demonstration materials are available for the more abstract subject matter.

Teacher 2 was in his third year of teaching during the year
of the experiment. He was open to new ideas and precise in carrying out instructions. Teacher 2 was careful to reorganize his own laboratory program according to the order of instruction of subject matter in the experimental course, and he tailored his classroom lectures to the advance organizer-sample problem format suggested in the experimental course design. He also offered some suggestions for modifying the projected plan for student-group work activities which were incorporated into the experimental plan by both teachers.

The only previous negative teaching experience reported by Teacher 2 resulted from his choosing a textbook too difficult for his students; since the Basic Concepts text was found acceptable, the experimental course plan was not reported to cause him particular difficulties. Also, information derived from taped interviews and other conversations with Teacher 2 indicated that his initial strategies and objectives were close enough to those of the investigator to necessitate little or no need for conflict or rethinking of values. He was uniformly efficient and cooperative in implementing the experimental course design.

There was, in contrast, difficulty in implementing the experimental course plan at School 1. Teacher 1's own approach is an inductive teaching strategy, based on teacher-performed classroom demonstrations. Students' use of inductive thought processes is maximized; fact-giving is minimized, at least in the teaching rationale professed by Teacher 1. It is probable that a high-pressure, high-academic type of physics course
is inappropriate to the needs and prerogatives of Teacher 1's classes. The average score on the Dunning Physics Test from these classes (this is a pooled average) was in the 26th percentile according to the nationwide norm. Students who wish to continue their study have the option of a second year of physics at School 1; thus the need to provide a one year college preparatory course is not acute. It should also be noted that School 1 students are generally not, socio-economically and academically, representative of the type of student population that most often enrolls in a high school physics course. Thus a major concern of Teacher 1 has been to maintain enrollment.

Points in favor of the experimental classroom approach, as devised by the investigator, and as administered by Teacher 1 are these:

1. The textbook was popular with the students. In fact, Teacher 1 reported some difficulty in keeping control class students from making use of Basic Concepts of Physics texts borrowed from students in the experimental class.

2. In the final taped interview with Teacher 1 conducted by the investigator, he expressed the intention of teaching more material on field and wave theory and modern physics, with less material on mechanics for future classes. This intention corresponds with one of the investigator's primary objectives for the experimental course.

Problems with the experimental classroom approach, as administered by Teacher 1 were these:
1. Teacher 1 was unable to modify his selection of classroom demonstrations or his laboratory program to correspond with the learning material chosen by the investigator for the experimental course.

2. The time schedule followed by Teacher 1 did not permit coverage of much of the learning material scheduled for the experimental class. Teacher 1 felt that it was necessary to include the experimental class students in a number of the special activities planned for the control class--such as a school wide bridge building project. Again, this was done in the interest of maintaining enrollment.

3. Teacher 1 reported giving more classroom time to the subject of electrostatics in the experimental class than in the control class, in accordance with the emphasis in the Basic Concepts text. However, time allocated for the study of electromagnetic wave theory and modern physics was minimal. Teacher 1 considered it inadvisable to introduce subject matter for which visual demonstration materials were unavailable.

4. The inductive/demonstration approach preferred by Teacher 1 made it difficult for him to adopt the expository/organizer approach advocated for the experimental course.

Because of the points stated above, the investigator finds it difficult to differentiate experimental and control treatments at School 1, except insofar as the use versus non-use of the Basic Concepts text is concerned. Cognitive test scores and questionnaire data do not indicate differential treatment of the
various subject areas here. Teacher 1 used the sample problem teaching technique and allocated some classroom time to problem solving in both experimental and control classes. Questionnaire data substantiated the favorable student response to the Basic Concepts text reported by Teacher 1 (see page 120).

Classroom Programs in Effect

Teacher 1 used as the main text in his control course Lehrman and Swartz (Foundations of Physics, Holt, Rinehart and Winston, Inc., 1969). In this text, chapter one provides introductory material, chapter two an introduction to measurement and mathematical tools, chapters three through seven cover mechanics, with heat, energy, and the wave covered in chapters eight through 12. Chapters 13, 14, and 15 deal with "Electrostatics," "Electric Current," and "Magnetism;" this is the extent of textbook material included in Teacher 1's control course. Additional chapters, dealing with alternating current, the electromagnetic wave, optics, and atomic and nuclear physics were not covered.

For his control course, Teacher 2 chose Genzer and Youngner (Physics, Silver Burdett, 1969) as his main text. This text treats mechanics in its initial eight chapters; in later chapters, the topics of basic electricity, energy and momentum, electricity as energy, wave motion, optics, and electromagnetic waves are interspersed. Teacher 2 found it preferable to treat these topics separately, so although he followed the book closely throughout the mechanics section, he did not follow textbook chapters in order for other subject areas. The control course content
included those areas described above, as well as some introduction to relativity and modern physics.

In the control class of Teacher 1, the first semester was devoted to the study of mechanics. The classroom program included lecture, demonstration, laboratory experiments and problem-solving sessions. Generally, three or four periods per week were allocated to lecture/demonstration; two periods per week were spent on laboratory experiments; and one or two periods on working problems. Sample problems were included in the lecture/demonstration presentation. Teacher 1 reported that this breakdown on classroom time spent on the various learning activities applied to his experimental class as well, but there was a difference in time spent on certain subject areas. Mainly, a greater proportion of time was spent on the study of electrostatics in the experimental class. This was in accordance with the relative emphases on the various subject areas in the Basic Concepts text (as contrasted with subject emphases in Lehrman and Swartz).

Teacher 2 described his differential treatment of control versus experimental class as being considerably more extensive. Specifically, three months were spent on the study of mechanics in the control class, whereas this area comprised eight weeks of experimental class time. Also, one month in the experimental class, as contrasted with two weeks in the control class, was allocated to modern physics. Also, there was a considerable difference in classroom instructional procedures. In the
control class, no overviews of the learning material were provided. For experimental students, an overview was scheduled prior to the introduction of each subject area—for example, the whole area of mechanics was covered in the overview. Then students were consulted, and allowed to choose specific areas of instruction. This choice could be a reflection of special interest on the part of the students, or of an area of special difficulty later in the unit. In the study of mechanics, for example, a number of students chose to emphasize "Force."

Teacher 2 then referred these students to reading in the appropriate sections of the Basic Concepts text. It was emphasized by Teacher 2 that he was able to very closely adhere to the suggested time schedule and classroom program for the experimental class.

**Modifications in the Experimental Course Plan**

It was concluded in the previous section that the teaching strategies of Teacher 2's experimental class were more representative of the investigator's plan and intent than those of Teacher 1. However, the major modification of the experimental course plan that evolved from the formative evaluation phase (at the beginning of the school year) appeared to be equally valid for both school situations. This modification involved the investigator's plan for student group work, and student's formulating study questions in their own words. This plan was described on pages 54 and 55 in chapter III.

Both participating teachers found that students were unable
to verbalize the more sophisticated physics concepts, and time spent in verbalizing the simpler concepts was time wasted. In addition, students worked poorly in groups unless given a highly directive task to be performed in a minimum of time. For this reason, group work in the experimental classes was essentially limited to the following highly structured mathematical problem-situation suggested by Teacher 2; this exercise was also found to be effective by Teacher 1.

Groups of five students were given the assignment of making up and solving a problem in a specified subject area. These problems were to be used as "challenges" for another group of students, or for the teacher, who would have to solve the problem on the blackboard. This exercise occupies between one and two classroom periods; since students are required to solve their problem before using it to challenge others, meaningless or unsolvable problems are avoided. The element of challenge in this group problem-solving causes students to deal with problems that are on as advanced a level as their capacities allow.

Specific instruction in problem solving was given by Teacher 2 by means of sample problems for students to solve at their desks; these sample problems were incorporated into his lecture. He also utilized problem-solving labs. The advance organizer portion of the lecture (days one and two in the introduction to any new subject area) was, according to the course plan, not interspersed with sample problems but all additional classroom lecture utilized the sample problem technique. The
amount of time spent by Teacher 2 on systematic review varied according to need, but generally occupied one to one and a half weeks for each of the five major Basic Concepts units.

Teacher 1 allotted classroom time for students to work singly and together on problem-solving, study, and review. This time was often that left after a laboratory experiment was completed. He did employ the sample problem technique and also devoted classroom time to exercises on the order of problem-solving labs. According to interview data, the main thrust of Teacher 1's approach was, however, more inductive than expository.

Changes from the original plan in time allotments for the study of each subject area at School 1 have been described. At School 2 time allotments per unit were more rigidly adhered to; however, only four weeks at the end of the course rather than the projected six to eight were devoted to the study of modern physics. Despite this, School 2 students in the experimental class managed to achieve considerable depth in their understanding of this material as indicated by the cognitive examination performance on the Harvard Project Test.

Generally, it appears that Teacher 2 accurately carried out the major premises and intent of the experimental course plan; his time schedule differed from that projected mainly in that a somewhat higher proportion of expository lecture was utilized. This was to be expected in view of the highly academic and traditional nature of the School 2.
Teacher 1 stressed demonstrations and laboratory work in his classes. Sample problems were utilized, as well as expository lectures, and classroom time scheduled for review. However, the expository/organizer aspect of his approach seemed less systematic than the induction/demonstration focus which reflected his teaching philosophy. Thus the organizer function was performed by means of lecture-demonstrations in Teacher 1's classes. It would seem that Teacher 1's scheduling of classroom time for problem-solving instruction and planned review was less systematic and extensive than that suggested in the experimental course plan.

Consideration of Extraneous Variables in Effect

A number of extraneous variables were anticipated, to be compensated for in the course evaluation design. These variables are described in chapter III, pages 66-68. Information gathered during the course of the experiment indicates the following assessments of the effects of these variables on the results obtained:

1. Teacher personality/effectiveness variable. In both schools, students' overall course ratings, as replicated on a number of questionnaires, fell in the "fair to good" range. (These ratings will be further discussed on pages 99-100.) Both teachers seemed well able to generate the respect of their students and to maintain a productive classroom atmosphere. Therefore, this variable should cause no problem in the interpretation of affective (questionnaire) data. So for the
purposes of this experiment, the teacher-effectiveness variable can be said to have been "controlled."

2. Student aptitude variable. Results from the Engineering and Physical Science Ability Test indicated no significant differences at the .05 level between experimental and control classes at either school. These scores were analyzed by means of the F statistic; the difference between experimental and control class performances on the Ability Test at School 1 is given by a p value of .194; at School 2, by a p value of .107. However, because the School 2 result was close to being significant at the .10 level, all numerical (Harvard Project and Dunning) achievement test scores were subjected to a covariate analysis with the pre-test scores from the Engineering and Physical Science Ability Test used as the covariate.

3. Student attitude variable. A number of results from the pre-test questionnaire indicative of student attitude are reported on pages 129-131, 103-104. At School 1, there were no significant differences at the .05 level in distribution of experimental and control class responses on this pre-test questionnaire. At School 2, the only significant difference at this level was on a motivation index compiled by the investigator; this was largely a difference in distribution with the motivation index ranging from three (least motivated) to eight (most motivated) as summarized from the data. In both classes the majority of students fell under the number six category indicating good motivation for both experimental and control students.
4. Teacher attitude and performance. Taped interviews with teachers did not reveal any major biases against groups of students participating in the experiment. However, some difficulties with the initial experimental class at School 1 arose over the attempt to initiate student group work. The intended group project involved students working together on common areas of confusion to be designated by the students, not the teacher. Interview data with Teacher 1 indicated that students in the experimental class were not given the degree of leeway to choose these study areas that had been intended. Because of the failure of the initial group project and the resulting negative attitude towards group work on the part of Teacher 1 and the original experimental class, experimental and control classes were interchanged after six weeks. There was considered to be no danger of contamination of the old experimental-new control class since few learning materials had been distributed at that point.

It should be remarked that the group problem-devising and solving-project initiated in collaboration with the participating teachers was considered more successful than the previous plan, according to teacher reports. However, the initial failure of the planned group work learning project at School 1 was considered to result in negative attitudes toward group work on the part of Teacher 1 and students in the original experimental class. Though there were no other similarly negative responses to the experimental course plan during the experiment, Teacher 1 was reluctant to teach wave and field theory and modern physics
subject areas for which no classroom demonstration materials were available.

5. Student socio-economic class and sex differences. It was this difference in student population at the two schools that prompted the decision not to pool results. Sex differences seem to be most strongly reflected in student's career plan intentions as indicated by data from the pre-test questionnaires. Specifically, a higher proportion of School 1 students have career interests outside of the sciences; a lower proportion from School 1 reflected interest in careers in mathematics. Yet, a good number of School 1 students (nine in each class) did indicate career interest in the physical sciences. And the similarity of data from the two schools in areas relating to course expectations, preferred learning styles, and evaluation of specific classroom activities makes a number of generalizations possible in this study.

6. Teacher grading/student success variable. Questionnaire data indicated students rated themselves as doing average to well in their courses (see pages 99-100 for further discussion of these self-ratings). This was generally true of experimental and control classes in both schools. It is interesting to note the only major difference between self-ratings of students from the different schools was on the Harvard Project Exams. Here, School 1 students rated themselves poor to fair whereas School 2 students rated themselves fair to good.
(see further discussion of this rating on page 98). However, since students' ratings of their own success in their courses were generally fair to good, there are no indications that overall data might be biased by this attitudinal factor. Also, there were no statistically significant differences in final course grades administered by Teacher 1 to experimental and control classes (see cognitive test data, and letter grade scores, summarized in Table 5 on pages 90 and 91).

7. Laboratory program variable. Questionnaire data was designed to elicit separate evaluations of laboratory and classroom programs. On questionnaires administered to experimental and control classes in both schools, laboratory experiments were rated fair, or fair to good in terms of their usefulness as a learning activity. Students generally wanted to spend the same amount of time as allotted on experiments. On questionnaires administered to experimental classes only, School 2 students found lab experiments from not helpful to somewhat helpful in their ratings of various types of learning activities. Most students found both the non-laboratory part of the course and the lab program fairly interesting. Students in Teacher 1's experimental class found laboratory experiments from somewhat to very helpful. These results lead the investigator to conclude that in both schools, the laboratory program did not elicit a
markedly different student response from the non-laboratory part of the course. It seems reasonable to conclude that there was no extreme student reaction to the teacher designed laboratory programs which would bias ratings of other aspects of the course.

The above considerations can be summarized by noting that, among the anticipated extraneous variables, it was the teacher performance variable that had the most significant effect on the outcome of this experiment. In a number of respects, Teacher 1's experimental class cannot be said to have reflected the course design intended by the investigator. According to the original plan for the analysis of data, statistical comparisons are made only between experimental and control classes in the same school. But despite this, it was found that a number of generalizations about the learning style of the high school physics student could be made. Attitudes of students from both schools seemed sufficiently consistent and favorable to provide a coherent body of questionnaire data.

Data from Measurement Instruments

The data obtained during this experiment includes cognitive test scores and questionnaire responses. Questionnaires were designed to indicate student attitudes toward their particular physics course, the physics subject area, and their own success/satisfaction as a physics student. In addition, extensive data on optimal subject matter selection, learning activities, and time allotments (as applied to subject areas and learning activities) was gathered from all participating students.
In a number of cases, modifications were made in the cognitive test data obtained from School 1. The first of these modifications was necessitated by Teacher 1's failure to record numerical test scores on the Harvard Project Mechanics Test (rather, he recorded letter grades) before returning exams to students. Also, Teacher 1 used the Holt, Rinehart, and Winston Test from the 1968 edition of *Modern Physics* to test experimental and control classes in the subject area of "The Wave," rather than the Harvard Project exam. On this Holt, Rinehart, and Winston Test, he again recorded letter grades. He provided the final course grades that he gave to serve as additional data; though the investigator did not request this data, it was subjected to the same "crossbreaks" statistical analysis as the other letter grade scores provided by Teacher 1. Questionnaire data serves to indicate students' assessments of the relative difficulty of their teacher's exams and the Harvard Project exams.

Also, Teacher 1 failed to obtain the March-experimental only and May-experimental only questionnaires, which were never returned by his students. Among the questionnaires administered to the experimental classes only (rating specific aspects of the experimental course, and the *Basic Concepts* text), the January questionnaire was available for summary data from both schools; questionnaires administered in March and May were available from School 2 only.

Besides the modifications in the data-gathering plan described above, Dunning Physics Test data was obtained from
Teacher 1's classes only. This was done as a time concession to Teacher 2, who was caught in an end-of-the-year rush. Also, it was decided that the Dunning data would be redundant here since Teacher 2 had supplied a complete set of Harvard Project test data (representing approximately six and one half hours of testing during four time sessions). School 1 results from the comprehensive Dunning Physics Test somewhat compensate for the incomplete Harvard Project test data supplied by Teacher 1.

A probability level of .05 was generally considered to indicate statistical significance; a report of results follows.

General Procedures for Analysis of Data

The first consideration in the analysis of cognitive test scores is that of initial ability differences between experimental and control classes. For this reason, the MANOVA computer program was utilized in a covariate analysis, with the covariate being students' scores on the Engineering and Physical Science Ability Test; this analysis was chosen in the interest of obtaining a more accurate evaluation of differences in cognitive gains even though pre-test differences between experimental and control classes were not significant at the .05 level.

For the cognitive test scores reported in the form of letter grades only by Teacher 1, a crossbreaks analysis was used, by means of the SPSS program. Letter grades were placed in the four categories of A, B, C, and D or F; these scores were compared by experimental versus the control class distribution. For this crossbreaks analysis of ordinal data, the Kendall's
Tau C statistic was appropriate.

Consideration was also given to possible initial affective or attitudinal differences between experimental and control classes, as would be indicated on the pre-test questionnaire. This is discussed under Extraneous Variable in Effect (pages 80-85). It was thus noted that the assumption of no significant difference between experimental and control classes (in each school) was validated by the data.

The analysis of questionnaire data was performed by means of the SPSS program. A crossbreaks analysis was used for the three questionnaires administered to both experimental and control classes. Significant differences between experimental and control were determined by means of the following statistics, as appropriate:

(a) Corrected Chi Square - for a 2 x 2 crossbreak exhibiting nominal data;
(b) Chi Square - for a nominal data crossbreak that is not 2 x 2;
(c) Kendall's Tau B - for a 2 x 2 crossbreak exhibiting ordinal data;
(d) Kendall's Tau C - for an ordinal data crossbreak that is not 2 x 2.

It should be noted that the crossbreaks display of data, as printed by the SPSS program, was applicable to summary data generalizations as well as to a direct comparison of significant differences between experimental and control classes.
Summary data from questionnaires administered to experimental classes only was obtained by means of the codebook option of the SPSS program. Included here are three questionnaires administered at School 2 during the second semester (January, March, and May, 1974) and one questionnaire administered at School 1 (January, 1974).

In analyzing this questionnaire data, the investigator found that an objective approach involved attaching equal importance to similarities of response (as between experimental and control classes describing the types of learning activities they found most useful), as to statistically significant differences. The greatest importance was attached to statistical differences and summary-similarities that reflected overall patterns in the data.

Report of Statistical Results

In this section, the results of the analysis of cognitive test scores are reported. This analysis includes the covariate analysis of numerical scores, and the crossbreaks analysis of letter grade scores. Questionnaire results of special significance (selected on the basis of reflecting overall patterns from the data) will also be summarized in this and the following sections.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Number</th>
<th>Type of Test</th>
<th>p Level</th>
<th>Type of Analysis</th>
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<td>562  Engineering and Physical Science Ability Test</td>
<td>.194</td>
<td>F Test</td>
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<tr>
<td>567  Letter Grade Mechanics Test</td>
<td>.0000</td>
<td>Kendall's Tau C = -0.60523</td>
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<tr>
<td>568  Energy Test</td>
<td>.022</td>
<td>MANOVA covariate</td>
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<tr>
<td>572  Letter Grade Waves Test</td>
<td>.0007</td>
<td>Kendall's Tau C = .28419</td>
<td></td>
<td></td>
</tr>
<tr>
<td>576  Final Course Grade</td>
<td>.2159</td>
<td>Kendall's Tau C = .07018</td>
<td></td>
<td></td>
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<tr>
<td>575  Dunning Physics Test</td>
<td>.737</td>
<td>MANOVA covariate</td>
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### TABLE 5 - Continued

**Cognitive Test Scores**

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<th>p Level</th>
<th>Type of Analysis</th>
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<td>Engineering and Physical Science Ability Test</td>
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<td>F Test</td>
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<td>MANOVA covariate</td>
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<td>Correct Items Energy Test</td>
<td>.488</td>
<td>MANOVA covariate</td>
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<td>570</td>
<td>Correct Items Waves Test</td>
<td>.001</td>
<td>MANOVA covariate</td>
</tr>
<tr>
<td>573</td>
<td>Correct Items Modern Physics Test</td>
<td>.022</td>
<td>MANOVA covariate</td>
</tr>
</tbody>
</table>
A summary of cognitive test results is shown in Table 5 on pages 90 and 91 with statistically significant differences between experimental and control classes highlighted.

From this analysis of cognitive test scores, the following observations are especially significant.

1. On Harvard Project exams administered in all four subject areas (including mechanics, energy, waves, and modern physics), Teacher 2's experimental class received scores with a mean value as high or higher than those of the control class mean.

2. In Teacher 2's classes, the experimental class Harvard Project exam scores were higher than control class scores at a statistically significant p value of .001 for the waves subject area, and .022 for the modern physics area. (Again, these are the results of a covariate analysis--so experimental class exam scores remain significantly higher even after adjustment for initial ability differences.)

3. For Teacher 1's classes, there was no statistically significant difference between experimental and control class scores on the comprehensive Dunning Physics Test administered at the end of the school year. Also, there was no significant difference in distribution for the final letter grades administered by Teacher 1.

4. Exam scores on the mechanics test, energy test, and waves test administered by Teacher 1 were (statistically significant) higher for control classes. In those instances where letter grade scores only were available, this represents a
significant difference in distribution among the grades of A, B, C, and D or F. The fact that after six weeks the original experimental class became the control class for the duration of the experiment has been accounted for in this summary. No cognitive exam in modern physics was administered since the subject area was not taught by Teacher 1.

In the examination of questionnaire results, significant differences have been noted as they reflect overall data patterns, and are relevant to the objectives of the experiment. The following highlighting includes student responses on the usefulness of working with the assigned textbook; on evaluation of interest, difficulty, and time allotments for the modern physics subject; and on course evaluation criteria dealing with the perceived difficulty of the course, the quality of preparation for Harvard Project exams, and the student's estimation of his own success in the course. Also included is a rating of the course as a preparation for career goals in terms of student expectations.

1. Working with the assigned textbook. On the end of course questionnaire administered by Teacher 2, experimental class students rated more favorably than did control class students the usefulness of working with the assigned textbook. Here experimental students were referring to the Basic Concepts text; control students were referring to Genzer and Youngner.

The p value for Kendall's Tau C was .022, so this result is significant at the .05 level. For Teacher 1's classes, there was no statistically significant difference between experimental class
responses and control class responses to this question.

2. Evaluation of interest, difficulty, and time allotments for the modern physics subject area. Summary data from the March questionnaire administered to the experimental class only by Teacher 2 deals with interest and understandableness of learning material (listed by types in the Basic Concepts text) in the four subject areas of "Newtonian Physics," "Energy," "The Wave," and "The Field." This data showed that a higher proportion of students indicated a good (rather than fair) interest in "The Field" and "The Wave" as compared to interest ratings for "Newtonian Physics" and "Energy" subject matter. Also, a slightly higher proportion of students indicated an understandableness rating of material in "The Field" and "The Wave" as good (rather than fair), as compared to "Newtonian Physics" and "Energy." The fact that this more abstract learning material (taught from the Basic Concepts text) was considered somewhat more understandable as well as interesting than the more concrete introductory areas is also substantiated by results from the end of course questionnaire described below.

End of course questionnaire data supplied by Teacher 2 indicates that in the subject area of Einstein's Law there is a significant difference in rating of difficulty. The experimental class generally perceived the subject area as average in difficulty; control students perceived it as difficult. This difference in distribution is significant at a p level of .0000.
similar data is not available for other modern physics areas since material on the photon/quantum, electron energy levels, nuclear binding, radioactivity, fission and fusion, and sub-atomic particles was taught in the experimental class, but not in the control class. It can be noted that all of these modern physics subject areas were rated average in difficulty by most students in the experimental class. These difficulty ratings generally followed a normal distribution, with 13 to 21 students rating the difficulty level average, three to eight students rating such an area difficult, and three to four students rating each area easy.

The fact that students were genuinely interested in learning about these modern physics subject areas can be demonstrated by two examples from the data. First, when these areas were evaluated as interesting versus not interesting, the overriding majority of students (in the experimental class) rated these topics interesting by approximately a four-to-one ratio. As has been noted, control class students did not study many of these topics, so no control ratings are available. Experimental class students generally indicated a preference for spending the same amount, or more time, on these subject areas.

Second, for the Einstein's Law topic that was found so much more difficult by the control class, there was also a statistically significant (at a p level of .0068) difference in responses on time allotments. In this case, most control class students would have wanted to spend more time on Einstein's Law; most experimental class students found the actual time allotment
appropriate for their class, though a good number would also have wanted more time on the subject.

Favorable student ratings of studies in this modern physics area were also confirmed by summary data (again, rating interest, understandableness, and desired time allotments) on the questionnaire administered in May to Teacher 2's experimental class. Here, 68.0 percent of the students rated modern physics good in interest, as compared to 24.0 percent who rated interest as fair, and 8.0 percent who rated interest poor. This was overall the most favorable interest rating among the five major subject areas of the Basic Concepts text. On this questionnaire, students generally rated interest in the modern physics subject areas as fair to good; understandableness fair to good; and desired time allotments as the same or more. Especially high interest was expressed in nuclear binding and sub-atomic particles.

3. Perceived difficulty of the course. In response to the question, "How would you rate the difficulty of the course?" on the end of course questionnaire, there was a difference in distribution of responses between Teacher 2's experimental and control classes. The p level for Kendall's Tau C was .0597, the difference being significant at a .1 level. Although this is not a high level of significance for hypothesis testing, it seems worth noting that students in the experimental class generally perceived their course as easier than
did control class students. Two experimental class students perceived the course as very easy, whereas no control class students marked this category; four control class students perceived the course as very difficult whereas two experimental class students marked this category; and slightly more experimental class students perceived the course as average in difficulty, fairly easy, or very easy, than as very or somewhat difficult. However, most control class students perceived the course as very or somewhat difficult. The result seems especially noteworthy in view of the fact that there was a larger quantity of abstract learning material, especially in the modern physics area, taught in the experimental class. Also, in response to the question (also on the end of course questionnaire), "How well did you expect to do in the course?" there was no significant difference between experimental and control classes; that is, there was no initial bias evidenced here.

For the classes of Teacher 1, there was no significant difference between experimental and control student ratings of the level of difficulty of the course. There was, however, some difference in response pattern (Kendall's Tau C was significant at a p level of .0368) to the question "How well did you expect to do?" Here, control class students generally expected to do fairly well, experimental class students expected to do average to fairly well.
4. Quality of preparation for Harvard Project exams. Students in Teacher 1's experimental class generally rated themselves better prepared for Harvard Project exams than did control class students. These ratings on the end of course questionnaire were statistically significant with a p level for Kendall's Tau C of .0136. Generally, experimental class students rated their preparation for Harvard Project exams as fair; that is, the ratings form a normal distribution centered on fair. Most control class students rated themselves poorly prepared for Harvard Project exams. There was no significant difference between responses on this question of Teacher 2's experimental and control classes.

5. Applicability of course to career plans. Students were asked how the applicability of their physics course conformed to their expectations on question 12 from the end of course questionnaire. Teacher 1's experimental class students responded more favorably here than did control class students. The difference in response distributions was statistically significant at a p level of .0127 for Kendall's Tau C. Most experimental class students (all except three) considered their physics course to have been as or more applicable to their career plans than they had expected; most control class students (again, all except three) considered their course as or less applicable. There was no significant difference in experimental and control class response distribution to this question from
Teacher 2's classes.

6. Rating of success in course. This rating, on the end of course questionnaire, was obtained in response to the question "How would you rate your own success in this course with: homework problems, teacher's exams, Harvard Project tests, lab experiments, quality of preparation for future work?" In general, Teacher 1's experimental class students gave more favorable ratings on preparation for Harvard Project exams (as mentioned) and on preparation for future. There were no other significant differences on this question between control and experimental class ratings here.

For Teacher 2's classes, summary self-ratings for both experimental and control were fair to good on homework, good on teacher exams, fair to good on Harvard Project exams, fair on lab experiments, and fair to good on quality of preparation for future work and success in general. Differences in distribution were statistically significant on the latter two categories only; here a higher proportion of control students rated themselves good rather than fair. Equally few students from experimental as from control classes rated their success as poor on this question.

7. Rating of course as compared to expectations. In response to question 12 on the end of course questionnaire "In general, was this course as you expected it to be?", the only statistically significant differences between Teacher 1's experimental and control classes were that control classes
generally found the course more lab oriented, and less applicable to career plans than expected; whereas experimental classes found the course as lab oriented as expected, and as or more applicable to career plans. Teacher 1's students generally found the course as time consuming and as difficult as expected; more interesting than expected; and as or more math-oriented and lab-oriented than expected.

Teacher 2's experimental class students generally found the class as time consuming as expected. Control class students found it as or less time consuming. Most students in both classes found it as or more interesting than expected, generally as difficult as expected and as or more math-oriented. Additional evaluations shared in common by students in Teacher 2's experimental and control classes were that the course was less lab-oriented than expected, and as applicable to career plans (with, however, about one third of the students in each class finding the course less applicable to career plans than expected). Statistically significant differences here seem less meaningful than the summary information provided by the data. That is, Teacher 2's students generally found the course as expected, with the exception of providing less lab work and (for one third of the students) less direct future applicability.

One of the objectives of the experiment was to provide a course structure that would allow students to attain
greater self-confidence in the technical subject area; so student self-ratings were solicited from the questionnaire data. On the questionnaire administered in February to students in experimental and control classes, students were asked (question eight) "How do you feel that you are doing so far in each of these aspects of your course: general understanding of concepts and theories, success in problem solving, success in examinations, lab experiments, and problem-solving labs?"

Experimental and control class responses to this question obtained by Teacher 1 were significantly different in the areas of general understanding, lab experiments, and problem-solving labs. Experimental class students rated themselves more favorably in general understanding with most students feeling that they were doing well; though there were a good number of average ratings, there were no "poor" ratings from the experimental class here. Teacher 1's control class students rated themselves somewhat more favorably in laboratory experiments and problem-solving labs; ratings in both classes were generally average, but with many students rating themselves as doing well.

There were only two significant differences in responses to this question obtained by Teacher 2, and these seemed to "balance-out"—that is, control class students rated themselves somewhat higher in success with problem solving, experimental class students rated higher on problem-solving labs
(significant to a p level of .0567). As in Teacher 1's classes, those of Teacher 2 generally rated themselves as doing from average to well.

On the questionnaire administered in March to Teacher 2's experimental class only (the questionnaire was not returned from Teacher 1's students), most students rated themselves as doing as well as expected in the course (question seven). Specifically, four students rated themselves as doing better than expected, 20 as well, and five not as well as expected. It can generally be concluded on the basis of this data that students in both experimental and control classes were reasonably satisfied with their progress in the course. Students most often felt they were doing from average to well, according to their responses to the end of course questionnaire question ten.

The most divergent results in these summary ratings were obtained from Teacher 1's students rating their success on Harvard Project exams. These students did not rate themselves as being as successful on these exams as in most other aspects of the course. (There is no such discrepancy in self-ratings from students of Teacher 2.)

In general, the overall course ratings as obtained from question one of the February questionnaire (administered to experimental and control classes) were notably fair to good for both schools. Students were asked to "Please rate your
physics course on the following points: general interest, understandableness of concepts and theories, preparation for solving homework problems, preparation for exams, and learning about the type of subject matter anticipated." Ratings for interest and learning about type of subjects anticipated were especially good for both schools; ratings for preparation for solving homework problems were not quite so favorable but were nevertheless fair to good.

Despite the fact that Teacher 1's experimental class was not conducted as specified in the experimental course time schedule, a number of similarities between students at both schools became apparent in the data. Summary data was obtained dealing with students' learning styles, their expectations as to the type of course to be offered, their rating of the usefulness of various classroom activities, and suggestions for the appropriate balance of time allotments among these activities. This data revealed a considerable degree of "universality" among the two groups of high school students. The sampling from this data reported here may well indicate that there is indeed a "best" way of structuring the high school physics course.

In response to question three on the pre-test questionnaire, "I felt that I learn best from ...," few students marked studying alone. A number of students found classroom lecture valuable for learning, and many felt they learned best from problem solving. Although most students did not indicate that they learn best
from review for exams on this pre-test questionnaire, a number did subsequently find this learning activity valuable. In response to question seven, "I would like this course to stress . . .," both classes expressed interest in laboratory work and technology, and a general survey of the subject. Less interest was expressed in specifically mathematical, or historical subject matter, with the lowest interest in the "historical background of physics." It can also be noted that few students marked the response indicating that the course should simply stress "whatever is needed to make college physics seem easier." In other words, a purely futuristic orientation on the part of the students was not indicated.

Data from the questionnaire administered in February to experimental and control classes provides an evaluation of the usefulness of a number of learning activities. Neither experimental nor control classes found reading the textbook to be among the more valuable activities here. Rather, classroom lecture, problem solving in class, sample problems solved by the teacher, and class review for exams were found to be the most generally helpful by students in both schools. On an intermediate, or "somewhat" level of helpfulness were problem solving at home, studying at home for exams, studying alone, studying with classmates, group work in class, problem-solving labs, and lab experiments. This information was supplied in response to question three "Please rate the following aspects of the course
on how helpful you are finding them for your general understanding of the subject (skip those categories that have not been included in your class)."

Question four from this questionnaire requested student opinions on whether they would want to be spending more, less or the same amount of time on the learning activities named under question three. Confirming the above results, students generally wanted to spend more time on sample problems solved by the teacher, problem solving in class, and class review for exams.

Results from the questionnaire administered to experimental and control classes at the end of the course deal again with which type of course activity students would want stressed more (less, or the same amount) or would want more time spent. A composite of information from questions four, twelve, six and seven provide time/value ratings of lab and theoretical work, technology and machines, mathematical, historical or survey-type subject matter as well as college preparatory learnings and a stress on current developments. More time was desired for the study of current developments in physics; the same or less time was indicated for historical subject matter. Mathematical and college preparatory work also rated somewhat more time; laboratory, survey, and theoretical work rated the same time allotment as had been given. The similarity of these overall results between the schools seem to indicate that some generalizations about student priorities can be made.
Students were also asked to rate specific parts of their classroom program in question five on the questionnaire administered in January to experimental classes only. Learning activities were rated as very helpful, somewhat helpful, or not too helpful. Again, the most helpful learning activities were considered to be sample problems solved by teachers, and going over exams in class; also helpful were introductory lectures, asking questions in class, problem-solving labs, and in-class review. Somewhat helpful, but less highly rated than the preceding activities, were reading in the textbook, group projects in making up problems, and problem solving at home. Laboratory experiments were not considered as helpful by Teacher 2's students as by those of Teacher 1; but there were few differences in the overall rating pattern for the various types of learning activities.
<table>
<thead>
<tr>
<th>Not Too Helpful</th>
<th>Somewhat Helpful</th>
<th>Very Helpful</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reading in Textbook</td>
<td>Problem Solving at Home</td>
<td>Classroom Lecture</td>
</tr>
<tr>
<td>Studying at Home for Exams</td>
<td>Problem Solving in Class</td>
<td>Sample Problem by Teacher</td>
</tr>
<tr>
<td>Studying Alone</td>
<td>Class Review for Exams</td>
<td></td>
</tr>
<tr>
<td>Studying with Classmates</td>
<td>Group Work in Class</td>
<td>Problem-solving Lab Sessions</td>
</tr>
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<td></td>
<td></td>
</tr>
</tbody>
</table>
TABLE 7
Classroom Program Ratings: School 2, February

<table>
<thead>
<tr>
<th>Not Too Helpful</th>
<th>Somewhat Helpful</th>
<th>Very Helpful</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reading in Textbook</td>
<td>Classroom Lecture</td>
<td></td>
</tr>
<tr>
<td>Problem Solving at Home</td>
<td>Problem Solving in Class</td>
<td>Sample Problem by Teacher</td>
</tr>
<tr>
<td>Class Review for Exams</td>
<td>Studying at Home for Exams</td>
<td></td>
</tr>
<tr>
<td>Group Work in Class</td>
<td>Studying Alone</td>
<td></td>
</tr>
<tr>
<td>Studying with Classmates</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Problem-solving Lab Sessions</td>
<td>Laboratory Experiments</td>
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</tbody>
</table>
### TABLE 8
Classroom Program Ratings:
School 1, End of Course

<table>
<thead>
<tr>
<th>Not Useful</th>
<th>Fairly Useful</th>
<th>Very Useful</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Assigned Text</td>
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<td></td>
<td>Other Texts</td>
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</tr>
<tr>
<td>Lecture</td>
<td>Laboratory Experiments</td>
<td></td>
</tr>
<tr>
<td>Sample Program by Teacher</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Problem Solving at Home</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asking Questions in Class</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Studying with Classmates</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Discussing Mistakes on Exams</td>
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TABLE 9
Classroom Program Ratings:
School 2, End of Course

<table>
<thead>
<tr>
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<th>Very Useful</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assigned Text</td>
<td>Other Texts</td>
<td>Lectures</td>
</tr>
<tr>
<td>Studying with Classmates</td>
<td>Sample Problem by Teacher</td>
<td></td>
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<tr>
<td>Problem Solving at Home</td>
<td></td>
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</tr>
<tr>
<td>Laboratory Experiments</td>
<td>Asking Questions in Class</td>
<td>Preparing for Exams</td>
</tr>
</tbody>
</table>
### TABLE 10

**Classroom Program Ratings: School 1, January**

<table>
<thead>
<tr>
<th>Not Too Helpful</th>
<th>Somewhat Helpful</th>
<th>Very Helpful</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introductory Lectures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sample Problem by Teacher</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asking Questions in Class</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reading in Textbook</td>
<td>Problem-solving Lab Sessions</td>
<td></td>
</tr>
<tr>
<td>Group Projects</td>
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<tr>
<td>In-Class Review</td>
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<tr>
<td>Problem Solving at Home</td>
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<tr>
<td>Preparing for Exams</td>
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<tr>
<td>Discussing Mistakes on Exams</td>
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<tr>
<td>Laboratory Experiments</td>
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### TABLE 11

Classroom Program Ratings: School 2, March

<table>
<thead>
<tr>
<th>Would Have Wanted</th>
<th>Would Have Wanted</th>
<th>Would Have Wanted</th>
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<tbody>
<tr>
<td>Less Time</td>
<td>Same Amount of Time</td>
<td>More Time</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introductory Lectures</td>
</tr>
<tr>
<td>Sample Problem by Teacher</td>
</tr>
<tr>
<td>Asking Questions in Class</td>
</tr>
<tr>
<td>Reading in Textbook</td>
</tr>
<tr>
<td>Problem-solving Lab Sessions</td>
</tr>
<tr>
<td>Group Projects</td>
</tr>
<tr>
<td>In-Class Review</td>
</tr>
<tr>
<td>Problem Solving at Home</td>
</tr>
<tr>
<td>Preparing for Exams</td>
</tr>
</tbody>
</table>
Analysis of the Significance of Results

As has been emphasized, the results to be highlighted here will be those which are representative of an overall pattern of statistical differences (or similarities). This caution should prevent poorly substantiated conclusions; that is, overall conclusions should not be based on a single instance of statistical significance in questionnaire data. Generalizations reported in this section are considered to be educationally as well as statistically significant, because they reflect a consistent pattern of cognitive or affective responses.

Results will be considered in terms of the following priorities for the experimental course:

1. Inclusion of theoretical learning material in electromagnetic wave theory and modern physics within the one year course. In his experimental course, Teacher 2 devoted four weeks exclusively to the "Modern Physics" section, and material on "The Wave" was taught in depth. This was reflected in cognitive exam scores; on the Harvard Project exams in "The Wave" and "Modern Physics," experimental class students scored higher (statistically significant results). This inclusion of more current learning material is considered to have been accomplished without sacrificing cognitive gains in the traditional "Newtonian Physics" or "Energy" subject matter. On these first two Harvard Project exams, there was no statistically significant difference in test scores between experimental and control classes (although experimental class mean scores were slightly higher). As has
been noted, these are results from a covariate analysis, with students' scores on the Engineering and Physical Science Ability Test used as the covariate; so initial ability differences (which were not, however, found to be significant at the .05 level) have been taken into account.

This objective of including modern physics learning material in the one year course was not attempted by Teacher 1. Both because his time priorities lay elsewhere, and because he felt the available experimental/demonstration materials in the more theoretical subject areas were inadequate, he did not cover electromagnetic wave theory or modern physics in his experimental class.

2. Presentation of this modern physics material in such a manner that it would not be considered overly difficult by students. Among the modern physics subject areas, Einstein's Law was the most advanced that was taught to both experimental and control classes by Teacher 2. This subject area was perceived as average in difficulty by most students in the experimental class, but difficult by most control class students; the level of statistical significance here is very high, Kendall's Tau C is significant at the .0000 level. It can also be noted that control class students also found learning material on the electric field more difficult (the p level here for Kendall's Tau C is .0660), and control class students found material on the electromagnetic wave more difficult (the
3. Motivating interest in modern physics learning material. This objective is considered especially relevant since these are the areas in which a physicist would actually work. Both experimental and control class students of Teacher 2 expressed considerable interest in this area. For experimental class students (who studied Einstein's Law, the photon and quantum theory, atomic energy levels, nuclear binding, radio-activity, fission and fusion, and sub-atomic particles), the ratio of interest to non-interest was approximately four to one. About half of the experimental class students found the amount of time spent on each of these areas appropriate; and half would have wanted more time. Most control class students would have wanted to spend more time on Einstein's Law. Also note that most students in experimental and control classes would have wanted more stress on current developments in modern physics (only one student in each class would have wanted less stress here).

4. Utilization of learning facilitators including specific problem-solving instruction, and planned in-class review to make this technical subject easier for students. On questionnaires administered to experimental classes only (January, March, and May at School 2; January only at School 1), students were asked to rate a number of learning activities as not helpful, somewhat helpful, or very helpful. Activities uniformly
rated among the most helpful by students from both schools were sample problems solved in class and in-class review. Introductory lectures, which were to serve as advance organizers, were rated somewhat to very helpful. A good number of Teacher 2's students (approximately half the class) would have wanted to spend more time on introductory lectures, asking questions in class, problem-solving labs, group projects, preparation for exams, and lab experiments. Approximately two thirds of the class would have wanted to spend more time on sample problems solved in class, and in-class review.

The learning activities designated here are generally not unique to the experimental course design; rather, they are a part of most teacher's repertoires. However, the relative time allotments devoted to these activities might be questioned on the basis of the data. Note that Teacher 2 generally spent one and one half days in introductory (advance organizer) lecture for each new sub-section of the Basic Concepts text. Additional lecture time was devoted to solving sample problems in class; about one to one and one half weeks of directed in-class review was scheduled for each of the five major Basic Concepts sections.

Students did not consider textbook reading or problem solving at home worthy of more time. Most would have wanted to spend the same amount, or less time, on these learning activities. It might be stipulated that the need for more
teacher direction is indicated by these results; that is, students may secure reinforcement of previously learned skills through at-home study, but technical problem solving, and conceptual clarifications (gained through review prior to exams) must be taught.

5. Inclusion of Basic Concepts textbook material in a format consisting of introduction/examples (experimental or empirical observations)/and explanation. This format was developed to lead the student through more orderly thought processes and lessen the "cognitive load." When explanatory material is not sectioned in this manner, the student is often confused by simultaneously attempting to grasp a highly theoretical explanation, and attempting to identify the class of phenomena to which the explanation applies. Results from the questionnaire administered in March to Teacher 2's experimental class indicate especially high ratings, in interest and understandableness, for the following sub-sections of the Basic Concepts text:

(a) Wave Demonstrations;
(b) The Traveling Wave and the Obstacle;
(c) Experiments Involving Forces on a Current-Carrying Wire in a Magnetic Field;
(d) Explanation for Experiments.

These were the sections that relied most heavily on the example/explanation approach. Examples were presented in the form of a documentation of laboratory results (with diagrams).
Explanations "picked-up" where the examples left off, with a summary, then an explanation, of these results.

6. Selection of subject matter to be included in the Basic Concepts text so as to provide a coherent body of theory. This, again, is suggested by the theories of Ausubel for the purpose of permitting the student to comprehend how the "parts" of the conceptual framework fit together to form the "whole."

On questionnaires administered in January and March to Teacher 2's experimental class, students were asked to rate each sub-section of the Basic Concepts text (covered to date) in terms of interest, understandableness, and preferred time allotments. This data was obtained from question six on the January questionnaire and question one on the March questionnaire. For interest ratings, an average of only two students rated interest poor for each sub-section title; for understandableness ratings, the average number of poor ratings was approximately 2.5. The total number of students who gave ratings here ranged from 17 to 29. Question four on the May questionnaire provides similar data.

The only Basic Concepts sub-section for which the interest rating was not above average (that is, averaging higher than "fair") was "Electric and Magnetic Field Formulae." All sections averaged higher than fair in understandableness. Some credit for these high ratings must be given to the presentation of the textbook material by Teacher 2, but class satisfaction with the subject matter selection is evident.
Since Teacher 1 taught so much of his own learning material in his experimental class, and did not progress into the theoretical areas of electromagnetic field theory and modern physics (as covered in the Basic Concepts text under "The Field," "The Wave," and "Modern Physics"), the investigator hesitated to attach a great deal of significance to Teacher 1's experimental class ratings of subject matter selection.

7. Deletion of anecdotal and historical learning material from Basic Concepts textbook format (again, in accordance with Ausubel). This represents a conscious attempt to avoid confusing students with unrelated or inessential material, or ideas that are only partially explained. Questionnaire data uniformly indicated that the area of lowest student interest was historical material; also, that students felt that (proportionally) the least time should be allocated to this area. It should be noted that the low interest rating for historical subject matter initiated with the pre-test questionnaire; that is, it was not a result of the non-inclusion of this type of subject matter in the Basic Concepts text. (See Tables 6 through 11, pages 107 to 112, for a summary of student ratings of learning activities from the February, End of Course, January, and March questionnaires.)

Another category of questionnaire data also substantiates the decision to eliminate historical material from the experimental course. This is in the area of time allotments. It
can be observed from all questions on whether the student would have wanted more, less, or the same amount of time on a particular subject area that students would seldom have felt comfortable with less time. The trend is to request the same amount, or more time on all areas. This "time-bind" that so often develops in the high school physics course indicates that the educator must seriously weigh his priorities. Subject matter that can be designated as inessential should be eliminated.

8. Advance and perceptual organizers included in the Basic Concepts textbook format. This is in accordance with the theories of Ausubel; the advance organizer informs the student of what he is to look for in subsequent readings; the perceptual organizer provides him with a categorical label to which he can relate his learnings. The textbook format was generally rated fair by Teacher 2's experimental class (ratings formed a perfect normal distribution). Written responses on questionnaires indicate the students' objection to this format was simply that illustrations were not more professionally rendered. Fourteen out of 21 of Teacher 1's students rated the textbook format as good. Teacher 1 noted that students found organizer charts especially useful, and he was having difficulty in preventing students in the experimental class from sharing this information with control class students.

On the basis of this data, it is difficult to form a conclusion on the effectiveness of the organizer format.
Cognitive exam scores from the experimental class of Teacher 2 were sufficiently favorable so that it can be assumed that a textbook written in outline form was in no way detrimental to learning. Both participating teachers described the text as reasonably successful with their students.
Chapter V
Conclusions and Recommendations

Special Concerns in Interpreting Data

Cognitive and questionnaire data must be interpreted in view of information shown to the investigator about the specific classroom situations. The significantly higher achievement scores attained by Teacher 2's experimental class students in "The Wave" and "Modern Physics" can be taken at face value since it is known that he was able to teach more of the subject matter from these areas to his experimental class. But cognitive data from non-objective tests and questionnaire data must be subjected to closer scrutiny.

Among the cognitive test score data from Teacher 1's classes, the Dunning Physics Test is considered to be a more accurate indicator of achievement than letter grades or teacher made tests. This caution applies equally to the assessment of students' self-ratings of success. It was pointed out in section 4E that though Teacher 1's students generally rated themselves as doing from fair to good in the course, they did not rate themselves as being as successful on the Harvard Project exams as in other aspects of the course.

In rating himself, a student is primarily comparing his
own work to that of his classmates. If overall course work is somewhat below the national norm in achievement (as appears to have been the case at School 1 according to Dunning Physics Test data), a student can rate his own work quite highly, but still be suffering from inadequate preparation in the subject. Harvard Project exams are considered to provide an objective indicator here; and the point can be debated whether a student is done a disservice in being made to feel that he is a fair to good physics student if his course does not reflect generally acceptable standards.

Results reported in these sections were chosen on the basis of being reflective of a general pattern in the data and interpretable in terms of the overall objectives of the investigator and the participating teachers. For example, statistically significant differences, such as those that arose between Teacher 1's experimental and control classes in response to question eight on the February questionnaire generally have not been reported. Students responded to "How do you feel you are doing so far in each of these aspects of your course?" with experimental class students rating themselves higher in general understanding and control class students rating themselves higher in lab experiments and problem-solving labs.

The investigator did not feel justified in concluding here that students in the experimental class were gaining a better conceptual understanding of the subject, but control
students better problem solving ability, since neither of these statistical differences were substantiated throughout the data. This type of result seems best interpreted as random differences in distribution especially since Teacher 1 did not differentiate between experimental and control classes in the laboratory program provided.

The type of student self-rating that has been interpreted as being more significant is exemplified by responses from Teacher 1's control and experimental classes to questions ten and eleven from the end of course questionnaire. When students were asked, "How well did you expect to do in the course?" expectations for both classes centered around average to fairly well, but control students' initial expectations were significantly higher (the p level for Kendall's Tau C was .0368). But in response to the question, "How would you rate your own success in the course?" students from the experimental class rated themselves significantly higher on success on Harvard Project exams (Kendall's Tau C significant at a p level of .0136) and on preparation for future work (Kendall's Tau C significant at a p level of .0696). There were no other significant differences here (i.e. control class students did not rate themselves higher than experimental class students in any of these areas). Thus this result may be worth noting as indicative of a gain in self-confidence for students in the experimental class.

Another series of statistically significant differences
that may shed light on the overall outcome of the experiment arose on the end of course questionnaire administered to Teacher 2's students. Experimental and control classes evaluated the perceived level of difficulty of a number of specific subject areas taught in both courses. In their overall distribution of responses, control students found mathematical work (including vectors, graphing, and slide rule) easier as well as electrical circuits, and heat and sound. Students in the experimental class generally found easier the electric field, the electromagnetic wave, and Einstein's Law. These differences in distribution of responses are significant at the .05 to .10 level, as given by Kendall's Tau C.

Because these results seem indicative of a difference in thrust between experimental and control classes, they exemplify the type of data that should be reported. The traditional (control) class spends a great deal of time on less abstract subject matter upon the assumption that more modern material is beyond the student's understanding within the time limitations of the one-year course. Students also may come to reflect the attitude that conceptually--rather than empirically--based insights are beyond them. It should be noted that experimental class students did not generally find mathematical work, circuits, or heat and sound difficult; rather, most students marked average on these questions. However, these student ratings of subject area difficulty were not reflected in
cognitive exam scores, since experimental class means were uniformly as high or higher than control class mean scores. The fact that student ratings of the perceived difficulty of a particular subject area may not be directly related to cognitive achievement in that area should also be kept in mind.

An additional factor that must be taken into account in interpreting questionnaire data is the existence of an overall trend of class responses, resulting from personality factors or previous learning experiences of these students. This consideration is exemplified by the rating of the Basic Concepts text on questionnaires administered in January to experimental classes. Most School 2 experimental students rated the text fair (some rated the text good) in interest, understandableness, preparation for problem solving, and writing style. Overall ratings were good for selection of subject matter. Most School 1 experimental students rated the text good in all of the above areas. There is no way to substantiate an interpretation of results such as these which could reflect previous experiences with textbook materials or other attitudinal factors.

It is also generally observed, for the purpose of interpreting questionnaire data, that questions asked of students regarding their future plans elicit no guarantees as to what they actually will do in the future. Nevertheless, such questions can be valuable for eliciting present attitudes toward the area in question. Question 12 on the February
questionnaire asked experimental and control class students if they plan to take another physics course and, if so, what type of course. Differences in experimental and control class responses to this question were evaluated by the Chi Square statistic. The statistical difference in distribution of responses from School 1 was significant at a p value of .0833. A greater proportion of control class students were planning to take a physics course in college; more experimental class students intended to take advanced placement physics during their senior year. From School 2, there was no statistically significant difference in experimental and control class responses to this question, though a greater number (thirteen as compared to five) of students from the experimental class was planning to take one more physics course in college.

Generally there was no significant difference between experimental and control class distributions (from both schools) in response to the effect of the course on future plans. This was evidenced by responses to question two on the February questionnaire. It should be noted that these future plans responses were generally more favorable at School 2 than at School 1. In response to question 12 on the end of course questionnaire, Teacher 1's experimental class students generally found the course more favorably applicable to their career plans than expected, as compared to control class students. The statistical significance
here is given by Kendall's Tau C, at a p level of .0127 (see variable 558 in Appendix G). There was no significant difference between Teacher 2's experimental and control classes in response to this question; most students in both classes do intend to study more physics.

Features of the experimental course plan most likely to increase motivation included modern physics material that was not overly difficult for students; sample problems solved in class to provide explicit problem solving instruction; a more selective inclusion of learning material in the Basic Concepts text; and planned in-class reviews. If indeed there does prove to be a difference between the proportion of experimental versus control class students who are motivated and able to continue successfully in the subject, a careful interpretation of the data would probably attribute this difference to one or more of the above features.

General Conclusions From This Study

Cognitive test results have been interpreted in the previous section; the significantly higher Harvard Project exam scores in "The Wave" and "Modern Physics" have been noted, as achieved by Teacher 2's experimental class. This is considered to indicate the fulfillment of one of the major objectives for this study. Teacher 1's cognitive test results were less favorable, and difficult to interpret when reported in non-standardized form. Questionnaire results were considered
especially valuable when coherent patterns of response were identified; the many similarities in student ratings of the usefulness of various types of learning activities, and suggested time allotments for these activities, have been noted. The overall coherence of these results gained from the questionnaire data indicates that mature and serious student responses were obtained here.

An evaluation of the results of this study, in respect to a number of specific priorities set by the investigator, was given in section 4F. These priorities included instruction in the modern physics area, more careful selection of subject matter, and the use of a number of learning facilitators incorporated into the Basic Concepts text and classroom program. But some questionnaire results were so general in their applicability (this can be termed a time/utility analysis of the high school physics course), even an educator who does not subscribe to the priorities of the investigator would wish to note certain recurrent patterns of the data.

Question seven on the end of course questionnaire asked students to circle the responses that reflected their opinions on, "Do you feel that a course like this should ...?" Very few students in either school marked response d, "be geared to the people who are not planning to take physics in college more than to those who are, so that the amount of homework will not be excessive," or response f, "just be made as easy as possible." Students who sign up for physics as a high school
elective are not looking for a "quick and easy" credit. Most students from School 1 checked response e, the course should "just be made as interesting as possible." The majority of School 2 responses were also to option e, as well as to option b, "cover the subject in whatever way will be the most helpful for college physics."

However, on the pre-test questionnaire, in response to questions seven ("I would like the course to stress:") and eight ("I would like this course paced so as to:"), most students from both schools expressed a preference for laboratory work, technology and machines, and a general survey of the subject content. Few students marked a preference for the primarily college-preparatory option of "whatever is needed to make college physics seem easier" and/or "cover the whole text even if some students are left behind." Also, few preferred a stress on mathematical aspects of physics and problem solving, or historical background of physics.

In response to question ten on the February questionnaire ("In general, on what basis do you feel that subject material should be included in a course like this?"), the preparation for college physics was one of the least frequently marked options by students from both schools. Rather, students generally thought material should be included on the basis of being the type of thing that is easy to remember, and interesting even for people who will not take another
Students also considered preparation for careers in engineering or physical sciences, preparation for work with tools and machines, and interest for people who like math to be of some value.

This data can be summarized with the observation that the selection of interesting subject matter is a first priority with students; the preparation for specific careers in the physical sciences is also a priority, but not a first one. Few students marked preference for the "as easy as possible" option, or the "even if some students are left behind" option. In short, student priorities seem highly similar for the two school populations represented here. These priorities also seem compatible with the educator's "humanistic" goal—that is, to provide an interesting course, adequate for future specialists, but certainly accessible to non-specialists as well.

It was cited under the Report of Statistical Results (section 4E) that certain types of learning activities were uniformly rated as more valuable than others. This data is exemplified by responses to question two from the end of course questionnaire ("Please rate the following parts of your course on how useful you found them--please skip those things that you haven't done."). Rated as very useful were classroom lectures, sample problems solved in class, as well as asking questions in class, preparing for exams, and
discussing mistakes on exams. Working with the assigned text and other textbooks, laboratory experiments, and studying with other students were generally rated as fairly useful. Few students rated any of the learning activities listed here as not useful, but working with textbooks was the least highly rated of the ten options.

Results such as these (also reported on pages 103-112) substantiate the premise that the highest possible proportion of class time should be devoted to teacher-directed reinforcement of conceptual understandings and problem-solving skills. Students need professional instruction, from their teacher rather than from fellow classmates, to prepare for problem solving and test taking.7

These results tend to confirm the preference for expository teaching subscribed to by Ausubel. It can be added that students should be given practice (to provide reinforcement) in performing problem-solving skills demonstrated at the blackboard by the teacher. The sample problem solved at the student's desk which immediately follows the problem-solving demonstration performed by the teacher was widely used by Teacher 2. Teacher 1 also endorsed this strategy, though he described his overall approach as inductive learning based on teacher demonstrations. The sample problem technique is widely used by math and science teachers and can in no way be considered an innovation specific to this experiment.
However, a great deal of substantiation for the value of this technique as perceived by students was evidenced by the data reported here.

It should also be noted that the basis of the functional approach, which provides much of the rationale for the experimental course plan, is to emphasize the use of physics concepts (as in problem solving) and their place in the overall scheme of the science. Those learning activities most highly rated by students such as sample problems solved in class and reviewing for exams seem especially representative of this approach. Directed problem solving illustrates how a concept is used; planned review emphasizes the overall conceptual scheme of the unit.

The use of questionnaire data to obtain students' ratings of the interest, difficulty, and appropriate time allotments for specific subject areas makes possible the pinpointing of "trouble areas." These subject areas which may cause special difficulty will not necessarily be the same for every class even if students are exposed to essentially the same curriculum. This type of result was especially apparent from the responses of Teacher 1's control and experimental classes to the end of course questionnaire.

This subject area analysis from Teacher 1's classes did not reveal notable differences in content areas taught in control and experimental courses. However, it is interesting
to note that students in the initial control class (which was then assigned as the experimental class after the first six weeks) found more difficult the study of motion, and also would have wanted to spend more time on this area. Students in the control class (control from the sixth week onwards) had more difficulty with light—lenses, reflection and refraction and would have wanted to spend more time on reflection and refraction. The statistically significant differences in experimental versus control class ratings have been highlighted because the rating of difficulty specifically corresponded to a request for more time.

Teacher 1 did report some difficulties with his initial experimental class during the first six week period when the study of motion was introduced. This data substantiates Teacher 1's observations and demonstrates the overall applicability of this type of research pinpointing trouble areas for a particular class.

Similar data from School 2 revealed a statistically significant tendency on the part of the experimental class to perceive subject material in electromagnetic wave theory and modern physics as average in difficulty whereas control class students perceived it as average to difficult. These results were elaborated on pages 94-96 and pages 114-115. It is interesting to note that these results did not necessarily correspond with a statistically significant difference whereby control class students would have wanted to spend more time
on these subjects. Rather, students in the experimental class generally would have wanted to spend the same amount, or more time on the electric field, and the electromagnetic wave. A greater number of control class students simply wanted to spend the same amount of time on these areas; these differences in distribution are statistically significant at the .05 level. Here, the request for more time on the part of the experimental class seems to reflect not a trouble area, but rather a subject area perceived as less difficult, but more worthwhile.

It has been noted that few students actually want to spend less time on anything in high school physics. This is one of the problems of the physics course in general, and the reason why a careful selection of subject content material is imperative. Whether the students' continued requests for "more time" reflect frustration and confusion with the learning material, versus an in-depth appreciation of the possibilities of the subject, stipulates a major concern for the educator.

Significance of the Study as Compared to Other Research

Major aspects of the innovative course design evaluated in this study include use of the Basic Concepts text (incorporating a number of learning facilitators and a specific selection of subject matter), a number of instructional aids in the classroom program, and the overall rationale of the functional approach. Cognitive test data seemed conclusive from School 2
only, since the selection of subject matter taught by Teacher 1 was not as specified by the experimental course plan. Questionnaire data assessed initially and terminally student preferences as to the focus of the course; evaluations of various learning activities; and ratings of interest, difficulty, and optimal time allotments for specific subject areas. As has been mentioned, much of the information gained from this questionnaire data will be applicable to any classroom situation where a technical subject is being taught. This should be the case even if many of the specific objectives of the instructor differ from those of the investigator.

One issue raised in the professional literature regards the problem of developing a college preparatory versus a terminal course, or a course equally valid for either goal. Results of this study indicated that few students felt that their course should "cover the whole textbook even if some students are left behind" or be exclusively college preparatory in thrust (pages 129-131). It can also be noted that School 1 offers advanced placement physics in the senior year to college bound students who have completed the regular course during their junior year.

Another problem emphasized by many instructors involves teaching concrete versus abstract subject matter. The investigator found this very much in evidence during the course of the experiment. This reluctance to teach concepts not practically demonstratable in the classroom formed much of Teacher 1's
rationale for subject matter selection. It has been demonstrated through the course of this experiment that Teacher 2's experimental class students achieved superior cognitive test scores in these areas; and that students demonstrated a high interest in this conceptually-oriented subject matter. (See pages 94-97 and pages 113-115.) It can also be noted that Teacher 1 expressed the intention of teaching more wave and field theory during the subsequent (1974-75) school year, though he did not clarify the reasons for this change in policy.

The teaching rationale characterized by the functional approach seems to have been substantiated by students' estimations of the value of various learning activities. Students find solving sample problems in class and planned review most valuable; reading the textbook (or other supplementary texts) is regarded as least valuable, with solving problems at home also not too highly rated. (See pages 103-112.) The data reinforces the plea for specific problem-solving instruction and for planned assistance in fitting ideas into an overall conceptual framework--again, in accordance with emphasizing how ideas are used.

Also emphasized in these ratings was the value of expository teaching. Reading the text, studying at home, and studying with other students were uniformly rated as less valuable than introductory lectures, sample problems solved in class, and in-class review. The uniformity of results here contradicts the study by Andrews (1964). Though some
of the instructional methods rated by students in Andrews' study were not included in this investigator's assessment, her results were also less conclusive. Andrews did consider laboratory experiments, problems in text, summarizing review, and tests among the learning activities to be rated. She found that, for the attainment of learning goals, no specific methods of instruction were uniformly most highly rated (see page 27).

The highly useful ratings given to expository teaching methodologies by students from both schools in this study raises questions as to the efficacy of instituting an individualized physics program. Euller and Smith (1973) report favorably on the individualized course that was used to replace all traditional physics courses at Eastridge High School. Results of this investigator's study, however, do not support the individualized instructional approach, especially where most of the student's time is devoted to solitary, self-taught "programmed-type" activities. Students participating in this study did rate studying with classmates as more useful than reading the text, or problem solving at home, but less useful than the expository teaching methodologies.

As has been noted, the PSSC physics course was partially based on student attainment of insights through inductive reasoning (replacing some expository teaching), and many more recent science programs also pick up on this trend. Teacher 1 planned his strategy on the basis of this inductive reasoning
process to follow up classroom demonstrations; Teacher 2 made no special effort to stimulate inductive thought processes as a part of his instructional methods. The direct comparison of cognitive exam scores from Schools 1 and 2 has been carefully avoided in the interpretation of results of this study, since the difference in student populations alone could account for the superior scores attained by Teacher 2's classes. For this reason, no substantial conclusions can be formed in regard to the efficacy of inductive teaching. It can simply be stated that none of the evidence here suggests that students learn more easily through the process of exercising inductive thought patterns.

Results of this study tended to dispute the premise of the widely accepted Harvard Project Physics program that historical subject matter is motivating. Students from both schools expressed the least interest in historical subject matter of any of the suggested emphases or "focusses" for the course. (See pages 103-106 and pages 119-120.) It must be cautioned that this result cannot be interpreted as implying that the historically based Harvard Project course is not motivating. But it does raise the question as to which aspects of the Harvard Project course are most responsible for its widespread acceptance.

Research results on the high school physics course tend to be highly divergent in nature, probably because formal research is rare, and informal research tends to emphasize its
successes. It is always safer to raise questions than to attempt to substantiate conclusions. And in this study the following widespread practices in high school physics instruction have been questioned:

(a) The virtue, or value, of spending the first semester of the course on mechanics;
(b) The usefulness of stimulating inductive thought processes as an instructional strategy;
(c) The value of "repackaging" the physics program into an individualized, self-instructional course;
(d) The motivating nature of historical learning materials;
(e) The presumed inability of the first year student to grasp conceptual material on the electromagnetic wave and modern physics.

A number of statistically significant results and uniform patterns of summary data were obtained through the medium of this study. Hopefully, these results will help educators in their decision-making processes; data on the inclusion of modern physics and the types of learning activities considered most helpful may be especially relevant here.

Suggestions for Further Research

A major value of this type of study as a model for further research lies in the acquisition of both cognitive test scores and questionnaire "attitudinal" data. Many educators despair
of obtaining results from classroom research projects that can be replicated. The number of "unknowns" in the areas of teacher behavior and student characteristics is formidable. And it is too often necessary to rely on word of mouth reports as to what was actually done in the classroom.

At both schools that participated in this study, experimental and control class students generally rated their physics course as fair to good. These ratings were obtained in response to question one on the February questionnaire, "Please rate your physics course on the following points: ...," and question two on the end of course questionnaire, "Please rate the following parts of your course on how useful you found them: ...." For the February rating, students from both schools were least enthusiastic about being well prepared for solving homework problems, giving ratings of fair to good. They were most enthusiastic about the course being generally interesting, giving ratings of good here. On the end of course questionnaire, students were least enthusiastic about the utility of working with the assigned and other texts, rating this learning activity as not useful to fairly useful. They showed the greatest enthusiasm regarding the value of lecture, sample problems solved in class, asking questions in class, and preparing for and discussing exams. These highly consistent results seem most applicable to classroom planning. It is cautioned, however, that
student satisfaction is but one criteria for course evaluation; cognitive gain must also be considered.

One of the priorities of this experiment was to increase the range of learning material included in the one year course (to include electromagnetic wave theory and modern physics) without increasing the academic burden on students. Results reported in previous sections substantiate the fact that this objective was attained for Teacher 2's experimental class. Future research in this area will be useful for the purpose of assigning optimal time allotments to the most effective learning activities; validating the appropriate subject matter selection for the one year course; and dealing with those "universal" teaching elements which make students rate a course as favorable. The areas of usefulness of the many learning facilitators incorporated into the Basic Concepts text should be verified. And research on students' initial (and subsequent) motivation and confidence in this subject should be applied to the teacher's moral commitment to provide decent academic preparation, together with his practical commitment of maintaining favorable ratings from his students.

Specifically, follow up research can be focussed on obtaining specific evaluations of a number of learning facilitators that have been utilized for this study. The aspects of experimental course design listed here are chosen on the basis of research results. The following seem to represent the type of instructional plan most likely to prove successful
in future efforts:

(a) The use of outline format textbook or supplementary material, with historical and anecdotal information deleted from the text;

(b) The use of advance and perceptual organizers, sections on problem-solving hints, and problem solving and organizer charts in the text or supplement;

(c) The use of a non-individualized and generally expository classroom teaching basis;

(d) A classroom teaching format including introductory lectures serving as advance organizers which complement the organizer textbook format;

(e) The selection of classroom learning facilitators based on the functional approach; these include specific problem solving instruction and planned in-class review to emphasize how concepts are used (in problem solving) and fit into the overall conceptual framework of the subject (advance organizers and planned review stress this);

(f) A subject matter selection including an introduction to current developments in modern physics; this would seem to have an important place in the first physics course for giving students a realistic picture of the science.

One aspect of this study was the evaluation of an innovative course design incorporating the above methodologies. An area for investigation that became apparent as a result of this research is the commonality of student expectations as
to type of course; goals as to what should be stressed; and preferences as to the type of learning activities found most useful. Questionnaire data from both student populations involved forms a basis for this type of survey. The correspondence of expectations, and other priorities, among the four classes of students was evident on the pretest questionnaire as well as on subsequent assessments. And the contrast between Teacher 1's demonstration-induction approach, and Teacher 2's introduction-sample problem-review approach did not evidence itself in the student preference ratings obtained here.

It would seem that a follow-up of this aspect of the study might be especially meaningful. At this time of emphasis on individualized course offerings, programmed instruction and multi-media, the virtue of the teacher in his old expository role should be supported or refuted by research. Since the results of this study indicate that there may well be a "best way" (or at least a set of most useful learning activities) for the teaching of high school physics, follow-up research is in order.

**Overall Implications for the Teaching of High School Physics**

Results from this study raise questions both as to the value of the individualized/programmed instructional mode, and the traditional read-the-textbook/work-the-problems approach. Questionnaire data substantiated the value of expository
teaching but especially specific instruction in problem solving and reviewing for exams, that is, in applying conceptual learnings. This functional approach could lend its rationale to a variety of teaching situations.

The Basic Concepts textbook used here may have suffered from its unprofessional illustrations and looseleaf binding; but Harvard Project test scores (subjected to a covariate analysis) from Teacher 2's experimental class indicate that cognitive gains in no way suffered from student use of a shorter text written in an outline/organizer format. The superior scores evidenced here in "The Wave" and "Modern Physics" lend support to Ausubel's plea for the use of organizers as well as the deletion of unnecessary or anecdotal learning material.

Another priority of the investigator, which has been much stressed in this report of results, is the inclusion of learning material in modern physics. Successful instruction in this area must be preceded by a thorough grounding in the electromagnetic field and wave, which constitutes modern physics' theoretical basis. Students from Teacher 2's experimental class (who had been instructed in these areas by means of the Basic Concepts text and suggested classroom techniques) indicated on questionnaires that they found these areas less difficult than did control class students. (Statistically significant differences were reported here, see page 114.) A high level of student interest was evidenced in the modern
physics subjects. The educator might remark that high school students who have successfully completed this rigorous technical course should not find themselves more ignorant of the current state of the subject than those who have leisurely perused Isaac Asimov's small paperback on the subject.9

It was heartening to learn that students from both populations were initially reasonably confident and well motivated. Also a reasonably positive attitude toward the course was expressed throughout. Verbal comments from School 2 experimental class students on the end of course questionnaire were generally positive, including such expressions as these:

(a) "I think the proper items were emphasized."
(b) "I liked the course and it formed a nice foundation for further work."
(c) "It started me thinking about a career in electrical engineering."

Comments from Teacher 1's students were mixed and may have been an influencing factor in his decision to teach more electromagnetic theory in next year's introductory classes. Some examples are these:

(a) "I would have like to learn more about space, and atomic power."
(b) "I really liked the course and the stress on equations."
(c) "I didn't like the labs too much, I'd like to see more problems in class."
(d) "I would have liked to have seen more modern physics."

It should also be noted that a few students from each school remarked that they would have wanted more work on practical circuitry.

Assessments reported here should reassure educators that they are dealing with a reasonably mature and motivated student population, in those students who opt for this technical elective subject. It is, therefore, worthwhile to assess systematically the course expectations and most effective learning styles of this population. With this information in hand, the educator should base his strategy on a coherent framework of educational psychology. What the student should be taught (specific subject areas) and how he learns it best (textbook format and classroom program) should correspond and reflect a justifiable rationale. This type of rationale is especially necessary to guide the introductory teaching of a technical elective subject. The functional approach characterizing this study may be considered to have some merit here. And the uniformity of student responses on optimal learning activities may encourage the educator to continue his search for "the right way to do it."
References


American physicists' drive to improve high school teaching. *School and Society*, 1962, 90, 43.


Swales, W. Physics for all--an important thought for our nation. School Science and Mathematics, 1957, 57, 220-222.


Wilson, D. J. A study of achievement, understanding of science, and teacher role perception in various groups of the Nebraska Physical Science Project. (Doctoral dissertation, The University of Nebraska) Lincoln, Neb.: University Microfilms, 1973. No. 74-13,033.
FOOTNOTES

1 As described in the literature reviewed in chapter two, pages 8-12.

2 Abegg and Crumb, p. 212.

3 Ivany, Mullaney, Hugel, Faust, and Strassenburg, p. 227.

4 Ivany, Mullaney, Hugel, Faust, and Strassenburg, p. 228.

5 Bauman, p. 289.

6 As was indicated in the review of the literature, pages 26-35.

7 These conclusions have also been substantiated by responses to questions three and four on the February questionnaire (see variables 392 to 415 in Appendixes E and F); by question nine on the February questionnaire (see variables 434 to 445 in Appendixes E and F); by question five on the January-experimental only questionnaire (see variables 041 to 051 in Appendixes I and J); and by question two on the March-experimental only questionnaire (see variables 249 to 259 in Appendixes K and L).

8 This substantiated by variables 361 to 391 on the February questionnaire (Appendixes E and F); variables 449 to 502 on the end of course questionnaire (Appendixes G and H); variables 054 to 135 on the January-experimental only questionnaire (Appendixes I and J); and variables 141 to 248 on the March-experimental only questionnaire (Appendix K).

Appendix A

Copies of Questionnaires
Pre-test questionnaire—to be administered at the beginning of the course to experimental and control classes.

Name __________________________
Class __________________________

Questionnaire

1. I am taking this course because of:
   a. my general interest in mathematics.
   b. my general interest in science.
   c. to apply for admission to a college math or physical science program.
   d. to apply for admission to a college pre-med program.
   e. to find out if I am interested in a physics-related college major.
   f. because my high school counselor recommended this course.
   g. as part of the biology-chemistry-physics high school program.
   (check all the reasons that apply to you)

2. I feel as though I will be most interested in:
   a. the study of motion and mechanics.
   b. the study of light and sound.
   c. the study of electricity and magnetism.
   d. the study of technology and machines.
   e. the study of relativity and modern physics.
   f. a more general background in basic physical laws and conservation principles.
   g. laboratory work.

3. I feel that I learn best from:
   a. studying alone.
   b. classroom lecture.
   c. studying with classmates.
   d. laboratory work.
   e. reviewing for exams.
   f. solving mathematical problems.
4. I am most interested in:
   a. mathematics.
   b. physical sciences.
   c. biological sciences.
   d. working with tools and machines.
   e. art or literature.
   f. philosophy, psychology, history, or religion.
   g. education, social work, working with people.

5. I am least interested in:
   a. mathematics.
   b. physical sciences.
   c. biological sciences.
   d. working with tools and machines.
   e. art or literature.
   f. philosophy, psychology, history, or religion.
   g. education, social work, working with people.

6. I feel that I do my best work in:
   a. mathematics.
   b. physical sciences.
   c. biological sciences.
   d. working with tools and machines.
   e. art or literature.
   f. philosophy, psychology, history, or religion.
   g. education, social work, working with people.

7. I would like this course to stress:
   a. mathematical aspects of physics and problem solving.
   b. historical backgrounds of physics.
   c. laboratory work and technology.
   d. a general survey of the subject.
   e. teaching scientific thinking.
   f. a particular subject area in physics (such as electricity, or nuclear physics).
   g. whatever is needed to make college physics seem easier.

8. I would like to see this course paced so as to:
   a. get all the theory in but cut down on the labs if necessary.
   b. emphasize lab and technology, but leave out theory if necessary.
   c. cover all the material in: (choose one of the following—mechanics and motion; light, heat, and sound; electricity and magnetism; nuclear physics and relativity) but the
course could spend less time on other subject areas if necessary.

d. cover every subject area with a little material left out in each area, if necessary.

e. cover the whole text even if some students are left behind.

9. I prefer a course that is:

a. as challenging as possible.
b. fairly challenging.
c. neither especially easy nor especially difficult.
d. fairly easy.
e. as simplified as possible.

10. I feel that I do best on examinations that are:

a. multiple choice—in class.
b. solving problems in class.
c. writing about the subject in class.
d. solving in-depth problems at home.
e. researching and writing about the subject at home.

11. Choose the statement that describes your feelings about how you expect to do in this course:

a. I expect to do very well in this course.
b. I expect to do fairly well in this course.
c. I expect to come out about average in this course.
d. I expect to have some difficulty in this course.
e. I expect to have a great deal of difficulty in this course.
Questionnaire to be administered in January to experimental classes only.

Name ____________________________
Class ____________________________

Please choose the one response that gives your evaluation of this course:

1. How would you rate the *Basic Concepts of Physics* textbook on these points:

<table>
<thead>
<tr>
<th></th>
<th>very good</th>
<th>good</th>
<th>fair</th>
<th>not so good</th>
<th>poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>general interest level</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>making concepts and theories understandable</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>preparation for problem solving</td>
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<tr>
<td>choice of subject matter included</td>
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</tr>
<tr>
<td>format</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>writing style</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. How does the textbook compare with what you expected?
3. How would you rate the laboratory work in this course on these points?

<table>
<thead>
<tr>
<th>General Interest Level</th>
<th>Very Good</th>
<th>Good</th>
<th>Fair</th>
<th>Not So Good</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Making Concepts and Theories Understandable</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Good Use of Classroom Time</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. Was the type of laboratory experimentation in this course what you expected?

5. Please rate each of the following parts of the classroom program on how helpful you are finding them in general for this course.

<table>
<thead>
<tr>
<th>Introductory Lectures</th>
<th>Very Helpful</th>
<th>Somewhat Helpful</th>
<th>Not Too Helpful</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample Problems Solved in Class</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asking Questions in Class</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reading in Textbook</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Problem-Solving Labs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group Projects; Making Up Problems</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In-Class Review</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Problem Solving at Home</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preparation for Exams</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Going Over Exams in Class</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Laboratory Experiments</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
6. Here is a list of subjects covered in Newtonian Physics and Energy. Consider only those subject covered to date, and please rate each subject as covered in the textbook and in class on general interest level and on how easy or difficult you found it to understand.

<table>
<thead>
<tr>
<th>Interest</th>
<th>Understand-ability</th>
<th>Would have wanted same amount time less</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Law of Universal Gravitation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Velocity</td>
<td></td>
<td></td>
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<tr>
<td>Acceleration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Cause of Motion--Force</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exercise in Newtonian Physics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Circular Motion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Working with Vectors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frames of Reference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Force and Acceleration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calculus in Physics Problem Solving</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Momentum and Impact</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHART I--Physics Parameters Used in Mechanics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHART II--Physical Concepts Based on Symbols shown in Chart I</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Introduction to Conservation of Energy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interpreting Newton's Third Law</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### The Dissipation of Energy

<table>
<thead>
<tr>
<th>Interest</th>
<th>Understandability</th>
<th>Would have wanted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good</td>
<td>Good</td>
<td>More time</td>
</tr>
<tr>
<td>Fair</td>
<td>Fair</td>
<td>Same amount of time</td>
</tr>
<tr>
<td>Poor</td>
<td>Poor</td>
<td>Less time</td>
</tr>
</tbody>
</table>

#### CHART I -- Examples of Energy Dissipation in a System.

- Potential and Kinetic Energy
- Energy Conversion in an Extended Time Period
- Problem Solving: Kinetic and Potential Energy
- Conservation of Energy
- Energy Conservation -- Our Everyday Experience
- Work and Energy
- Energy and the Environment
- Electrical Energy
- The Volt

7. Which group of problems (1, 2, 3, or 4) do you consider to be on the right level of difficulty for you?
   - a. Group 1
   - b. Group 2
   - c. Group 3
   - d. Group 4
8. How would you rate the level of difficulty of the in-class examinations that you have taken so far?

   a. very difficult
   b. somewhat difficult
   c. about average in difficulty
   d. fairly easy
   e. very easy

9. Please rate the course, in general, that is, the textbook, choice of subject matter, and classroom program (but do not include your opinion of the laboratory experiments in this rating). Rate the course on how helpful you are finding it for your overall understanding of the subject matter, and consider these points:

<table>
<thead>
<tr>
<th>good</th>
<th>fair</th>
<th>poor</th>
</tr>
</thead>
</table>
   making concepts and theories understandable
   preparation for problem solving
   usefulness in terms of what you expected from the course
   your motivation to take further courses in physics

10. How do you feel that you are doing so far in this course?

    a. I am doing very well in this course.
    b. I am doing fairly well in this course.
    c. I am coming out about average in this course.
    d. I am not doing too well in this course.
    e. I am doing very badly in this course.

11. How applicable do you feel that this course will be in preparing you for your future career plans?

    a. This course will be very applicable to my career plans.
    b. This course will be somewhat applicable to my career plans.
    c. This course will not be too applicable to my career plans.
Questionnaire to be administered in March to experimental classes only.

Name ______________________
Class ______________________

Questionnaire

Please choose the (one) response that gives your evaluation of this course:

1. Here is a list of subjects covered in The Field and Waves. Consider only those subjects covered to date, and please rate each subject as covered in the textbook and in class on general interest level and on how easy or difficult you found it to understand. Also indicate whether you would have wanted to spend more, less, or the same amount of time on each of these subjects.

<table>
<thead>
<tr>
<th>Interest</th>
<th>Understandability</th>
<th>Would have wanted</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Topic</th>
<th>Interest</th>
<th>Understandability</th>
<th>Would have wanted</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Good</td>
<td>Fair</td>
<td>Poor</td>
</tr>
<tr>
<td>The Magnet</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Electromagnet</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Magnetic Field</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Magnetic Field Intensity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Experiments involving forces on a current-carrying wire in a magnetic field</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Explanation for experiments</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Magnetic Field and the Induced Current</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| Parameters that Cause Variation in a Wave | Interest | Understandableness | Would have wanted
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Pattern of Transmission of a Wave</td>
<td>Good</td>
<td>Good</td>
<td>more time</td>
</tr>
<tr>
<td>The Sine Wave in Equation Form</td>
<td>Fair</td>
<td>Fair</td>
<td></td>
</tr>
<tr>
<td>The Rope Wave and the Sine Wave Equation</td>
<td>Fair</td>
<td>Fair</td>
<td></td>
</tr>
<tr>
<td>Inter-Relationships among Frequency and Wavelength</td>
<td>Fair</td>
<td>Fair</td>
<td></td>
</tr>
<tr>
<td>The Sine Wave and the Longitudinal Wave</td>
<td>Good</td>
<td>Good</td>
<td></td>
</tr>
<tr>
<td>The Travelling Wave and the Obstacle</td>
<td>Good</td>
<td>Good</td>
<td></td>
</tr>
<tr>
<td>Huygen's Laws</td>
<td>Good</td>
<td>Good</td>
<td></td>
</tr>
<tr>
<td>The Wavefront: Superposition and Interference</td>
<td>Good</td>
<td>Good</td>
<td></td>
</tr>
<tr>
<td>The Mathematics of Sine Wave Addition</td>
<td>Good</td>
<td>Good</td>
<td></td>
</tr>
<tr>
<td>The Standing Wave</td>
<td>Good</td>
<td>Good</td>
<td></td>
</tr>
<tr>
<td>The Wavefront</td>
<td>Good</td>
<td>Good</td>
<td></td>
</tr>
<tr>
<td>The Electromagnetic Wave</td>
<td>Good</td>
<td>Good</td>
<td></td>
</tr>
<tr>
<td>The Photo-Electric Effect: Measuring the Energy Carried by an Electromagnetic Wave</td>
<td>Good</td>
<td>Good</td>
<td></td>
</tr>
<tr>
<td>Correlation of Quantum Theory with Results of Photo-Electric Experiment</td>
<td>Good</td>
<td>Good</td>
<td></td>
</tr>
</tbody>
</table>
2. Would you like more, less, or the same amount of time spent on each of these parts of the course?

<table>
<thead>
<tr>
<th></th>
<th>more</th>
<th>same amt.</th>
<th>less</th>
</tr>
</thead>
<tbody>
<tr>
<td>introductory lectures</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>sample problems solved in class</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>asking questions in class</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>reading in text</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>problem-solving labs</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>group projects--making up problems</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>in class review</td>
<td></td>
<td></td>
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<tr>
<td>problem-solving at home</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>preparation for exams</td>
<td></td>
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<tr>
<td>going over exams in class</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>laboratory experiments</td>
<td></td>
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</tbody>
</table>

3. In general, how well-organized do you consider this course to be? That is, is the course organized so as to make the material easy or difficult to learn?

   a. I consider the course to be very well organized.
   b. I consider the course to be fairly well organized.
   c. I consider the course to be about average in organization.
   d. I consider the course to be rather poorly organized.
   e. I consider the course to be very poorly organized.

4. How interesting are you finding the lab experiments?

   a. The lab experiments seem very interesting.
   b. The lab experiments seem fairly interesting.
   c. The lab experiments seem somewhat interesting.
   d. The lab experiments do not seem too interesting.
   e. The lab experiments are not at all interesting.
<table>
<thead>
<tr>
<th>Interest</th>
<th>Fill</th>
<th>Fair</th>
<th>Poor</th>
<th>Understand-</th>
<th>Would have wanted</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Food</td>
<td>Good</td>
<td>Poor</td>
<td>ableness</td>
<td>time of sameamt.</td>
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<tr>
<td>Electric and Magnetic Field Formulae</td>
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<tr>
<td>Problem examples using formulae</td>
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<tr>
<td>Symbols and Units: Electric and Magnetic Flux</td>
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<tr>
<td>Electric and Magnetic Flux E and B</td>
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<tr>
<td>The Unchanging Electric and Magnetic Field</td>
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<tr>
<td>The Time Changing Electric and Magnetic Field</td>
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<tr>
<td>Interrelationships between Time-Changing Fields</td>
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<tr>
<td>The Current and the Electric and Magnetic Fields</td>
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<tr>
<td>Time Changing Fields and Lenz' Law</td>
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<tr>
<td>The Time Changing Electromagnetic Field and the Travelling Wave</td>
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<tr>
<td>The Antenna, the Field, and the Travelling Wave</td>
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<tr>
<td>Wave Demonstrations</td>
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<tr>
<td>The Medium</td>
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<tr>
<td>The Traverse Wave versus the Longitudinal Wave</td>
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<tr>
<td>The Sine Wave and the Signal</td>
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<tr>
<td>The Message</td>
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</tbody>
</table>
5. How interesting are you finding the non-laboratory part of the course (the textbook, choice of subject matter and classroom teaching)?
   a. very interesting
   b. fairly interesting
   c. somewhat interesting
   d. do not seem too interesting
   e. not at all interesting

6. How would you rate the level of difficulty of the Harvard Project Multiple Choice Tests that you took at the end of the Newtonian Physics, Energy, and Field units?
   a. The tests seemed very easy.
   b. The tests seemed fairly easy.
   c. The tests seemed about average.
   d. The tests seemed somewhat difficult.
   e. The tests seemed very difficult.

7. Are you doing as well as you expected to do in this course?
   a. I am doing better than I expected to do.
   b. I am doing just about as well as I expected.
   c. I am not doing as well as I expected to do.

8. Do you feel that the type of subject matter covered in (1) Newtonian Physics, (2) Energy, (3) The Field, or (4) Waves will be genuinely useful as preparation for your future career plans?

<table>
<thead>
<tr>
<th>Career Plans</th>
<th>very useful</th>
<th>somewhat useful</th>
<th>not at all useful</th>
</tr>
</thead>
<tbody>
<tr>
<td>Math</td>
<td></td>
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<tr>
<td>Newtonian Physics</td>
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<td></td>
<td></td>
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<tr>
<td>Energy</td>
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<td></td>
<td></td>
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<tr>
<td>The Field</td>
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<tr>
<td>Waves</td>
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<tr>
<td>Physical Science or Engineering</td>
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<tr>
<td>Newtonian Physics</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Energy</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>The Field</td>
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<td></td>
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<tr>
<td>Waves</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Career Plans</td>
<td>very useful</td>
<td>somewhat useful</td>
<td>not at all useful</td>
</tr>
<tr>
<td>------------------------------</td>
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<td>-----------------</td>
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</tr>
<tr>
<td>Biology, Medicine</td>
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<tr>
<td></td>
<td>Newtonian Physics</td>
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<td></td>
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<tr>
<td></td>
<td>Energy</td>
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<td></td>
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<tr>
<td></td>
<td>The Field</td>
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<tr>
<td></td>
<td>Waves</td>
<td></td>
<td></td>
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<tr>
<td>Working with tools or machines</td>
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<tr>
<td></td>
<td>Newtonian Physics</td>
<td></td>
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<tr>
<td></td>
<td>Energy</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>The Field</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Waves</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Working in the humanities</td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Newtonian Physics</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Energy</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>The Field</td>
<td></td>
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<tr>
<td></td>
<td>Waves</td>
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</tbody>
</table>
Questionnaire to be administered in May to experimental classes only.

Name ______________________
Class ______________________

Questionnaire

1. Generally, how would you rate this course in comparison with a more traditional (standard textbook, straight lecture) course?
   a. I very much prefer this type of course.
   b. I somewhat prefer this type of course.
   c. I would find both types of course equally effective.
   d. I somewhat prefer a more traditional course.
   e. I very much prefer a more traditional course.

2. How does the type of subject matter covered so far meet your expectations for the course?
   a. I am learning about exactly the type of thing I hoped to learn about.
   b. I am mostly learning the sort of thing I expected.
   c. Some of the subject matter is what I expected it to be, some is not.
   d. Much of the subject matter is not what I was expecting.
   e. Very little of what I am learning here is what I expected.

3. Please fill in your ideas on the type of subject matter that you would want to see covered in this course.
   a. I would have wanted to spend more time on:

   b. I would have wanted to spend less time on:
c. I would also have wanted to learn about:


d. I think the course did a very good job in covering:

4. Please rate each of the five units of the course on how interesting it was, how difficult you found it, and how much time you would have wanted to spend on it.

<table>
<thead>
<tr>
<th>Interest</th>
<th>Understand-</th>
<th>Would have</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good</td>
<td>ableness</td>
<td>more</td>
</tr>
<tr>
<td>fair</td>
<td>poor</td>
<td>same time</td>
</tr>
<tr>
<td>poor</td>
<td>good</td>
<td>less time</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ENERGY</th>
</tr>
</thead>
<tbody>
<tr>
<td>NEWTONIAN PHYSICS</td>
</tr>
<tr>
<td>The FIELD</td>
</tr>
<tr>
<td>WAVES</td>
</tr>
<tr>
<td>MODERN PHYSICS</td>
</tr>
<tr>
<td>(specific subjects)</td>
</tr>
<tr>
<td>Mass and Energy</td>
</tr>
<tr>
<td>Natural Radioactive Decay</td>
</tr>
<tr>
<td>Nuclear Binding</td>
</tr>
<tr>
<td>Fission</td>
</tr>
<tr>
<td>Fusion</td>
</tr>
<tr>
<td>Interest</td>
</tr>
<tr>
<td>----------</td>
</tr>
<tr>
<td>good</td>
</tr>
<tr>
<td>fair</td>
</tr>
<tr>
<td>poor</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>The Electron in the Atom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computational Methods for Hydrogen Spectral Lines</td>
</tr>
<tr>
<td>Energy Levels; Quantum Theory as Applied to Atoms more Complex than Hydrogen</td>
</tr>
<tr>
<td>The Electron in the Atom: Wave Theory</td>
</tr>
<tr>
<td>The Standing Wave</td>
</tr>
<tr>
<td>Indeterminacy and the Electron in the Atom</td>
</tr>
<tr>
<td>Mass and Motion: Relativity</td>
</tr>
<tr>
<td>Other Implications of Relativity</td>
</tr>
<tr>
<td>Other Sub-Atomic Particles</td>
</tr>
</tbody>
</table>

5. What is your overall rating of the textbook, *Basic Concepts in Physics*?

a. I found the textbook very good.
b. I found the textbook fairly good.
c. I found the textbook about average.
d. I found the textbook rather poor.
e. I found the textbook very poor.

6. What is your overall rating of the laboratory experiments?

a. I found the lab experiments very good.
b. I found the lab experiments fairly good.
c. I found the lab experiments about average.
d. I found the lab experiments rather poor.
e. I found the lab experiments very poor.
7. What is your overall rating of the classroom program—include scheduling of introductory lectures, problem solving practice, group work, and reviewing for exams in this rating.

a: I found the classroom program to be very good.
b: I found the classroom program to be fairly good.
c: I found the classroom program to be about average.
d: I found the classroom program to be rather poor.
e: I found the classroom program to be very poor.

8. Which group of problems (1, 2, 3, or 4) did you find to be on the right level of difficulty for you in each of these units? Please circle one group for each unit.

Newtonian Physics 1 2 3 4
The Field 1 2 3 4
Energy 1 2 3 4
Waves 1 2 3 4
Modern Physics 1 2 3 4

9. How would you rate the level of difficulty of:

<table>
<thead>
<tr>
<th></th>
<th>very difficult</th>
<th>somewhat difficult</th>
<th>about average</th>
<th>fairly easy</th>
<th>very easy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teacher's Exams</td>
<td></td>
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<tr>
<td>Harvard Project Exams</td>
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<tr>
<td>Homework Problems</td>
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<tr>
<td>Sample Problems</td>
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<tr>
<td>Problem Labs</td>
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</tbody>
</table>

10. Did you do as well as you expected to do in this course? Please comment.
11. Do you feel that this course (textbook, choice of subject matter, and classroom program) was good enough to prepare you to take more advanced physics courses in the future? Do you plan to take any other physics courses?

12. If you had it to do over again, would you sign up for this course?
Questionnaire to be administered in February to experimental and control classes.

Name ___________________________
Class ___________________________

Questionnaire

1. Please rate your physics course on the following points:

<table>
<thead>
<tr>
<th>Is the course generally interesting?</th>
<th>good</th>
<th>fair</th>
<th>poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Are concepts and theories reasonably understandable?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Are you well prepared for solving homework problems?</td>
<td></td>
<td></td>
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<tr>
<td>Are you well prepared for exams?</td>
<td></td>
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<tr>
<td>Is the amount of time that you are spending on homework reasonable?</td>
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<tr>
<td>Are you learning about the type of thing you expected to learn about?</td>
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</tr>
</tbody>
</table>

2. Tell what effect, if any, this course is having on your future career plans.
3. Please rate the following aspects of the course on how helpful you are finding them for your general understanding of the subject (skip those categories that have not been included in your class).

<table>
<thead>
<tr>
<th>Activity</th>
<th>Very Helpful</th>
<th>Somewhat Helpful</th>
<th>Not Too Helpful</th>
</tr>
</thead>
<tbody>
<tr>
<td>reading the textbook</td>
<td></td>
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<tr>
<td>classroom lecture</td>
<td></td>
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<tr>
<td>problem solving in class</td>
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<tr>
<td>problem solving at home</td>
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<tr>
<td>sample problems solved by the teacher</td>
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<tr>
<td>reviewing in class for exams</td>
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<tr>
<td>studying at home for exams</td>
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<tr>
<td>group work in class</td>
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<tr>
<td>studying alone</td>
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<tr>
<td>studying with classmates</td>
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<tr>
<td>problem-solving labs</td>
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</tr>
<tr>
<td>lab experiments</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. Which of these activities would you have wanted to spend more time, less time, or the same amount of time on?

<table>
<thead>
<tr>
<th>Activity</th>
<th>More Time</th>
<th>Same Amount of Time</th>
<th>Less Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>reading the textbook</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Learning Activity</td>
<td>More Time</td>
<td>Same Amount of Time</td>
<td>Less Time</td>
</tr>
<tr>
<td>-----------------------------------------------</td>
<td>-----------</td>
<td>---------------------</td>
<td>-----------</td>
</tr>
<tr>
<td>Classroom lecture</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Problem solving in class</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Problem solving at home</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sample problems solved by the teacher</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reviewing in class for exams</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Studying at home for exams</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Group work in class</td>
<td></td>
<td></td>
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<tr>
<td>Studying alone</td>
<td></td>
<td></td>
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<tr>
<td>Studying with classmates</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Problem-solving labs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lab experiments</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5. What other types of learning activities covered help you in this course? Please give your ideas.
6. Which of these subject areas have you found interesting so far?

<table>
<thead>
<tr>
<th>Subject Area</th>
<th>Very Interesting</th>
<th>Somewhat Interesting</th>
<th>Not Too Interesting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mathematical work (vectors, graphing, slide rule)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mathematical work with equations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The study of motion</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Kinetic and Potential energy</td>
<td></td>
<td></td>
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<tr>
<td>Electrical energy</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electrical circuits</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waves (rope, water, etc)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electromagnetic fields</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electromagnetic waves</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat and sound</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light--lenses</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light--reflection and refraction</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Einstein's relativity laws</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The photon and quantum physics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The atom, electron energy levels</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>The atom, nuclear binding</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Radioactivity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fission and fusion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sub-atomic particles</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
7. Among those subject areas that you have not studied yet, which do you expect to be the most interested in?

<table>
<thead>
<tr>
<th>Expect to be:</th>
<th>very interested</th>
<th>somewhat interested</th>
<th>not too interested</th>
</tr>
</thead>
<tbody>
<tr>
<td>electromagnetic fields</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>electromagnetic waves</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>heat and sound</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>light--lenses</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>light--reflection and refraction</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Einstein's relativity laws</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>the photon and quantum physics</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>the atom, electron energy levels</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>the atom, nuclear binding</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>radioactivity</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>fission and fusion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>sub-atomic particles</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

8. How do you feel that you are doing so far in each of these aspects of your course:

<table>
<thead>
<tr>
<th>aspect</th>
<th>doing well</th>
<th>doing about average</th>
<th>not doing very well</th>
</tr>
</thead>
<tbody>
<tr>
<td>general understanding of concepts</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>and theories</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>success in problem solving</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>success in examinations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lab experiments</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>problem solving labs</td>
<td></td>
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</tr>
</tbody>
</table>
9. Which of the following are you the most interested in? Which do you expect to find unseful in your career plans?

<table>
<thead>
<tr>
<th></th>
<th>Interested</th>
<th>not interested</th>
<th>seems useful</th>
<th>does not seem useful</th>
</tr>
</thead>
<tbody>
<tr>
<td>mathematical aspects of</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>physics and problem</td>
<td></td>
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<tr>
<td>solving</td>
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<tr>
<td>historical background</td>
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<tr>
<td>of physics</td>
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<td></td>
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</tr>
<tr>
<td>lab experiments</td>
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<td></td>
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<td></td>
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<tr>
<td>technology and machines</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>a general survey of the</td>
<td></td>
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<tr>
<td>subject matter</td>
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<tr>
<td>preparation for a college</td>
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<tr>
<td>physics course</td>
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</tbody>
</table>

10. In general, on what basis do you feel that subject material should be included in a course like this? (Check all those reasons which you find important for including material).

a. Material should be interesting for people who like math.
b. Material should prepare for careers in engineering or physical sciences.
c. Material should prepare for college physics.
d. Material should be interesting even for people who will not take another physics course.
e. Material should prepare people to work with tools and machines.
f. Material should be the type of thing that is easy to remember.
g. Material should stress current developments in modern physics.

11. Do you feel as though you will be able to make use of material learned from this course in the future? Please explain.
12. Do you plan to take another physics course? If so, what type of course?

a. I do not intend to take another physics course.
b. I plan to take advanced placement physics in high school.
c. I plan to take one more physics course in college.
d. I plan to specialize in a physics-related major in college.
e. I am undecided.
End of course questionnaire to be administered to experimental and control classes.

Name ____________________________
Class ____________________________

Questionnaire

1. Which of the following subject areas would you want to see more, less, or the same amount of time spent on? Which did you find most interesting? Most difficult?

<table>
<thead>
<tr>
<th>Subject Area</th>
<th>Interest</th>
<th>Easy</th>
<th>Difficult</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>mathematical work (vectors, graphing, slide rule)</td>
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<tr>
<td>mathematical work with equations</td>
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<tr>
<td>the study of motion</td>
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<tr>
<td>kinetic and potential energy</td>
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<tr>
<td>electrical energy</td>
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<td></td>
</tr>
<tr>
<td>electrical circuits</td>
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<td></td>
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<tr>
<td>waves (rope, water, etc)</td>
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<tr>
<td>electromagnetic fields</td>
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<tr>
<td>electromagnetic waves</td>
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<td></td>
</tr>
<tr>
<td>heat and sound</td>
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</tr>
<tr>
<td>light—lenses</td>
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<tr>
<td>light—reflection and refraction</td>
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</tr>
<tr>
<td>Einstein's relativity laws</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>the photon and quantum physics</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
the atom, electron energy levels
the atom, nuclear binding
radioactivity
fission and fusion
sub-atomic particles

<table>
<thead>
<tr>
<th>Not Interesting</th>
<th>Difficult</th>
<th>Easy</th>
<th>More Time</th>
<th>Same Amount</th>
</tr>
</thead>
</table>

2. Please rate the following parts of your course on how useful you found them: (Please skip those things that you haven't done.)

<table>
<thead>
<tr>
<th>Very Useful</th>
<th>Fairly Useful</th>
<th>Not Too Useful</th>
</tr>
</thead>
</table>
| work with the assigned textbook
| work with other textbooks
| lecture
| sample problems solved in class
| homework problems
| asking questions in class
| studying with other students
| preparing for exams
| discussing mistakes on exams
| lab experiments

3. Can you think of any other study procedures that might have been useful? Give your ideas.
4. Which of the following aspects of physics would you have wanted the course to stress more, less, or the same amount?

<table>
<thead>
<tr>
<th>Should be stressed</th>
<th>more</th>
<th>the same amount</th>
<th>less</th>
</tr>
</thead>
<tbody>
<tr>
<td>mathematical aspects of physics and problem solving</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>historical background of physics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lab work</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>technology and machines</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a general survey</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>current developments in modern physics</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5. Give your own ideas on what you would have wanted to see in this course, and what you liked or disliked about what was emphasized.

6. What suggestions do you have for the pacing of this course—that is, would you like to see any of the following. (Circle those responses that express your opinions).

a. Theory stressed more, with less time spent on lab work.
b. More lab work with less time spent on theory.
c. More demonstrations by the teacher, but less time spent by students on lab work.
d. More stress on a particular subject area. Would you have wanted to spend more time on
   1. mechanics and motion
   2. light, heat, and sound
   3. electricity and magnetism
   4. nuclear physics and relativity
e. Would you have wanted less time spent on
   1. mechanics and motion
   2. light, heat, and sound
   3. electricity and magnetism
   4. nuclear physics and relativity
7. Do you feel that, in general, a course like this should:
(circle the responses that reflect your opinions)

a. cover every subject area about equally to give a good survey of physics.

b. cover the subject in whatever way will be the most helpful for college physics.

c. give more than the average amount of homework, if necessary, so that the students get a really good background in the subject.

d. be geared to the people who are not planning to take physics in college more than to those who are, so that the amount of homework will not be excessive.

e. just be made as interesting as possible.

f. just be made as easy as possible.

8. Would you have wanted to spend more, less, or the same amount of time on:

<table>
<thead>
<tr>
<th>activity</th>
<th>more time</th>
<th>same amt. time</th>
<th>less time</th>
</tr>
</thead>
<tbody>
<tr>
<td>studying the textbook</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>doing lab experiments</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>doing homework problems</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>studying for exams</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

9. How would you rate the level of difficulty of this course?

a. I found the course very difficult.

b. I found the course somewhat difficult.

c. I found the course about average.

d. I found the course fairly easy.

e. I found the course very easy.
10. How would you rate your own success in this course with:

<table>
<thead>
<tr>
<th>Homework problems</th>
<th>good</th>
<th>fair</th>
<th>poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teacher's exams</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Harvard Project (multiple choice)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tests</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lab experiments</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quality of preparation for future work</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In general</td>
<td></td>
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</tr>
</tbody>
</table>

11. How well did you expect to do in this course?

a. I expected to do very well in this course.

b. I expected to do fairly well in this course.

c. I expected to come out about average in this course.

d. I did not expect to do too well in this course.

e. I expected to do very badly in this course.

12. In general, was this course as you expected it to be?

a. The course was (more time consuming, as time consuming, less time consuming) than I expected.

b. The course was (more interesting, as interesting, less interesting) than I expected.

c. The course was (more difficult, as difficult, less difficult) than I expected.

d. The course was (more mathematically oriented, as mathematically oriented, less mathematically oriented) than I expected.

e. The course was (more laboratory oriented, as laboratory oriented, less laboratory oriented) than I expected.

f. The course was (more applicable to my career plans, as applicable to my career plans, less applicable to my career plans) than I expected.

Give your comments on this:
13. Do you intend to study more physics?

14. What are your career plans?

15. What effect, if any, did this course have on your career plans?
Appendix B

Excerpts from the Basic Concepts of Physics Text
OUTLINE

BASIC CONCEPTS OF PHYSICS

Section I -- Newtonian Physics

- Introduction
- Mass
- Law of Universal Gravitation
  1. Universal Gravitation and Problem Solving
- Velocity
- Acceleration
- The Causes of Motion--Force
- Exercise in Newtonian Physics
  1. Working with Physics Formulae
  2. Problem Solving Techniques
- Circular Motion
  1. Circular Motion and the Satellite
  2. Force Considerations
  3. Equations and Unknowns
- Working with Vectors
  1. Vector Representations of Physical Parameters
  2. Vectors and Problem Solving
  3. Problem Solving Examples
  4. Problem Solving with Vector Arithmetic
- Frames of Reference
  1. Relative Motion
  2. Problem Solving Examples
  3. Relative Velocity and Vector Subtraction
- Force and Acceleration
  1. How Force Acts
- Calculus in Physics Problem Solving
  1. Physics without Calculus
- Momentum and Impact
  1. Momentum
  2. Impact
  3. Problem Solving
- CHART I--Physics Parameters Used in Mechanics
- CHART II--Physical Concepts Based on Symbols shown in Chart I
- Introduction to Conservation of Energy
  1. Action and Reaction
  2. An Equal Reaction
  3. An Opposite Reaction
- Interpreting Newton's Third Law
Section II -- Energy

- Introduction
- The Dissipation of Energy
- CHART I--Examples of Energy Dissipation in a System
- Potential and Kinetic Energy
- Energy Conversion, Potential and Kinetic Energy
  1. Description
  2. Examples
- Energy Conversion in an Extended Time Period
- Problem Solving: Kinetic and Potential Energy
- Conservation of Energy
  1. Examples
- Energy Conservation--Our Everyday Experience
- CHART II--Energy Conservation
- Work and Energy
  1. Work--Description by Numerical Examples
  2. An Example
  3. Projectile Problems
- Energy and the Environment
  1. Entropy
- Electrical Energy
  1. Static Electricity Phenomena
  2. Charging by Induction--The Induced Charge
     a. Description
     b. Explanation
  3. The Conductor
  4. The Insulator
  5. The Point Charge
  6. The Field
  7. Lines of Force
  8. The Test Charge in the Field
     a. Description of Charge Configurations
  9. The Superposition Principle Method
     a. Examples
  10. The Conductor in the Electrical Field
      a. Description
  11. The Electric Field Intensity or Electric Field Strength
- The Volt
  1. Zero Potential--"A Convenient Definition"
  2. Electromotive Force, or EMF
  3. Electrical Energy, EMF, and Power
  4. Electrical Energy, EMF, and the Moving Charge
  5. Electrical Energy, EMF, and the Circuit
  6. Electrical Energy, EMF, and the Field
Section III -- The Field

- Introduction
- The Magnet
- The Electromagnet
- The Magnetic Field--Lines of Flux
- The Magnetic Field Intensity
- Experiments Involving Forces on a Current-Carrying Wire in a Magnetic Field
  1. Explanation for Experiments
- The Magnetic Field and the Current-Carrying Wire
- Experiments Involving both Magnetic Field and Induced Current
  1. Explanation for Experiments
- The Magnetic Field and the Induced Current
- Electric and Magnetic Field Formulae
  1. Problem Examples Using Formulae
    a. Other Aspects of These Problems
    b. Methods of Solution
- Symbols and Units: Electric and Magnetic Flux
- Electric and Magnetic Flux $\Phi_E$ and $\Phi_B$
- The Unchanging Electric or Magnetic Field
- The Time Changing Electric and Magnetic Field
  1. Interrelationships Between Time-Changing Fields
- The Current and the Electric and Magnetic Fields
- Time-Changing Fields and Lenz' Law
- The Time-Changing Electromagnetic Field and the Travelling Wave
  1. Energy Considerations
- The Antenna, the Field, and the Travelling Wave
Section IV -- The Wave

- Introduction
- Wave Demonstrations
- The Medium
- The Transverse Wave Versus the Longitudinal Wave
- The Sine Wave and the Signal
- The Message
- Parameters that Cause Variation in a Wave
  1. Amplitude and Frequency of Transmission
  2. The Medium
  3. Irregularities in Transmission
  4. Superposition and Interference
- Patterns of Transmission of a Wave
- The Sine Wave in Equation Form
- The Rope Wave and the Sine Wave Equation
- Interrelationships Among Frequency and Wavelength
- The Sine Wave and the Longitudinal Wave
- The Travelling Wave and the Obstacle
  1. The Effect of the Obstacle on the Travelling Wave
- Huygen's Law
  1. Practical Implications of Huygen's Law
     a. Radio Transmission
     b. Radar
- The Wavefront: Superposition and Interference
  1. The Diffraction Grating
  2. Practical Implications of Superposition and Interference
     a. Light
     b. Radio
- The Mathematics of Sine Wave Addition
  1. Superposition at a Point
- The Standing Wave
  1. In Mathematical Terms
  2. A Practical Application
- The Wavefront
- The Electromagnetic Wave
  1. Generating the EM Wave
  2. The EM Wave and the Antenna
  3. The Electromagnetic Field and Energy
- The Photo-Electric Effect: Measuring the Energy Carried by an Electromagnetic Wave
  1. The Absorption of Light
  2. The Release of Electrons
  3. Experimental Work on the Photo-Electric Effect
  4. Answers to Questions
  5. Theoretical Explanation of the Photo-Electric Experiment
- Correlation of Quantum Theory with Results of Photo-Electric Experiment
Section V -- Modern Physics

- Introduction
- Mass and Energy
- Natural Radioactive Decay
- Mass and Energy: Nuclear Binding
  1. Nuclear Binding Energy and the Packing Fraction
- Fission
- Fusion
- The Electron in the Atom
  1. Energy Considerations
  2. Spectroscopy Analysis: Experimental Results
CHART I--Quantum Theory and Nuclear Physics
  3. Explanation of Experimental Results
- Computational Methods for Hydrogen Spectral Lines
  1. Bohr's Energy Level Equation for the Hydrogen Atom
  2. Spectral Series' of the Hydrogen Atom
    a. Balmer Series
    b. Paschen Series
- Energy Levels: Quantum Theory as Applied to Atoms More Complex than Hydrogen
CHART II--Electrons and Quanta
- The Electron in the Atom: Wave Theory
- The Standing Wave
- Indeterminacy and the Electron in the Atom
- Mass and Motion: Relativity
- Other Implications of Relativity
- Other Sub-atomic Particles
- CHART III--Interrelationships of Modern Physics
Mass and Motion: Relativity

The basic principle of relativity is stated as follows:

The laws of nature and the results of all experiments performed in a given frame of reference are independent of the translational motion of the system as a whole.

A mathematical application of this principle leads to our concept of the mass increase of particles moving at very high velocities (that is, velocities on the order of that of light, \(3 \times 10^8\) m/sec).

The concept of the frame of reference is most easily understood as follows:

- Observer 1 is moving at 1 m/sec.
- Observer 2 is at rest
- Observer 3 is moving at \(10^8\) m/sec (a speed on this order is essentially impossible for any mass greater than a sub-atomic particle; the reasons for this will be shown here.)

All three observers are viewing the same surroundings consisting of stationary and moving objects. Also, all three observers are capable of measuring such parameters as time, distance, and electro-magnetic field forces in their surroundings. How do their perceptions and measurements differ?

Relativity theory says that the measurements of Observer 3, even for such parameters as electro-
magnetic fields, do differ significantly from those of Observer 1 and Observer 2. Measurements taken by Observer 1 and Observer 2 of the physical parameter velocity will differ by 1 m/sec. Measurements taken by Observer 1 and Observer 2 of other physical parameters will not.

The basic principle of relativity is explained as follows: Suppose Observer 3 is moving at $10^8$ m/sec and so is everything around him (in the same direction). That is, light sources in his world are moving at $10^8$ m/sec; electrostatic charges are moving at $10^8$ m/sec; radio antennae are moving at $10^8$ m/sec. Then Observer 3 will see exactly the same things in his world as a stationary observer (Observer 1) would see in a similar world where none of the things around Observer 1 were in motion.

But if Observer 3 sees the same things in his high velocity world as Observer 1 sees in his stationary world, what does Observer 3 see looking at Observer 1's world? And conversely what does Observer 1 see looking at Observer 3's world?

When we derive the laws of relativity, we assume that we are at rest, ignoring the fact that earth is moving in space. And it is precisely the principle of relativity that permits us to make this assumption. Suppose Observer 1, at rest, sees a sub-atomic particle
that has been accelerated to a velocity of $10^8$ m/sec. How do observations of this high velocity particle differ from what would be observed if the particle were at rest?

The principle of relativity is used to give a mathematical answer to this question. The formula for what is known as the relativistic mass increase is as follows:

$$m = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}}$$

This formula implies that if the particle (for which the mass increase is being computed) were at rest, Observer 1 (at rest) would measure its mass to be $m_0$. But the particle is now moving at velocity, $v$, a velocity that is mathematically significant when compared to the velocity of light. So Observer 1 (still at rest) measures the mass of the particle moving at a relativistic velocity $v$ to be $m$. The numerical value of the relativistic mass $m$ is greater than that of the rest mass $m_0$.

As far as we are concerned, the relativistic increase of mass is an actual increase. It affects all the properties of motion (kinetic energy, momentum, etc.) in our (Observer 1's at rest) coordinate system. It implies that when we attempt to accelerate a particle to relativistic velocities, we have to apply greater and greater amounts of force to do so, because the mass of the particle keeps increasing.
A numerical application of this formula is as follows:

An electron, \( m_0 = 9.1 \times 10^{-31} \text{ kg} \) is accelerated in a betatron to a velocity \( v = 10^8 \text{ m/sec} \). What will its mass appear to be, to a stationary observer?

\[
m = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}}
\]

\[
m = \frac{9.1 \times 10^{-31}}{\sqrt{1 - \frac{(10^8)^2}{(3 \times 10^8)^2}}}
\]

\[
m = \frac{9.1 \times 10^{-31}}{\sqrt{1 - \frac{1}{9}}}
\]

\[
m = \frac{9.1 \times 10^{-31}}{\sqrt{\frac{8}{9}}}
\]

\[
m = 9.7 \times 10^{-31} \text{ kg}.
\]

As the electron reaches velocities greater than \( 10^8 \text{ m/sec} \), its mass will increase very quickly. It is most precisely stated that its relativistic mass will increase quickly; this is because its mass increases relative to or as measured by a stationary observer.
<table>
<thead>
<tr>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mathematical representation</td>
<td>Equal or equivalent Physical Quantities</td>
<td>Name or description of physical qualities</td>
<td>Measurement Units for Column I</td>
<td>Equivalent measurement Units</td>
</tr>
<tr>
<td>( \vec{F} = m \vec{a} )</td>
<td>force equals mass times acceleration</td>
<td>( \text{kg-m} )</td>
<td>newtons</td>
<td></td>
</tr>
<tr>
<td>( m \vec{v} )</td>
<td>( m_1 \vec{v}_1 = m_2 \vec{v}_2 )</td>
<td>conservation of momentum—see Column VI for a more general formulation.</td>
<td>( \text{kg-m} ) sec</td>
<td>---</td>
</tr>
<tr>
<td>( \vec{v} = \vec{a}t )</td>
<td>the velocity equals the acceleration times the time interval during which acceleration takes place.</td>
<td>( \text{m} ) sec</td>
<td>meters</td>
<td></td>
</tr>
<tr>
<td>( \vec{d} = \vec{v}t )</td>
<td>the distance equals the velocity times the time interval of travel</td>
<td>( \text{m} ) sec</td>
<td>meters</td>
<td></td>
</tr>
<tr>
<td>( \vec{F}_\Delta t = m \vec{v} )</td>
<td>impact equals momentum</td>
<td>newton-seconds</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>( \frac{\vec{v} - \vec{v}_0}{\Delta t} )</td>
<td>( \vec{a} = \frac{\vec{v} - \vec{v}_0}{\Delta t} )</td>
<td>acceleration equals changes in velocity divided by the time interval in which that change took place.</td>
<td>( \frac{\text{m}}{\text{sec}^2} )</td>
<td>---</td>
</tr>
<tr>
<td>( \vec{d} = \vec{v}_0 t + \frac{1}{2} \vec{a}t^2 )</td>
<td>the distance travelled by an object in a time interval ( t ) is equal to the initial velocity of the object times the time interval, plus an acceleration term of ( \frac{1}{2} \vec{a}t^2 ).</td>
<td>meters</td>
<td>---</td>
<td>meters</td>
</tr>
</tbody>
</table>

200
<table>
<thead>
<tr>
<th>II</th>
<th>VI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Restrictions on the Use of the Equations in Column II</td>
<td></td>
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</tbody>
</table>

**\( \vec{F} = m\vec{a} \)**

There are no restrictions on the equation in this form. If force and acceleration change with time, the force at a particular time must be used to find the acceleration produced at that time, and vice versa.

**\( m_1\vec{v_1} = m_2\vec{v_2} \)**

The conservation of momentum principle can be stated in various forms. Equation (3) is the general statement; equations (1) and (2) describe special cases, where particular terms in equation (3) are equal to zero.

1. \( m_1\vec{v_1} = m_2\vec{v_2} \)
2. \( m_1\vec{v_1} = m_1\vec{v_2} + m_2\vec{v_2} \)
3. \( m_1\vec{v_1} + m_2\vec{v_2} = m_1\vec{v_2} + m_2\vec{v_2} \)

The double subscript notation used above is explained as follows:

- \( \vec{v_1} \) = the initial velocity of mass 1
- \( \vec{v_2} \) = the initial velocity of mass 2
- \( \vec{v_1} \) = the final velocity of mass 1
- \( \vec{v_2} \) = the final velocity of mass 2

This is a standard form for keeping track of these parameters.

Equations (1) and (2) refer to the case where mass (2) is initially at rest. Equation (1) describes conservation of momentum for the case where mass (m₁) transfers all its momentum to mass (m₂). In this, the final velocity \( \vec{v_2} \) of mass \( M_1 \) is equal to zero.

Equation (2) describes the case where mass (m₁) transfers only some of its momentum to mass (m₂). In this case, both objects will continue in motion.

Equation (3) is the most general statement of the conservation of momentum principle. Both masses are initially and finally in motion.

All these equations (1) - (3) describe an actual collision between two objects.
### CHART II (continued)

<table>
<thead>
<tr>
<th>II</th>
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</tr>
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<tbody>
<tr>
<td><strong>Restrictions on the Use of the Equations in Column II</strong></td>
<td></td>
</tr>
<tr>
<td>( \dot{v} = \ddot{a}t )</td>
<td><strong>In its present form, this equation can be used only when the acceleration is constant.</strong> The object has been accelerated for a period of time &quot;t&quot;; the velocity &quot;( \dot{v} )&quot; given by this equation is the velocity of the object at the end of the time period. This assumes that the object started out at rest at the beginning of the time period &quot;t&quot;. More generally this equation is given by: ( \dot{v} = \dot{v}_0 + \dot{a}t ) (3b) In this form, the equation takes into account a non-zero initial velocity. &quot;( \dot{v}_0 )&quot; is the velocity of the object at the beginning of time period &quot;t&quot;, ( \dot{v} ) is its velocity at the end of this time period. This equation can also be used only for a constant acceleration. The ( t = 0 ) time reference must be used for the beginning of the time period.</td>
</tr>
<tr>
<td>( \ddot{a} = \ddot{v}t )</td>
<td><strong>The velocity is assumed to be constant. It is also assumed that the object starts out (at the beginning of the time period) at a &quot;zero reference&quot; distance point. Otherwise there would be an initial position term in this equation, which would correspond to the initial velocity ( \dot{v}_0 ) term in equation (3b).</strong> ( t = 0 ) time reference must be used for the beginning of the time period.</td>
</tr>
</tbody>
</table>
| \( \ddot{F} \dot{t} = \ddot{m} \ddot{v} \) | **If a constant force is applied to an object, the result is an acceleration; therefore, a non-zero constant force implies a non-constant velocity. But unless calculus is used, physical parameters in the motion equations should be held constant. In the above impulse-momentum equation, this problem is resolved as follows:**  
  A large impulse force \( \dot{F} \) is applied to an object over a short time interval \( \ddot{t} \). The object initially at rest, has a velocity \( \dot{v} \) at the end of the time interval. Since the impulse force is then removed, this velocity remains constant from that time on. |
CHART II (continued)

<table>
<thead>
<tr>
<th>II</th>
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</tr>
</thead>
<tbody>
<tr>
<td>( \ddot{a} = \frac{\dot{\vec{v}} - \dot{\vec{v}}_0}{\Delta t} )</td>
<td>Restrictions on the Use of the Equations in Column II</td>
</tr>
</tbody>
</table>

This assumes a constant acceleration \( \ddot{a} \). As long as this acceleration is kept constant, the length of the time interval \( \Delta t \) between the measurement of the initial velocity \( \dot{\vec{v}}_0 \) and the final velocity \( \dot{\vec{v}} \) can take on any value. The greater the time interval \( \Delta t \), the greater is the change in velocity \( \dot{\vec{v}} - \dot{\vec{v}}_0 \) produced by the acceleration process. The fraction, equal to the constant acceleration \( \ddot{a} \) will remain the same.

\( \ddot{d} = \dot{\vec{v}}_0 t + \frac{1}{2} \ddot{a} t^2 \) - The acceleration must be held constant. The time reference \( t = 0 \) must be used for measuring the time interval. The time \( t=0 \) is taken to be the time at which the velocity of the object was \( \dot{\vec{v}}_0 \).

Directions of motion must be incorporated into this equation. That is, if the object is being decelerated, the initial velocity vector \( \dot{\vec{v}}_0 \) and the acceleration vector \( \ddot{a} \) will have opposite signs. When this convention is adhered to, the equation will give the correct answer both for accelerated and decelerated straight-line motion.
The dissertation submitted by Bettyjean Houlihan has been read and approved by the following Committee:

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The final copies have been examined by the director of the dissertation and the signature which appears below verifies the fact that any necessary changes have been incorporated and that the dissertation is now given final approval by the Committee with reference to content and form.

The dissertation is therefore accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Date: May 18, 1975

Dr. Barney M. Berlin, Director