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An investigation of the effectiveness of a teaching machine in improving the formal reasoning ability of students engaged in the study of chemistry at a community college.

David A. Harvey
University of Massachusetts Amherst

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AN INVESTIGATION OF THE EFFECTIVENESS
OF A TEACHING MACHINE
IN IMPROVING THE FORMAL REASONING ABILITY
OF STUDENTS ENGAGED IN THE STUDY OF CHEMISTRY
AT A COMMUNITY COLLEGE

A DISSERTATION PRESENTED
by
DAVID ANDERSON HARVEY

Submitted to the Graduate School of the
University of Massachusetts in partial fulfillment
of the requirement for the degree of
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EDUCATION
AN INVESTIGATION OF THE EFFECTIVENESS
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David Anderson Harvey

Approved as to style and content by:

Leverne J. Thelen
Dr. Leverne J. Thelen, Chairperson

Raymond Wyman
Dr. Raymond Wyman, Member

Ward Hunting
Dr. Ward Hunting, Member

Mario Fantini
Dr. Mario Fantini, Dean
School of Education
DEDICATION

To Demargaret Lores, my favorite blond, my childhood sweetheart, my wonderful wife, mother of our children, keeper of our home, and Dean of all domestic functions and operations Who, with infinite patience and longsuffering, nudged but never pushed encouraged but never nagged endured but never complained (out loud) and never learned to type.
ACKNOWLEDGEMENTS

The author of this dissertation wishes to acknowledge the patient guidance, encouragement, and helpful support of the dissertation committee. It has been inspirational, in this attempt at scholarship, to experience helpfulness rather than harassment.

There are others also to whom the author wishes to express appreciation: to Dean Toby Sutton for granting permission to carry out this study within the College, and for his interest in, and support of such undertakings; to Professor Carleton Stinchfield for the use of his classes, and his support of the project; to Lab Technician Ron Smith for his supervision of the teaching machine use and administration of the tests, and his generous contribution of time and effort in many other details of the work; and to Robert Keir and Bill Sweeney for their many hours of proofreading and checking of the manuscript through its various editions. (What errors remain, however, the author insists on claiming as his very own.)

To the many other colleagues and friends who have assisted and encouraged, a debt of gratitude is owed; they have made vital contributions to the work.

If there is accomplishment found herein, then, let it be shared among all who have had a part.
ABSTRACT

An Investigation of the Effectiveness of a Teaching Machine in Improving the Formal Reasoning Ability of Students Engaged in the Study of Chemistry at a Community College

February, 1984

David Anderson Harvey, B.A., Taylor University
M.Ed., State College at Bridgewater
M.A., Ohio State University
Ed.D., University of Massachusetts
Directed by: Dr. Leverne J. Thelen

This study sought to determine whether or not a teaching machine could be effectively used to improve the formal reasoning ability of students studying freshman college chemistry at a small New England community college, particularly in regard to the concept of ratio and proportion.

The development and use of teaching machines and programmed learning were reviewed, and some widely held theories of learning were examined for their relevance. The study focused on the "formal operational stage," as identified by Jean Piaget, and its importance and possible implications for science education.
Fifteen students from an existing class in college chemistry were randomly assigned to the experimental group, while the remaining seventeen were assigned to the control group. The Campbell and Stanley Pretest-Posttest Control Group Design was used as the experimental format, and the treatment consisted of exposure to from sixteen to forty-eight frames of ratio and proportion principles and applications, and sixteen multiple-choice questions controlling machine advancement and feedback. A t test was applied to pretest and posttest means, and in all cases no significant difference was found.

The conclusion drawn was that the experimental results did not statistically support the hypothesis that formal reasoning ability relative to ratio and proportion could be improved within the parameters of this experiment. Implications are that (1) students may not have been able to operate at the formal level; (2) the experiment was faulty; (3) the measuring instrument was not adequate; (4) there were increments of improvement, but too small to detect; (5) exposure to the treatment was not long enough to yield measurable results.
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Research Problem Rationale

Present day societal needs dictate that technological subjects be taught to an ever-increasing number of students. The increased enrollments coupled with an awakening public interest in accountability in the educational process, and with the necessity for fiscal austerity in both public and private institutions, has imposed a search for methods to bring about higher levels of cost effectiveness in the teaching-learning process. This has happened at a time when learning theory is in the midst of a ferment over the nature of the highest levels of reasoning (mainly due to the work of Piaget), and the questions it raises about the readiness of students to deal with the intellectual demands of the college experience in science and mathematics. In summary, the solution to the problem seems to mandate that educational institutions teach at less cost and with a high degree of success greater numbers of students who may not yet be ready for the challenge posed by the different technical fields. If this is true it obviously calls for something different from the traditional practices in education.
Research problem. This study seeks to investigate the effectiveness of a teaching machine in improving the formal reasoning ability of students engaged in the study of chemistry at a community college.

In attempting to deal with improvement in technical education through the use of teaching machines, three distinct entities in educational research emerge: (1) programmed learning, (2) teaching machines, and (3) theories of learning. How these three areas relate to each other, and to the problem of science education will be expanded upon in the following sections.

Background and Theoretical Base

Programmed learning. Such names as Pressey, Skinner, Crowder, Lumsdaine, and Glaser are associated most frequently with the pioneer work in the field of programmed learning (Lumsdaine and Glaser, 1960). Essentially this approach has its roots in stimulus-response and reinforcement theories of learning, operant conditioning in Skinner's terms. Extensive work has been done in this field, beginning with the Pressey teaching machine in 1920 (Pressey, 1926), with more recent interest in this approach dating from the time of Skinner's work in the fifties (Skinner, 1954). It is now a well established fact that programmed materials,
whether presented by machine or text, can carry on the function of instruction quite adequately, at least when it involves simple learning experiences. Much of the earlier work dealt with rote learning, and factual information acquisition. More recent developments have successfully extended the technique to more abstract learning tasks in almost all fields of education and virtually at all levels of complexity from the early grades through adult education. Current development and research activities involve the ultimate teaching machine—the computer—with some programs capable not only of presenting a variety of sequences in an interactive learning program, but also capable of carrying on a dialogue with a student, evaluating his responses, and providing additional information as required by the nature of the student's responses.

Originally, programmed instruction referred to a method of self-instruction: material organized into small steps through which a student worked at his own pace, receiving constant feedback about the correctness of his responses. Programmed instruction might have referred to a book designed in this fashion, or to a simple presentation device such as a teaching machine; but now the term is sometimes used to refer to an integrated instructional system usually consisting of a
programmed book, at least in part, augmented by other means of material display, and often including sound—a multimedia approach.

Programmed materials may take several forms. For instance, motion pictures could be thought of as programmed learning sequences in which the student is not required to make any overt responses. But generally programmed materials, as the term is now used, whether presented by a machine, a book, or some other means, are so arranged as to require the student to continually interact with and overtly respond to the material as it is presented. If there is but one response possible in the program, it is a linear design. If alternate paths, determined by the nature of the student's responses, are provided throughout the program, it is a branched design or Crowder-type program. In the programming of materials for a learning sequence, a single concept, definition, word, phrase, idea, or statement is presented. This is often referred to as the information panel. A series of questions or exercises follow, requiring the student to make application of the material that was presented. These are called frames. Usually leading questions are asked; sometimes strong cues are given so that the student rarely makes an error. Reinforcement is gained when the answer or response is confirmed in the next
frame, or in some other way. Ideally, wrong responses are anticipated by the program designer, and if a student makes one of these anticipated or common errors, the program provides for directing the student back through the program (linear design), or through an alternate route (branched design). As the student progresses, gaining knowledge and confidence, the cues are gradually withdrawn, leaving the student progressively more and more on his own.

Though the actual details of a program format may vary considerably, all overtly interactive programs contain three basic elements of design: (1) presentation of information, (2) some form of required response, and (3) confirmation, reinforcement or correction of response.

The information element may vary from small explicit steps to entire paragraphs of information. Responses may be overt or covert, frequent or occasional, and chosen or constructed. Reinforcement may also take several forms.

Teaching machines. Though teaching machines are not necessary to programmed learning, they do offer some particular advantages over book variations of programs. Among the advantages are (1) cheating is less likely, (2) the element of novelty may contribute to student interest, and (3) machines differ from books, and thus
may reduce student anxiety in some cases, and (4) machines provide a means of required attention.

Just about the time that programmed learning began to flourish, and teaching machines began to flood the educational market (having become more elaborate and versatile), computers loomed large on the horizon as the ultimate teaching machine, capable of making "smart" decisions and offering almost-human communication with a student.

In a way, this rapid development of high technology was unfortunate for education at that time because it smothered the teaching machine in its infancy, and drove it from the classroom with the promise of bigger and better things to come long before its full potential was ever realized. Computer age technology certainly offers the ultimate in teaching machine capability and versatility, but to the average teacher and classroom they have yet to be delivered. And with the near-future promise of greater potential usefulness at lower costs through miniaturization and integrated circuit technology, another decade is likely to pass with most of our classrooms as they were in the fifties, waiting for something newer and better to come along. Perhaps the teaching machine was abandoned prematurely, never having reached its fullest potential. But to resurrect the
teaching machine from the past to try again would in the minds of some people be tantamount to imposing some sort of indignity upon education, for after all, hasn't it outgrown those simple electromechanical gadgets and wisely embraced the genius and sophistication of modern space-age high technology? While it may be true that computers are common educational machines at the heavily funded levels of research, they certainly are not yet common in the ordinary classroom, nor are they likely to be for some time yet, regardless of their extollable virtues. Perhaps we have come too far too fast. Might there not be virtue and reward in returning to the past for another critical look?

Piaget's theory of cognitive development. Currently in America and indeed throughout the world, there is a felt need and responsibility to provide advanced educational experiences for the average person. The community college movement of the past four decades attests to this. The world's increasingly complex and technology-dependent societies require this for their survival, maintenance, and perpetuation. However, it is difficult to educate the average student in the physical sciences, engineering, and advanced mathematics; fields that were traditionally reserved for only the "brightest" and well prepared students. Piaget's theory of cognitive
development deals explicitly, at the highest or formal level, with the intellectual process by which complex, abstract, and intangible ideas are grasped, understood, and applied, and his work has yielded some insight as to why so many students, particularly those of average ability, often find these courses nearly impossible to master.

Piaget's research into how children think has led to the identification of four stages of intellectual development through which all fully developed individuals are believed to normally pass. These stages represent degrees of progressively greater sophistication and complexity which the individual's thinking pattern exhibits at that stage of development. Very briefly, these stages of cognitive development may be summarized as follows:

1. **Sensory-motor Stage** (from birth to age 2)

   This stage is characterized by inherited behavior; manipulation of physical things; and eventually, learning to respond to things beyond view; development of cognitive reality of the physical world.

2. **Preoperational Stage** (from ages 2 to 7)

   The child forms mental symbols; engages in symbolic play; is egocentric, interprets things in terms of self.

3. **Concrete Operational Stage** (from age 7 to 11)
Precision in comparing objects develops, but all reasoning is related to things of experience; there is inability to reason in the abstract about things.

4. **Formal Operational Stage**. (from age 11 to adulthood)

This stage is characterized by an ability to perform experiments in the mind; think in terms of theoretical or hypothetical situations; deal effectively with constructs and their abstractions.

Piaget's cognitive stages of development have been extensively researched in recent years, and the following points are substantiated: (1) there is a progressive change in the thinking patterns of children from concrete to formal; (2) this development is culture-free; (3) while there is some variation in the age at which a child reaches a certain stage of development, the stages always occur in the same order; (4) there are periods of transition between stages wherein a child may reveal characteristic behavior common to two stages; (5) many students do not consistently operate at their highest cognitive level or stage, but often revert first to a lower stage of operation; (6) many adults do not operate at the formal operational level, yet this stage is normally expected to be in evidence by late adolescence.

Although the whole spectrum of his cognitive
development theory is relevant to science and mathematics education, it is this formal stage in the cognitive development theory of Jean Piaget that has become so important to educators, particularly those who are involved in the teaching of science and mathematics at the higher levels of abstraction. The formal operations stage is the final, most sophisticated level of human cognitive experience, involving increasing ability to deal with the intangible and abstract. Without this ability, much of what must be dealt with in science and mathematics (and other theoretical and abstract fields as well) can neither be understood nor mastered. But educational research into some of the aspects of Piaget's ideas concerning this particular stage of cognitive development has raised certain questions that are pertinent to science and mathematics education: (1) the universality of this final stage of human development (do all adults really develop this far); (2) the time of appearance of this skill in human development (does it really appear as early as Piaget first expected it to--by late adolescence); (3) consistency in use once this skill is in evidence (why do some people revert to concrete stage thinking when they apparently possess the ability to think at the formal level); and (4) can the formal operational stage of development be enhanced, improved,
helped along in its development (can it be taught, learned, or must it wait for some internal mechanism or maturity to trigger its development—or both).

These questions have obvious significance to the teaching of science and mathematics to young adults, particularly in view of the uncertainty of their cognitive ability to deal effectively with these abstract disciplines at the age at which they typically encounter them.

Summary

One of the most serious challenges for science education in modern times is that traditionally difficult subjects must be taught to students of average academic ability, who according to currently predominating learning theory may be largely intellectually unprepared for the rigorous abstractions required for such fields. It remains for educational researchers to find ways (if indeed it can be done at all) to enhance the process of developing skills in formal reasoning ability if our educational system is to keep pace with the ever-increasing technological expansion. Teaching machines, abandoned some years ago in favor of the educational potential of the computer, might possibly hold promise as an inexpensive and versatile aid in the
development of formal reasoning skills. Whether or not teaching machines can be effectively used in this way is the main thrust of this research project.
CHAPTER II
RELATED LITERATURE

Introduction

Programmed learning, teaching machines, and learning theory are all topics pertinent to this study, thus requiring review of the literature in these and other areas of related research.

Teaching machines date from the time of Pressey in 1920, and were extensively developed in the early post war years of the 1950's and 1960's. Interest in the teaching machine soon after yielded to its technically sophisticated cousin, the computer, whose greater educational potential and versatility was quickly realized during its period of rapid development.

Programmed learning was a natural outgrowth of the teaching machine era, and has been widely used as a materials format with or without the machine complement. Wide use persists today in the form of computer-aided instruction programs, and in self-instruction learning materials and textbooks.

Learning theory should be central to any educational research. Many efforts today are directed towards
clarifying some of the implications of Piaget's work. Other important theories of learning should also be examined for their possible relevance.

**Science and Mathematics Education**

No consideration of the literature would be complete without some indication of the forces, interests, concerns, and world events that gave the educational reform its particular direction.

After World War II the national interest and attention once again turned to domestic issues, and among them was education which was long overdue for close scrutiny and overhaul. During the 1930's the schools were essentially authoritarian, and emphasis was upon conformity. Military testing during the war years revealed inadequacies in American schooling, and thus the thrust of the post-war years' educational reform took a "back to basics" direction.

Concurrent with the concern for educational change were the "quantum" leaps in the progress being made by research and technology. It was in this period that the maser (predecessor to the laser) was invented, and the transistor was developed. There were also great new advances in the field of molecular biology. Thus there
was seen by some prominent scientists and educators a widening disparity between the sciences as they were being taught in the nation's schools and the progress being made at the leading edge of research and development. At the University of Illinois in 1951 the Committee on School Mathematics began a curriculum reform project that was destined to set the pace for science and mathematics education for several decades to follow. The launching of the Russian space satellite Sputnik in 1957 served to shock many Americans into the realization that this nation was no longer the undisputed world leader in the fields of science and technology. Real or imagined as this might have been, a period of intensive curriculum reform followed, strengthened by the concern and dedicated efforts of many of our nation's most prominent scientists, and supported by heavy federal government funding.

Sabar (1979) attributes the curriculum reform of the 1950's and 1960's essentially to four basic influences: (1) post-war dissatisfaction with the quality of the schools, and their approach to learning; (2) the gap between school science and the "real" science as practiced in industry; (3) involvement of scientists in educational reform; and (4) advances in behavioral science, and more insight into how children learn.
The infusion of huge amounts of federal government money made it possible for extensive science curriculum revision projects to be undertaken, the first of which was the Physical Science Study Committee Project hosted by the Massachusetts Institute of Technology (Arons, 1960). Many other similar projects followed this on somewhat the same format, but each with its own special attributes and objectives. A number of characteristics common to all of the earlier projects can be identified: (1) there was an integrated science approach at the elementary school level, and separate science disciplines at the secondary school level; (2) courses were designed around a single theme, or from a particular perspective (molecular biology, CHEM Study chemistry); (3) there was a strong emphasis upon methods of science as well as content (process and product); (4) professional scientists actively participated in the work of design and writing; (5) materials were tested and revised before general implementation; (6) teachers received training in the use of the new programs; (7) there was strong emphasis upon discovery and open-ended experiments; (8) a variety of media was developed to augment the programs (films, experiments, equipment, games, books, teacher guides); (9) there was no attempt to adapt the programs to special needs populations. Later, attention was turned
to the needs of such groups as minority, disadvantaged, and handicapped.

All of this had to do essentially with secondary school science, while the science courses at the colleges and universities continued to be directed mainly at science majors. Eventually, though, the fervor and concern about what was taught and how it was taught reached the college science classroom and changes began to appear, aided by extensive government interest and funding. The expanding technology of computers, calculators, statistics, learning theory, audio-visual devices, teaching machines, and government funding all contributed to the expanding science education research at the post-secondary school level. Also contributing to the impetus of expanding educational research was the establishment of the ERIC system [1] for information processing, storage, and retrieval.

The college science community has so long been oriented towards research that it has been slow in recognizing the value of the sciences in the general education curriculum. Little (1971) in discussing trends in physics education, attributes the lack of appropriate courses for general education to (1) inadequate secondary school teacher preparation, (2) inappropriate courses for general education, and (3) rapid expansion of the fields
of science, making teacher preparation obsolete in a short time, and (4) difficulty in keeping textbooks current. College level physics curriculum reform was stimulated by the Commission on College Physics, but there was still lacking a comprehensive plan based upon clearly defined objectives.

Some revised college science programs did emerge from this period. PSNS (Physical Science for Non-Science Majors), and IPS (Introductory Physical Science) were two such programs.

As the 1960's may be regarded as the decade of curriculum development, the 1970's may be characterized as the decade of teaching strategies and theoretical orientation. It was a period very much dominated by awakening interest in the cognitive development theory of Jean Piaget, and the consequent concerns it raised about the learning process and how current methods of instruction related to it. Research based upon learning theory (Piaget, Ausubel), PSI (Personalized Systems of Instruction) or Keller Plan, CAI (Computer-Assisted Instruction), and audio-tutorial systems were common research areas in this period (Little, 1971).

Gabel (1978), in reviewing the literature in science education in 1978, cited five studies that dealt with Ausubelian theory: two dealt with the effect of prior
knowledge, two with the effectiveness of advance organizers, and one with ordering of concepts. She concluded that too many studies dealt with Piaget's work, too few dealt with the theories of others, and many had no theoretical base at all.

**Programmed Learning and Teaching Machines**

It seems that the concept of programmed learning began as a necessary technique for designing and arranging learning material for teaching machines. And while in a sense teaching machines and programmed learning can not be separated, the one depending upon the other, they did eventually go their own separate ways. For while any machine designed to perform the function of teaching requires a program of learning material for its operation, material in and of itself may exist usefully without a machine for its presentation, it having the form of some kind of book or other software. To be sure, the mode of presentation of the program, be it book, projector, computer, and with or without sound, determines at least in part some of the parameters of design. Further, the mode of response, and the degree and form of reinforcement will also dictate some of the features of the program design, particularly in regard to
the element of flexibility.

Early in the development of teaching machines it was realized that the nature and quality of the teaching materials the machine was presenting, and the extent and nature of the interaction required of the learner, were critical issues upon which the success of a machine depended. But at first, primarily before Skinner's work, attention was essentially upon the machine and how best to arrange questions for it. Austwick (1964) accounts for this after listing some of the advantages Pressey claimed for his teaching machine:

One surprising omission is how little is said about the actual arrangement of subject matter—the programme, as it is now named. This neglect may have arisen because of the original orientation towards testing with a clear-cut question and answer style of presentation. Certainly there is today greater emphasis on the importance of studying how material should be presented. On the theoretical side some of Pressey's laws of learning have no great sanctity today, and indeed the point has been made by Skinner that Pressey's machines failed to gain support because the available theoretical structure of that time was inadequate. (Austwick, 1964, p.9).

While at first programs were designed to accommodate the presentation device, it became evident, especially with the work of Skinner, that materials written in a particular format, with or without the benefit of machine presentation, had certain pedagogical advantages. It was then widely recognized that the program, and not the
machine, was the critical element in effectiveness, and subsequently programmed learning became a special educational field concerned with certain elements of design of learning materials which were based upon particular educational philosophies and psychologies that were then held as basic and necessary. During this developmental period of growth, transfer of training, reception learning, and stimulus-response psychology tended to predominate and dictate the elements of program design. Gradually attention began to turn towards task analysis, behavioral objectives, and the importance of order and sequence. But by the time these important aspects of materials design were recognized, interest in teaching machines had somewhat subsided and the computer age had arrived. The use of programmed materials continued, however, mostly in book form, and the technique eventually became the base for developing autotutorial programs as sound and other visual aids were combined into a system of self-learning (Postlethwait et al, 1964).

Computer "software" refers to the teaching machine program of today, and there is a strong feeling in the industry that the hardware technology (machine) has far outstripped the development of programs that are capable of making full use of the microcomputers' extensive
capability [2]. Seemingly, the problem here is that in order to create imaginative, intricate, and complex learning routines which the present technology is capable of handling, the software designer must thoroughly know the academic field to be presented, the principles and techniques of good programming (which include knowledge of the teaching-learning process), and the techniques of computer programming. Obviously this calls for extensive training and special skills in combination. And because these skills are so valuable commercially, there are not many such technicians available to the fields of general education. This is not to say that such programs do not now exist; they do. But they are expensive, complicated, and require training for their use. Many programs are still in the developmental stage, and some have only limited application. It would seem that we are years away from effective and widespread use of computers as a common teaching device, even though they are becoming increasingly prevalent in some schools. Even so, appropriate software is still largely unavailable.

Teaching machines: development and research

In the broadest sense of the term, a teaching machine can be any device which involves the learner in
some educational experience: a typewriter, a movie projector, or a computer could all be so regarded. The meaning here, however, will be restricted to any mechanical or electro-mechanical device which presents information to a student, elicits some form of overt response to which the machine in turn responds with some kind of reinforcement or feedback, and then presents the next step in the program.

Porter (1957) in reviewing the literature on teaching machines defines them as devices which involve stimulus and response without the necessity of human mediation, and considers stimulus devices and response devices alone as only teaching aids.

Some individuals consider the device described by English (1942) as possibly the first teaching machine. It was a manometer connected to the trigger of a rifle to show, during training in 1918, whether the trigger was slowly squeezed, or jerked [3]. Good training success was reported.

In all probability there have been many kinds of teaching devices used down through the ages. Austwick (1964, p. 7) reports that the U.S. Patent Office records 600 teaching devices invented between 1809 and 1936. But probably the first teaching machine, as we think of them today, should be attributed to S. I. Pressey (1926).
His machine was designed to give and score a multiple-choice test. In the process of using his machine he discovered that it also taught. The device presented multiple-choice questions printed on an 8 1/2 x 11 inch paper. The machine advanced to the next question each time a correct answer was made, but it would not advance to the next question if a wrong response was made via one of the four response keys. The machine recorded the number of errors made. A later model repeated the incorrectly answered questions, and dropped out the correctly answered ones.

Pressey's machine did not seem to generate a great deal of interest, and only a few significant studies appeared between the time of Pressey's original publication in 1926 and that of Skinner in 1954.

J. C. Peterson (1931) reports a study involving students in a psychology class that used chemically treated paper to provide immediate feedback of test results. By using a moist felt tip, multiple-choice answers were marked on a test on psychology. The moisture from the felt tip marker would react with chemicals on the test to indicate, by means of resulting color change, which answers were right and which ones were wrong. Peterson reported significant gains for the groups which used this system as compared to the groups
which did not. Test content for the most part was factual.

James K. Little (1934) writes of a study using a Pressey-type teaching machine with efforts directed toward demonstrating the advantages derived from (1) immediate scoring of objective tests, and (2) tabulation of results by item. He used a college-level educational psychology course as the source for his experimental and control groups. Four of these groups used a teaching machine, four groups used a drill teaching machine, and six groups were used as a control. All sections were administered a pretest, midterm, and a final examination. The teaching machine groups were given twelve tests of thirty items each, and these were scored as soon as the students finished each test. They thus had immediate knowledge of their score. The most frequently missed questions were discussed by the classes. In the groups which used the machines for drill the same procedure was followed, but the grade on each test was the first performance grade, though they were allowed to continue the exercise on the machine until they achieved mastery. The control groups took written multiple-choice tests which were graded and returned the next day, but they did not have any make-up test options, nor did they have diagnostic review. Data was compared on matched pairs of
students from the experimental and control groups. Results indicated better performance for the drill group over the test group, and both of these groups performed better than did the control groups. The greatest benefit was realized by students who normally do not perform well in a typical classroom situation.

Angell and Troyer (1948) reviewed efforts to improve instruction by means of self-scoring test devices. They reported efforts by the military to mechanize some phases of military instruction. These were mostly efforts to utilize the then available machines to give immediate knowledge of test results. But since machines such as the one the military used—the Automatic Rater—are expensive, Angell and Troyer set about to investigate a simpler means by which to provide immediacy of test results: a punchboard answer device. At Syracuse University this system was used in chemistry and citizenship classes. Results support the idea that immediate feedback of results does improve learning performance.

Pressey (1950) also reports that students perform significantly better on a test if they have previously had access to the questions in another form and have used the punchboard answer device than if they had not. But this leaves one with the question as to whether a "second
pass" through the material is the real element of improvement, or whether it is the feedback instrument, or both.

Stephens (1953) used a Drum Tutor—a multiple-choice testing device that (1) showed the number of the question to be answered, (2) tabulated wrong answers, and (3) advanced to the next question number when the correct response was made. Thirty multiple-choice practice tests were administered to 1500 Ohio State University psychology students. Punchboard and Drum Tutor techniques were compared using easy Russian vocabulary, hard English vocabulary, and nonsense syllables. In addition to these programs, the Drum Tutor used subject matter material from a course in educational psychology. Three modes of material arrangement were designed and used for the punchboards: (1) retained: an answer was chosen until it was found correct; (2) test-as-test: only one answer per question was allowed with no indication of correctness; and (3) vanishing: only one answer allowed per test item, but knowledge of correctness was provided. Each practice test was taken three times. The conclusion reached was that the first of these methods (choosing an answer until it was found correct) produced the best results, but to a lesser degree for the nonsense syllables than for the meaningful material. The Drum
Tutor showed advantages only when the number of passes was increased (the number of times the material was reviewed).

It was apparently largely due to the work of B. F. Skinner and his classic article in the *Harvard Educational Review* (Skinner, 1954) that the field of teaching machines and programmed learning was redefined, and given a strong theoretical base. True, previous work was not without theoretical direction. Thorndike's connectionism, Guthrie's contiguous conditioning, and Hull's systematic behavior theory were all part of the current theoretical view during the early years of teaching machine development (Hilgard, 1956). But it was Skinner who tied a theory of learning directly to performance involved in the process encountered in learning by means of a teaching machine.

In his article, Skinner described a constructed-response teaching device that presented questions by means of a paper tape which appeared through a window. If the question was answered correctly by operating a combination of four keys, each one capable of presenting any number from zero to nine, the next question could be advanced by operating a knob. This was similar to Pressey's machine, but it differed in that it was designed specifically for constructed numerical answers.
of up to four digits, rather than choosing from among presented multiple-choice answers. His contribution was in the nature of the response rather than the machine. Skinner organized questions in a hierarchy of difficulty, so that each question was dependent upon an earlier one. In this way the learner was led through the material in small but progressive steps. This technique was intended to do two things: (1) improve the likelihood of a correct response and thus support improvement, and (2) reduce the chances of negative reinforcement (fixation of incorrect responses).

Programming, as it was later to be known, or arranging of materials in the proper sequence for maximum learning, is more difficult with the more amorphous or nebulous subjects so unlike the well-structured and ordered fields of science and mathematics. But Skinner was concerned that the proper choice of material had to be judged in terms of whether or not the student could get it right. If most of the students could not answer the problem correctly, then (1) the problem must be wrong for the sequence, (2) the problem must be in the wrong place in the sequence, or (3) the problem involved too large a step in the program. This particular system of programming, and consequently machine design, follows directly from stimulus-response theory which largely
dominated the field of educational psychology in America at that time. Perhaps some of the resistance to acceptance of S-R theory and the use of teaching machines sprang from the reticence to accept the idea that man and the lower forms of animals responded and learned much in the same way.

A study by Warren and Brown (1943) concluded that conditioning, extinction, disinhibition, and periodic reconditioning of an operant response in children are essentially similar to those phenomena which are found in laboratory rats. Skinner, of course, came to the same conclusion; the species made little difference:

In all this work, the species of the organism has made surprisingly little difference. It is true that the organisms studied have all been vertebrates, but they still cover a wide range. Comparable results have been obtained with pigeons, rats, dogs, monkeys, human children, and most recently by the author in collaboration with Ogden R. Lindsley, human psychotic subjects. In spite of great phylogenetic differences, all these organisms show amazingly similar properties of the learning process. (Skinner, 1954, p. 89)

Porter (1957) suggests caution at this point inasmuch as the classroom situation is not necessarily equivalent to the solitary laboratory experimental environment. Further, he suggests that since it is unethical (and illegal) to shock, starve, or dehydrate children--stimuli commonly employed in the laboratory--other reinforcers must be used with teaching
devices. Novelty, exploratory, or manipulative variations should be adequate for this purpose. This has been found to be so (Woodsworth and Schlosberg, 1954, p. 685), though it is also true that novelty and curiosity effects do tend to wear thin after a while. This can perhaps be remedied by variation, but satiation is eventually likely to occur with any method. Alternative reinforcers commonly used in teaching situations are social approval, desired activities or privileges, and aversive stimulation (punishment). One should not overlook, however, the reinforcing power of success and a feeling of accomplishment.

Though it is recognized that teaching machines are not necessary to programs in order for the programs to be effective as teaching instruments, it is generally recognized that teaching machines do have some advantages over book formats: (1) they provide a novel approach that differs from a book, a feature that is particularly attractive to those students who are intimidated by books; (2) attention and interaction are required inasmuch as the program can not continue without them (unlike a book where students may look at the words but allow their thoughts to wander); (3) forced study is assured since machines are usually assigned by appointment; (4) cheating is minimized; and (5) some
machines can be made more interactive than books.

The particular kind of machine does not seem to matter, nor does the mode of response seem to make much difference. In all probability the learning material or program, and how well it is developed for its purpose is the more critical issue.

It was only after World War II and the extensive work of B. F. Skinner at Harvard that appreciable interest in teaching machines and programmed learning developed. Some of the momentum of the teaching machine movement, brief though it was, apparently originated in military interest to efficiently train men in specific narrow areas on a massive scale.

Many educators believe that teaching machines cannot replace the teacher, as originally some had envisioned them to do; they serve their best function as an adjunct to classroom work, as an extension of the classroom. But this of course is relative, and depends upon the program and its objectives and the particular student.

Pressey's machine was originally designed to test and drill (Pressey, 1926). In its application it was also found to teach. But it was never intended nor envisioned by its inventor to replace—or even approach the accomplishments of—a real live teacher. It was seen
as an aid to the teacher, performing the task of review, drill, and testing.

Pressey's machine used multiple-choice questions. It was not until the time of Skinner's work (1954) and thereafter that programmed learning and constructed response programs became an issue.

Perhaps the reason that teaching machines were not strongly accepted until after the work of Skinner is that they were not strongly tied to a theory of learning—they just seemed to work! Skinner's theory of learning strongly embodied the principle of reinforcement; a principle extensively demonstrated in his experimental work with animals (Skinner, 1961). Ordinary classroom work does not readily provide for much or frequent reinforcement, but the teaching machine seemed to be a natural way for continual reinforcement, encouragement and fixation of correct responses through what is now called immediate feedback (immediate knowledge of the correctness of responses). In addition to reinforcement of correct answers, negative reinforcement or fixation of wrong information had to be minimized. This was done in Skinner-type programs by virtually eliminating all possibility of ambiguity, misunderstanding, or confusion by creating very small increments of information, and providing hints or "cues" to direct the student to the
right response. It was believed that answers generated by the student elicited more effective learning than did a mere selection of a correct response from among several possibilities as in the multiple-choice format.

Skinner's slider machine employed sliding keys for the selection of numbers and letters (Fry, 1963, p. 20). The machine was used for arithmetic and spelling drill and testing, and such constructed answers were made to questions that were presented through a window in the device. An earlier model of a Skinner machine employed disks upon which questions were printed, and the questions were exposed one at a time through an aperture on the machine. The student would write his response on a paper tape, trip the machine to advance his answer under a glass cover while exposing the correct answer. Comparison would be made by the student of his answer and the correct printed one. A lever would advance the machine to the next question.

Rath and others (1959) report the use of an IBM 650 digital computer which was connected to a keyboard input/output device. The computer presented problems in binary arithmetic. Two unique features of the program were that (1) wrong responses would be indicated as the answers were being constructed, and (2) additional problems would be presented, depending upon the skill of
the operator as evidenced in previous answers. As one might expect, this system was too expensive to be widely used except for experimental work.

Porter (1958) also developed a constructed-response type teaching machine utilizing mimeographed material. All such machines use Skinner's basic principle of operation and design: (1) presentation of a question or problem, (2) write-in of a response, (3) protection against alteration of the written response and exposure of the correct answer with which comparison is to be made, and (4) presentation of the next question.

Keislar (1959) developed a multiple-choice teaching machine for the teaching of arithmetic to elementary school children. The program was presented by means of a film strip, and responses were made by use of response buttons on a machine. A learning curve drawn as the student responded was an additional feature.

Hively (1960) and Skinner devised a machine that could be used to test discrimination ability. A picture would appear in one window of a device. Two other pictures would appear in the test windows which were to be compared to the first picture. The correct match was made by touching the window of the similar picture, thus activating a switch. The machine would advance to the next sequence if a correct choice had been made; and if
not, the windows would go dark and the reference window
would have to be touched to begin the cycle again. The
machine was intended for nursery school children, and
Hively reported only moderate success. A commercial
version of the machine was developed following a similar
design, but used three windows for comparison choices
rather than only two (Rheem Califone Corporation).

Coulson and Silberman (1961) used a computer linked
to a multiple-choice teaching machine, its purpose being
to provide elaborate branching routines based upon the
nature of student responses.

Probably one of the most familiar of the
commercially available teaching machines was the Mark I
Auto Tutor which was built by U.S. Industries, Inc. (Fry,
1963, p. 29). It followed a Crowder design, branching to
alternate paths of material which were determined by the
nature of the student responses. The program was on
microfilm, making it possible to fit into a program as
many as 10,000 pages of material. A motion picture
projector and a response-pattern recording provision were
also part of the system. A smaller, more limited portable
version of the machine, the Mark II Auto Tutor, could
accommodate 5,000 pages of material and also was designed
after the Crowder or scrambled-book design.

Other variations or combinations of projectors and
tape recorders were used as training devices in the 1950's, some of them meeting various degrees of success. All of these operated on the premise that the teaching machine did teach, and that the advantages were that (1) they were faster, and students could cover more material in less time; (2) students did as well as those who were taught in the conventional manner; (3) students could proceed at their own rate, and repeat the lesson if they wished; (4) programs could be made flexible, and changed to suit a particular need; and (5) lessons could be made available to students without the mediation of a teacher.

Roe and others (1960) used a multiple-choice teaching machine in their study, comparing its use to other modes of instruction and found no significant difference except that all programmed modes out-performed conventional instructional methods.

Rosenquist and Miller (1965), using a Mark II Auto Tutor evaluated its effectiveness and found no significant difference between their experimental group using the Mark II and the control group which was exposed only to conventional instruction. They found that attitudes towards programmed instruction ranged from highly favorable to negative.

Geller (1962) used a Koncept-O-Graph teaching machine which required write-in responses to the
information presented. The group used for the experiment was a college organic chemistry class, and the experiment yielded no significant difference between the experimental group using the teaching machine and the control group which was exposed to only conventional instruction.

Goss (1966) used automated visual programmed instruction with paraplegic and other seriously handicapped students ranging in ages from twelve to twenty-one. Results of this work showed that machine instruction was more effective for all students, and especially for those of low I.Q.

Yoder (1969) constructed four programmed lessons utilizing 35 mm slides and a synchronized audio tape to develop problem-solving skills in a college technical physics course. This mode of instruction was compared to instruction via a programmed textbook of identical material. The format of the lesson frames involved the presentation of a physics problem, and then a series of multiple-choice questions relating to features of the problem, and the appropriate steps to its solution. Twenty-eight students were used in the study, fourteen to each of two groups. A pretest and posttest of ten questions each were used, and no significant difference in problem-solving ability was found between the group
using the slide presentation and the group instructed by means of the programmed text.

Jackson (1976) investigated the premise that computer-assisted instruction is more effective than programmed instruction. Using a 2 x 2 repeated measures design experimental format, sixty students were divided into two groups. One group studied the topic of school bond issues for two hours via the programmed text, while the other group studied the same topic by means of material accessible through the use of computer terminals using BASIC programming language. Each group took identical posttests within two hours of completing its program, and again after a five day interval. Repeated measures of analysis of variance showed that the two groups performed about the same on the posttests. The study also revealed that there was significant loss of retention within the five day period between testing, but there was no significant difference in retention between the two groups. Under the conditions of this study, it was concluded that there were clearly no significant differences in the effectiveness of these two modes of instruction. The researchers caution against more general conclusions, however.

A research project by Kolz (1980) was designed to determine whether or not two sets of computer-assisted
instruction programs affect student performance in general chemistry. The programs tested were part of the PLATO CAI system originating from the Urbana campus of the University of Illinois [4]. One program was in mathematics; the other was in chemistry. Pretest-posttest control group design was used with sixty-eight freshmen chemistry students who were divided into three groups: (1) chemistry PLATO group, (2) math PLATO group, and (3) PLATO problem-solving group. Exposure was for one hour per week with the CAI programs used in addition to the regular course work. Math and chemistry placement tests comprised the pretest evaluation. Posttest scores utilized the Student's total course evaluation, final examination, and final examination sub-set scores relating to PLATO material. Analysis of variance yielded no significant difference among the three PLATO groups. Conclusions drawn from the study were that conventional instruction was quite adequate in meeting course objectives, and the cost of adopting the PLATO program exceeded its merits.

Summary of teaching machine research. Pressey's teaching machine dealt essentially with testing, and the consequent benefits of immediate knowledge of results. It soon became apparent that such immediate knowledge of test results or drill scores aided in the learning
process (Pressey, 1926). But learning theories at the time only weakly supported these results in that they seemed to be consistent with the "Law of Recency," the "Law of Frequency," and the "Law of Effect." Also mentioned in connection with teaching machine use was the "Law of Exercise."

The process, and not necessarily the means by which it was achieved, began to receive attention. Chemically-treated answer forms (Peterson, 1931) and later punchboard answer devices (Pressey, 1950) were used in place of a machine to provide knowledge of performance. But not much interest was generated in such methods until the time of B. F. Skinner at Harvard when a strong behavioristic theory of human learning was developed. It was then that a learning theory gave credence to learning by machine. Consequently Skinner developed a rather elaborate system of program writing consistent with stimulus-response and reinforcement principles (Skinner, 1954). Later this system was expanded by others, notably Crowder (1959), who demonstrated similar success with material presented in book form. Thus the "science" of programmed learning was born. Machines, however, continued to be used for a time inasmuch as they apparently still held a strong appeal, and offered some advantages not provided by book formats of programmed
learning. Programming, as it was called, became the dominating and essential element; and the means of presentation, whether by book, machine, or interactive computer, took second place in importance.

**Programmed learning: development and research**

Undoubtedly, programmed learning originated with the work of B. F. Skinner, for it was he who revived the interest in teaching machines, and stressed the need to carefully construct material to be used in such devices. He apparently realized that "the success of such a machine depends on the material used in it" (Skinner, 1958, p. 143). His own particular preference was for constructed response answers as opposed to multiple-choice type. But in order to take full advantage of the stimulus-response and reinforcement principles, the material had to be arranged according to a scheme that may be outlined as follows:

1. clearly define the field to be presented
2. collect technical terms, facts, laws, principles, and cases
3. arrange these in plausible order (linear if possible, branching if necessary)
4. arrange material among program frames to achieve an arbitrary density
5. use terms and facts throughout successive frames to reinforce development of concepts and vocabulary

6. obtain feedback from the student

Holland (1960) listed eight rules for writing a Skinnerian-type program:

1. Each response must be reinforced immediately

2. Only overt responses, suitably reinforced, are learned

3. Errors have an adverse effect on learning

4. Progress must take place in small successive steps

5. Aids to the student (cues, prompts) should be withdrawn gradually (fading)

6. The student's observing behavior should be controlled

7. Extensive discrimination training is needed to establish an abstraction or concept

8. The student must write the response

These rules, of course, are derived from the Skinnerian approach though they perhaps were not so stated in his words. To accomplish positive reinforcement of desired behavior, immediate knowledge of results was assumed to be rewarding and reinforcing. Overt responses are the only ones that can be observed and therein verified. To avoid errors, which were
regarded as negative reinforcement and therein detrimental to learning, very small steps in approaching new learning were employed, and cues, hints, or prompts were written into the material to help elicit only correct responses. It was felt, though, that these should be gradually withdrawn as the student builds confidence and knowledge of the field, so that he is progressively left more and more on his own. This technique of gradual withdrawal of cues or prompts is called "vanishing" or "fading." The control of "observing behavior" is a matter of limiting stimuli to the work at hand. This became one of the important advantages of a teaching machine over a programmed text: there is no way to see the entire program in a teaching machine except one item at a time. With a teaching machine, if the mind wanders and does not respond, the next item is not available and the process halts. In book form the student may look ahead, even skip material.

Ability to subdivide a concept into smaller parts was called discrimination. Training for the programmer in this skill would assure that each concept would be broken down into simple, understandable segments, with many examples. If this skill is not perfected in a programmer, vagueness and confusion may be the result of
Adjustment and redesign of a program is guided by student responses (feedback) so that student accomplishment and success is assured.

In order to teach rather than to merely examine, as the original Pressey machine was designed to do, greater amounts of material had to be processed. This was done in the written programs by arranging small units of information in information panels, sections of factual learning material the student would encounter and upon which the subsequent questions or responses would depend. In this way information was presented to the student in small increments that were easily assimilated by him before he would be required to proceed to the next information panel.

As others began working with the possibilities of programming materials, elaboration of Skinner's original routine began to develop. The RULEG (rule/example) programming scheme was developed by Homme and Glaser (1959). It does not deviate from the principles of Skinner, but it does specify a detailed system or routine by which a programmer may maximize the effect of the program by carefully and systematically examining what is to be accomplished, and arranging the material accordingly. Steps in the process are outlined as
1. specify the criterion behavior (identify)
2. list all rules (ru's) that are involved
3. collect stimulus support (texts, notes, other authoritative sources)
4. make a preliminary arrangement of the rules for the program
5. make a rule matrix, consisting of horizontal and vertical rows; cells indicate possible interrelationship of rules, and possible need for prompts
6. examine cells—make examples (eg's) of each
7. order cells as they are to be encountered in the program
8. assemble all ru's and eg's into a program format

In addition to these steps, a system for combining rules (ru's) and examples (eg's), and determining appropriate places to include cues was worked out, and suggestions for testing and revising the program was given. A system of abbreviations was created to indicate what combinations of rules and examples are to be used:

1. ru + eg + ëg  rule + example + incomplete example
2. eg + ëg  analogy frame
3. eg → ru → eg  induction—eg is given rule must be induced, then applied to complete example
4. ru + ū  introduction of technical vocabulary in stating rules
After a program is constructed from the ru-ru matrix, the program is given to students and an item analysis is performed on their responses. Two important suggestions are made for program revision: (1) over-prompting should be avoided, and (2) prompts should be faded so that towards the end of the program the student is left entirely on his own. The program is then repeated and revised as needed until the desired criterion can be achieved from the program.

One can see in this system preparation of materials an attempt to move away from rote learning and drill towards a specific and organized scheme for dealing with more complex ideas. After careful inventory of what is to be presented, the program designer maps out a progression of material presentation from principles, through examples, terminology, and finally two levels of application requiring student internalization of these ideas. This is clearly a move, in Piagetian terms, away from concrete operational to formal operational performance requirements.
One of the problems with educational research of the past was its frequent lack of any theoretical base (Gabel, 1978). Much of the effort followed a "try it and see if it works better" approach with little, if any, theoretical directive. This is not surprising, though, and not totally unwarranted because the past has taught us that even the most plausible theories last only for a short while, and are soon replaced by others. The best we can do, then, is to proceed with caution, taking what cues we have from experience, research, and the theorists. Many of the theories overlap, use different terms for similar phenomena or describe certain learning functions from widely different perspectives or philosophical viewpoints. Probably most of the theories that have gained wide attention have made some kind of significant contribution to our knowledge of the teaching-learning process, if nothing more than to generate other theories devised to refute or correct them. Brief descriptions of some of the more widely embraced theories are presented herein because of their similar features and consequently their possible relevance to this present undertaking.
Guilford's Structure of the Intellect model

Some of the older theories of learning were based upon lower animal behavior. Guilford's model (Guilford, 1968) is derived from factor analysis of complex human behavior, and therein offers a particular uniqueness over dominant traditional theories. The theory parallels current educational trends and interests, inasmuch as it attempts to define mental processes in terms of human behavior and particular mental functions. Five mental operations are defined in his three-dimensional model: (1) cognition, (2) memory, (3) divergent production, (4) convergent production, and (5) evaluation. Products relevant to each of these operations are (1) units, (2) classes, (3) relations, (4) systems, (5) transformations, and (6) implications. Areas of content have been identified as (1) figural, (2) symbolic, (3) semantic, and (4) behavioral. Interactions of operations, products, and content provide 120 possible combinations, and therein 120 separate definable mental abilities. Guilford represents these possibilities of mental operations by the intersection of rows in a three-dimensional rectangular solid model (Fig. 1, p. 50). Not all of the resulting categories have been identified, but about 80 of them have been, enough to suggest some usefulness to the theory. Probably a deterrent to wider
Fig. 1. Guilford's Structure of the Intellect Model, representing intellectual abilities (Guilford, 1968, p. 10).
acceptance of Guilford's model is its complexity, and the difficulty encountered in identifying so many different intellectual operations.

Implications for education are numerous, with high importance being placed upon information: that is, process begins with cognition as the base. This could be interpreted to support a return to stress upon factual content as a necessary base of knowledge and awareness against which decisions and associations can be made. What is not remembered can not be recalled when needed, and how things are best known or cognized, then remembered, relates to a hierarchy of output (products) that take the form of units first, then classes, relations, systems, transformations, and finally implications. Each of these can be manifested in the form of figures, symbols, meaning, or behavior. These last four are described as content. Regardless of the consequent problem of identifying all 120 possible intellectual functions or abilities within the model, three of them come through as important: (1) the prominence this model gives to factual content, the knowing of things; (2) the importance of organization in order to follow the progression from simple to complex abilities; and (3) the distinctions made between operations, products, and content. The model suggests
that intelligence requires cognition and memory, and that these are highly structured (units, classes, relations, systems, transformations, and implications). If an individual does not acquire the necessary input, it may be due to an innate lack of normal capacity, but it could also be due to lack of appropriate organization of the input and failure to provide exercise in each of the various facets of intellect at appropriate progressional levels. Perhaps much of the failure of students in science courses can be blamed on the stressing of convergent and divergent thinking processes before sound cognition levels have been established. The study by Swartney (1969, p.9) listing characteristics of students who failed a course in CHEM Study chemistry seems to point to the fact that they just did not know the necessary facts or have the necessary basic fund of knowledge from which to draw—a problem at the cognition level. Pertinent to all the theories of learning is this process of taking in information, and being able to use it in some way to interpret one's environment (physical or social, general or specific), and therein be able to order one's actions in a meaningful, rewarding, and organized way. Though we may not yet understand the actual process by which this is accomplished, that is, the mental mechanism that brings it about, we do know
that it must occur. Each of the theories of learning contributes something to our understanding as to just how this process might take place, and therein provides some insight as to how the process may be enhanced and managed wisely. Guilford's Model of the Intellect does at least suggest that an intellectual ability is an external manifestation of some particular internal and definable cognitive process.

There are several considerations that tend to weaken broad acceptance of Guilford's model (Anderson and Ausubel, 1965, p. 15). One objection has to do with the tenability of there being 120 separate, distinct, definable cognitive abilities as proposed by his three-dimensional model of juxtaposed categories of mental functioning. While some of the resulting functions can be identified, there remains a fair number of them that as yet have not been found to relate to presently known cognitive abilities.

The second objection comes from a consideration of the appropriateness of using factor analysis as an empirical justification for proposing the existence of a hypothetical model of a particular mental structure. Such technique may be acceptable for proposing some plausible origin of the outwardly manifested model abilities, but it can not hope to pass as a sound basis
for establishing it. A similar argument is leveled against Piaget's developmental stages (Neimark, 1969; Novak, 1977).

Guilford's model is important, for if it is seriously considered, it would lead one in the direction of favoring training towards perfecting separate and distinct abilities defined by the model. Guilford makes this point himself:

The idea that education is a matter of training the mind or of training the intellect has been rather unpopular, wherever the prevailing psychological doctrines have been followed. In theory, at least, the emphasis has been upon the learning of rather specific habits or skills. If we take our cue from factor theory, however, we recognize that most learning probably has both specific and general aspects or components. The general aspects may be along the lines of the factors of intellect. This is not to say that the individual's status in each factor is entirely determined by learning. We do not know to what extent each factor is determined by heredity and to what extent by learning. The best position for educators to take is that possibly every intellectual factor can be developed in individuals at least to some extent.

(Guilford, 1959, p.213)

Guilford goes on to point out that if education has for its objective developing the intellect of students, then the model provides numerous specific factors or goals. Each factor, being determined by some element of either content, operation, or product, requires specific practice if it is to be perfected. This requires deliberate choice of curriculum as well as specific
teaching techniques.

If one passes over the concern about the legitimacy of the basis for Guilford's Model of the Intellect, one can find a hierarchy of mental tasks arranged in order of complexity from the very simple and tangible (such as cognition, units, behavioral perhaps) to the very abstract (evaluations, implications, figural). This would seem to cover the full Piagetian range from preoperational to full formal operational functioning.

Bloom's Taxonomy of Educational Objectives

In an attempt to define, synthesize, classify, and organize the goals of education, Benjamin S. Bloom and others set about to develop a taxonomy of educational objectives (Bloom et al, 1956). Its purpose was to provide a dimension of precision to communicate among educational professionals at all levels in regard to curricular and evaluation problems. The Taxonomy was to be a set of standard classifications of the educational process and a catalog of its goals and intended outcomes. Part I, the Cognitive Domain, deals with knowledge and the development of intellectual abilities and skills. It has for its main classification the following:

1. Knowledge
2. Comprehension
3. Application
4. Analysis
5. Synthesis
6. Evaluation

Within each of these there are three levels of definition:

1. Major aspects of the classification
2. Sub-classes of objectives typically found associated with each classification
3. Task-oriented descriptions of the classification as might be found in test items

The Cognitive Domain is the traditional area of interest as exemplified by most research and evaluation efforts.

Part II of the Taxonomy of Educational Objectives (Krathwohl et al., 1964) deals with objectives that involve changes in interest, attitudes, and values: development of appreciations and adequate adjustments. The sub-headings for the Affective Domain are:

1. Receiving (attending)
2. Responding
3. Valuing
4. Organization
5. Characterization by a value or value complex.

A Third part of the taxonomy concerning manipulative or motor-skills was originally proposed, but was not
These ideas were developed at a time when concerns were more directed at the objectives and outcomes of education, and how these might affect what is done in the classroom. Hence, attention was focused not on the inside—on the actual internal psycho-physiological mechanisms by which cognitive processes take place—but rather on the outside where the end results of the educational experience can be defined, observed, and evaluated. Thus, once the end results had been defined, strategies for their progressive attainment could be devised.

Though at first this may not seem all that relevant to Piaget's ideas, it is in the practical sense, particularly in regard to the teaching machine since it does direct our attention towards designing around certain objectives, irrespective of our beliefs as to just how these may best be accomplished and by what internal mechanism. But Piaget's ideas do impose a certain question over all of this, however: is the organism ready—by virtue of cognitive maturity—to handle the level of concepts presented, regardless of the carefulness of design? We can not hope for particular development if we have not taught and tested towards accomplishment of that particular goal (and Piaget would
add—yes, within the context of cognitive ability at that stage of development).

**Skinner's stimulus-response theory**

Probably the great failure and consequently the wide rejection of this particular view of human behavior was that it was to a large degree misunderstood. It was widely held that:

...it formulates behavior simply as a set of responses to stimuli, thus representing a person as an automaton, a robot, puppet, or machine; it does not attempt to account for cognitive processes; it has no place for intention or purpose.

These and seventeen other commonly held misconceptions are listed, then refuted by Skinner (1974, p.4).

Briefly, the behaviorist accounts for learning by asserting that operant conditioning is an acquired behavior brought about by reinforcement, as opposed to innate behavior that is related to survival—a contingency of survival.

Operant reinforcers may take the form of wants, needs, desires, or wishes. These reinforcers are effective in reinforcing behavior to the extent the person has been deprived.

The probability that a person will respond in a particular way because of past operant reinforcement
changes as the contingencies change (ibid., 1974, p.57).

Skinner describes the process of thinking as covert behavior where we can act without suffering the consequences of poor action; we can revoke the "thought" behavior after we have tried it and regarded or imagined its consequences.

In dealing with cognitive control of stimuli, he points out that when selections are made as to what we pay attention to, and what we "tune out," it is not a matter of change of stimuli, but rather a matter of the contingencies that underly the process of discrimination that we exercise. This is a behavioral process; the contingencies rather than the mind make the difference based upon past experience under similar circumstances: contingency management, as it is called.

Concept formation is also viewed as involving contingencies of reinforcement rather than some abstract cognitive process. The referents of concepts are external to the mind—in the real world—and all that has been done is to gather a field of experience related to human behavior. An example is given (ibid., p.106) of two children learning that $3 + 6 = 9$. One of the children also recognizes that $6 + 3 = 9$ as well but the other child does not. Is this a matter of the one child grasping the mathematical principle of commutation, and
the other one not, or is it only a matter of contingencies: the one having greater experience or having been previously told that $6 + 3 = 9$? (This would seem to be a logical question to raise regarding Piaget's experiments with young children.)

The matter of search and recall, or remembering, is also accounted for in terms of stimuli. There is no array of stored information within the brain. We remember some thing, place, name, idea, or concept when we respond to stimuli that were a part of or are similar to stimuli which were a part of earlier contingencies. To Skinner, being reminded is to be made likely to respond, even perhaps perceptually.

Techniques for recall are not, then, a matter of searching some mental warehouse, but rather a technique for increasing the probability of responses. Memories are regarded as pre-learned behaviors which prompt or otherwise reinforce the behavior to be recalled.

Problem-solving—another major element of the cognitive process—is regarded as a situation in which a condition would be reinforcing if the individual had the means to make the proper response. When he finds the proper response, he will have solved the problem. A complex mathematical problem is solved by finding the solution; the problem of an illness is solved by
finding an effective cure. It is really more of a process than this, however, for it involves finding ways to make the response more probable, usually by manipulating the environment (that is, changing or varying the conditions of the problem). Systems for doing this are learned from the problematic contingencies to which we are exposed, either by direct experience or by transmission through training or culture.

Thought processes are behavioral, and can not be separated from genetic and personal histories. Skinner suggests that probably the behavior that indicates the possession of some physical concept like inertia, and the age at which it appears is useful information; but it shouldn't be viewed apart from the experiences that finally led to the concept: the many times things had been pushed, pulled, started, stopped. All of these experiences contributed to the development of the concept. The formation of ideas is seen more as the result of a constructing environment rather than a constructing mind. Human thought is seen simply as human behavior. As an example, mathematical symbols are the products of written and spoken verbal behavior, and the concepts and relationships of which they are symbols are in the environment. Thinking, then, has "dimensions of behavior" and is not then just a fancied inner process
which manifests itself in behavior (ibid., p.118).

Understanding comes when we can repeat a statement as though it were our own—something we could have said. Also it sometimes means knowing reasons. We may follow a certain set of procedures, the behavior undergoing extinction when it is not successful in reaching the desired outcome, and we go on to the next step, all along discovering reasons. Acquiring understanding is a matter of analyzing prevailing contingencies. Knowing becomes a matter of responding to the prevailing contingencies of reinforcement. The facts and laws are merely this, making it possible for a person to act more effectively than he would be able to learn to do in a short life time. The content of science has meaning only so far as it affects people. It has no power in and of itself.

Skinner's Stimulus-Response Theory was a "natural" theoretical base for the teaching machine, it would seem, since the machine only had to prompt the student enough for a response, and then reinforce it through the knowledge of results (feedback). Behaviorism was still much in the position of dominance in American educational psychology at that time, and apparently there was not much interest in moving too far beyond simple factual acquisition and elementary paradigms in designing teaching machine programs.
When teaching machines were reaching their peak of acceptance in educational circles, Piaget was just being "rediscovered," and attention was just beginning to turn towards such concerns as the scientific method, divergent thinking, convergent thinking, and critical thinking—all of which require abstract thinking and therein occur most strongly at Piaget's formal stage of cognitive development.

The question remains, then: can a teaching machine be an effective means by which to improve formal operations level thinking, especially when its orientation and previous success as a teaching device has been extensively at the concrete level?

**Ausubel's assimilation theory of learning**

Ausubel makes a distinction between rote-meaningful learning and reception-discovery aspects of learning. He holds that autonomous discovery is not necessary for learning to take place as long as meaningful material is being considered. Reception (expository) learning should not be regarded as a purely passive experience just because the material is presented rather than discovered. It is still necessary for the learner to relate the new material to relevant, established ideas in his own cognitive structure—he has to find a place for it—by
deciding what it relates to, what it is like, what it is unlike, and where it will best fit in the storehouse of what is already known and experienced. This process may often call for a reorganization of existing knowledge because it often extends or elaborates upon what is already known, or what has been experienced. Problem-solving experience is useful, particularly in learning to solve problems. But as a total approach to learning, it is neither necessary nor efficient, especially for the purpose of transmitting knowledge.

Many cognitive theorists agree that the main long-term objective of education is the learner's acquisition of clear, stable, and organized bodies of knowledge. Consistent with this view is that these bodies of knowledge, having once been acquired, constitute in their own right the most significant independent variable influencing the meaningful learning and acquisition of new subject matter. Holding this view puts emphasis upon two particular features of an educational system. One is the structure of the discipline: its organization and integrative order, its unifying concepts, and the principles which are most inclusive and which embrace the widest possible spectrum of the subject matter. The other feature that is emphasized in this view is the sequence of subject
matter, advantage being taken of a subject's internal logic and natural organization.

Novak (1977) feels that there is a viable alternative to Piagetian ideas for science education in the work of Ausubel. Dating from 1964 when a conference at Cornell and the University of California generated a report called "Piaget Rediscovered" (Ripple and Rockcastle, 1964), discovery learning had a resurgence from the days of Dewey and the progressive education movement of the late thirties (Hilgard, 1956, p. 330) and it was reflected in the curriculum revision movement of the 1960's. It was generally felt that students (young students in particular) needed to manipulate materials in order to advance in cognitive operations. After Sputnik there was a great wave of national concern over the apparent inadequacies of American education. The curriculum revision movements of the 60's began to discourage the vestiges of rote learning, and there began an almost religious zeal for adherence to discovery learning. But the argument put forth by Novak is that discovery doesn't always produce meaningful learning, and didactic and reception learning can be meaningful. Considering the current tide of public concern, there is now a movement "back to basics" and some educators feel that this may be a regression to rote learning.
Expository and reception learning must be made meaningful, and Novak proposes that Ausubel's theory of cognitive development is more meaningful and relevant to science education than is Jean Piaget's theory.

Novak defines concepts as regularities in facts designated by some culturally-agreed upon symbol, and facts as records of events. To acquire a concept, one has to acquire the meaning of the regularity in some sequence of events. Children do this largely through a discovery process. By the time a child reaches school age, he has a repertoir of concepts so that he can now understand the concepts merely through reception learning and concept assimilation. New concepts can be described in terms of concepts already known. Concrete examples are helpful, though they are perhaps not always necessary.

Most experiences require two or more concepts for their description. Novak uses the example, "rain comes from clouds." These relationships between concepts are propositional and most of our explanations of phenomena involve them. Both the concepts therein contained, and the syntax, give meaning to the propositions which in turn reflect a kind of overall inventory of the concepts which an individual possesses.

The question being raised by Novak is whether
children develop general cognitive structures or operations in the process of understanding experience, or whether they acquire a hierarchically structured array of specific concepts, each of which alone or in some combination allows reality to be understood. If cognitive operations are generated by maturation and only influenced by experience in a general way, then there should be apparent a definite pattern in the nature and use of concepts in children from youth to adulthood. If, however, specific concepts are outcomes of specific learning experiences, then wide variability in concept attainment will be in evidence both (a) between individuals of a given age, and (b) for any given individual across subject matter areas. Since all concepts have an overlapping relationship to others, concepts acquired over a lifetime will influence the acquisition and use of other concepts. The first of these arguments is in harmony with Piagetian theory, while the latter reflects that of Ausubel.

Key to Ausubel's theory is that the most important factor influencing learning is what the learner already knows. There are seven major elements to his theory:

1. Meaningful Learning. This involves a deliberate effort on the part of the learner to relate new knowledge to already known concepts in his cognitive structure
2. Subsumption. New concepts are not merely added to old ones, but are assimilated into old ones, thus adjusting and altering them. The anchoring concept is called a subsumer, and the process of meaningful learning results in subsumption of new knowledge.

3. Obliterative Subsumption. Meaningful learning can be retained much longer than rote learning, but one does forget. Residual concepts that are left after details are lost tend to facilitate new learning. A general concept may be remembered in essence long after the details are lost (obliteratively subsumed).

4. Progressive Differentiation. Every concept that is ever acquired by an individual will undergo continual modifications, differentiations, refinements, as new linkages expand its meaning and relevance. Individual differences are not so much differences in cognitive stages, but rather differences in the complexity of the cognitive framework of interrelated concepts held by a person.

5. Superordinate Learning. New relationships replace old ones. Progressive differentiation still takes place since this new concept broadens meaning of the old concept.

6. Interactive Reconciliation. Superordinate learning takes place, and separately seen concepts take
7. Advance Organizers. New knowledge is most easily acquired if it can be linked to relevant concepts which are already a part of the cognitive structure. This is done through an advance organizer, and this works only when the new material is meaningful, and when some relevant concepts already exist in the cognitive structure.

The most important difference between Piaget and Ausubel as stressed by Novak (1977) is found in the matter of subsumption. This differs from Piaget's idea of assimilation in the following ways: (1) new knowledge is linked to specific relevant concepts, and (2) the process is continuous and changes in learning do not occur as stages of development, but rather as continually expanding processes of differentiation and integration of specific concepts. Older children can solve more complex problems than younger children, not because they have arrived at some more sophisticated cognitive stage, but because the level of differentiation and integration of concepts is much more elaborate and extensive. Novak feels that this is the reason that research shows that 40 to 60 percent of adults fail to operate at the expected formal operational level, while some children may be able to do so in reference to certain tasks. It also may
explain why "experts" in one discipline often display such incredible mental obtuseness when they try to reason in another discipline (Novak, 1977, p.456).

Novak reviews a number of experimental studies that examine some aspect of Piagetian theory, and concludes that Ausubel's theory better accounts for the smooth transition from low ability to high ability in performing certain tasks, thus demonstrating that concept formation occurs gradually, and not in jumps or stages. Conclusions from still other studies suggest that (1) there is a smooth transition from low to high Piagetian task ability, (2) there is wide variation in ability among children of the same age group, and (3) progression from simple to complex task ability seems to be concept-specific (ibid., p. 456).

**Piaget's cognitive development theory**

The wide interest in the cognitive development theory of Jean Piaget might be due in part to the "critical mass" element (Bauman, 1976). Once popularity and acceptance reaches a certain level, they become rather self-generating, and widespread interest tends to generate even more interest. This is to be expected once the importance of a new approach is discovered and finally implemented.
Still another element contributing to the extensive popularity of the ideas of Piaget might lie in the fact that for some time now American education has been dominated largely by the stimulus-response behavioristic approach to education, and this in turn has generated a whole generation of teaching technology such as teaching machines and programmed learning. This technology has not been without its contribution to education, but it did not yield the extraordinary results that some educators had expected. Piaget's work, possibly more than any other's, is based upon the direct observation of young children and how they reason while they are in the act of performing certain "tasks." Piaget's work, then, represents an empirically-derived theory of cognitive development. It has provided a strong alternative to neobehaviorism which for the most part has dominated American educational thought for the last fifty years, originating to a large degree in the work of Watson (Behaviorism), and Thorndike (Connectionism, or Stimulus-Response Theory). It is not altogether surprising, then, that Piaget's views would "rise to the top" during a time when science and mathematics education seems to be highly regarded by many societies as the educational base for ensuring economic, social, and national survival and well-being.
There are a number of prominent people who feel that the work of Piaget is not without its difficulties (Berlyne, 1956, p.190; Ausubel, 1965, p.13; Bauman, 1976; Lippincott, 1978; Novak, 1977; Neimark, 1979). Many of Piaget's writings have not been translated, and those that have been translated have been found often difficult to understand. This increases the possibility of misinterpretation and misunderstanding. Further, his empirical methods involve one-to-one interviews and questioning technique that concentrate not so much on answers to questions, but rather upon the reasoning process that generated the answers. This technique is time-consuming and not easily administered or tightly controlled; nor are the results a simple matter to interpret. Efforts to reduce the technique to pencil and paper evaluations have surely led in some cases to questionable results. Much of the current research seems to suggest that perhaps Piaget's theory needs to be modified for application to the post-adolescent period of cognitive development (Bauman, 1976, p.95).

Intelligence. Piaget defined intelligence rather generally as a kind of biological adaptation, allowing an individual to react effectively with his environment, and maintain an equilibrium with it. His concepts suggest a kind of dynamic rather than a static balance, requiring
constant interaction and adjustment. While he recognized emotion as the driving force of intellectual activity, for the most part he ignored this aspect of human behavior, turning his attention essentially to matters of the structure of intellect. His concept of intelligence may be interpreted in terms of three elements: (1) content, (2) structure, and (3) function.

Content is perhaps the least important aspect of thought to Piaget. Content he simply regarded as what thought was about, or focused upon. Of greater importance was the process by which content was determined. Structures are the physical features (biological or physiological) that are hereditary and part of the natural makeup of man. These structures also refer to the automatic behavioral reactions which are typical of a species: reflexes. But for Piaget these automatic behaviors play only a minor role; they are modified by experience.

Functioning. Part of the biological inheritance involves adaptation and organization. Organization is the organism's ability to order its processes into a coherent working system which may be either physical or psychological, typical of that particular species.

Adaptation is also characteristic of all forms of life. This is a tendency for an organism to behave so as
to best benefit from its environment. There are variations as to just how this is accomplished from species to species, individual to individual, and even from stage to stage within an individual. Two subprocesses involved in adaptation are (1) assimilation and (2) accommodation. Assimilation is the process by which a person deals with the environment in terms of his inner structure, whereas accommodation is the process by which the structures are modified to deal effectively with the new experiences or information. Accommodation, then, is the process in which the individual responds and adjusts to environmental forces (conditions or circumstances). When certain features of the environment are taken in and made a part of the inner structure of the organism, assimilation has taken place.

Intellectual adaptation, then, involves an interaction with the environment. It is a dynamic rather than a passive process, requiring response and acknowledgment, and finally adjustment. In this process certain features of the external world become absorbed into the organism's psychological make-up. Assimilation is the process, accommodation is the result; they are complementary functions of adaptation.

Piaget believes that humans do not inherit particular intellectual functions, but rather only the
tendency to perform them by (1) an ability to organize responses and (2) by an ability to adjust to their environment.

**Psychological structures.** In adapting to his environment, man moves through certain chronological stages of development. At each stage of development behavior is characterized by structures which are unique to that particular stage. Structures are a kind of pattern of action (Ginsburg and Opper, 1969, p.20). Schemes are the outward physical means by which some action is carried out, but structures are the mental entities that are common to a host of physical actions: a kind of meaningful framework that may be manifested in a variety of outward activities. Some might even call it a concept. Certain structures, mental abilities, or concepts, are characteristic of Piaget's stages of development. During a life-time, structures are continually constructed and reconstructed. At birth only a few structures may be present. As the organism begins to react and interact with its environment, these structures are expanded, modified, and become the basis for perceiving new information, and creating more structures. The construction of mental structures has strong adaptive value, for it is through the creation and adjustment of these structures that meaningful behavior
results (Lawson and Renner, 1975, p.336).

One of the strongly unique features of Piaget's view is found in the way these structures are formed. They are not the result of merely registering external reality in the mind, for without mental structures things can not be correctly perceived. The process of perceiving alters these structures, and continually refines them. Structures, then, are the result of the dynamic, continuous exchange or interaction between the organism and its environment. Self-regulation is the process of fine-tuning these structures to accommodate that which is perceived from the environment. Equilibration results from the harmonious and satisfying continuity between adjusted or modified structures and the environment. Disequilibrium results when structures are not adequate to deal with a situation. Self-regulation is the process by which alternate actions, reassessment of input, and readjustment of structures bring about a new balance with reality. Thus, structures are created by a dynamic and continuous interaction with the environment; not by merely receiving information from it.

The entire process of development of mental structures is viewed as a process of self-regulation or equilibration. The emphasis in this process is on the self, because the process is by its very nature an internal regulation that can not be circumvented using external agents.

(Lawson and Renner, 1975, p.337)
Equilibrium with the environment is the tendency of any organism. Man develops structures which work well towards this end. When new experiences are encountered he can fit these new experiences into existing structures that have been created from similar experiences in the past, if they have been adequately formed, or he will modify these structures to be in harmony with the new experiences and information. As the organism matures more structures are formed through interaction with the environment, and consequently adaptation becomes easier; equilibration or balance is maintained.

There are essentially two aspects to the learning process: one is the acquisition of new responses, and the other is the acquisition of new structures of mental operations. With extended experience, new insights are gained, and new responses are called for. But only when an individual has the necessary prerequisite mental structures to assimilate new experiences is it possible for real and meaningful learning to take place, and only then is it possible to generalize about novel experiences. When the necessary cognitive structures are present, then it is possible to learn from experience. When such structures are not present, however, only superficial awareness takes place; never real understanding. If experience can not be matched to a
person's developmental structures when a new experience is encountered, either the new experience will be interpreted to fit the existing structures, and little real learning will take place, or perhaps a certain seemingly appropriate response will be learned which will have no real meaning. This leads to the conclusion, then, that according to Piaget's view, certain things cannot be learned by a child until he is ready by having first developed the necessary cognitive structures. External reinforcement or new experience can be meaningful only when cognitive structures have reached a certain developmental level through the process of equilibration. New information is meaningful, then, only when existing structures are developed sufficiently to deal with (assimilate) the new experiences.

Development and consequent learning is dependent upon four factors: (1) maturation wherein certain physical features both limit some and make possible other aspects of cognitive development; (2) experience, whereby knowledge of things is gained directly; (3) social transmission, the process of acquiring knowledge by means of reading and other forms of communication; and (4) equilibration, the self-regulatory process by which the balance between disequilibrium and equilibrium is maintained.
Cognitive development, then, according to Piaget's views, is an ongoing, dynamic process wherein the individual constantly reacts to new experiences, and the cognitive structure is constantly being modified, adjusted, updated. Equilibration results from the process of assimilation and accommodation, adjustment or modification of cognitive structures, a process of self-regulation. The individual constantly constructs general mental schema by which to interpret experience and events. These schema are constantly being altered in the mind of the child as it attempts to adjust to new information. Some information can be assimilated into constructs in the mind by slight adjustment; other information may require that entirely new schema be created in order to be assimilated. When new information is received or experienced, a condition of disequilibrium is produced if it contradicts mental structures already present. Accommodation requires that new schema then be established which are in harmony with the new information, or that old ones be modified. When this is done successfully, equilibrium is reestablished. There are, however, limitations to the ability of the mind to create these new constructs, and these limitations are represented by the cognitive stages of development.
Piaget's stages of development. Piaget's observations of how children think, and his attempt to describe these observations in terms of the precise language of logic and mathematics, has led to the identification of four stages of intellectual development through which all fully developed individuals are believed to normally pass. These stages of development represent degrees of progressively greater mental sophistication and complexity which the individual's thinking process characteristically exhibits at that period of development. Briefly, these stages are described as follows:

1. Sensory-Motor Stage (from birth to about age two). This period is characterised mainly by inherited behavior, increasing ability to manipulate physical things, and increasing awareness of the physical world.

2. Preoperational Stage (from about age two to about age seven). Precision in comparing objects begins to develop, but all thinking or reasoning is related to things of experience; the child lacks the ability to reason about things in the abstract.

3. Concrete Operational Stage (from about age seven to about age eleven). All reasoning is related to things of experience, and there is inability to reason in the abstract.
4. Formal Operational Stage (from about age eleven to adulthood). This final and ultimate stage of development is characterized by an ability to perform experiments in the mind, think in terms of theoretical or hypothetical situations, ability to deal effectively with constructs and their abstractions.

Because children have normally reached the concrete operational stage by the time they enter the 2nd grade or thereabout, and this stage is well developed by the time they begin any real serious study of the sciences, only the last two stages of development, the concrete operational stage and the formal operational stage (and of course the transitional stage between them) are of major concern to science education at the secondary and college level. As previously stated (see page 8), there are some concerns that have been generated by research involving these last two stages: (1) many individuals do not consistently operate at the formal operational level, even though there are indications that they should be able to, but revert first to concrete operational reasoning in solving certain problems; and (2) some adults do not function at the formal operational stage of development at all; yet according to Piaget's theory this stage should be in evidence by late adolescence in normally developed individuals.
Research and its implications. Probably the most far-reaching research into the ideas of Piaget and the implications for science education on the high school and college levels are those which have revealed that most young adults have not reached the formal operational level by the time they begin their high school sciences.

Chiappetta (1976) reports a study by Lovell (1961) revealing that a sample of English students showed that some were not formal operational by age fifteen. It has been suggested that perhaps Piaget set too low an age for formal operational characteristics to develop inasmuch as he might have been working with exceptional children, and certainly not a random sample. Piaget later seemed to recognize this flaw in his research, and revised his theory to accommodate the research findings (Piaget, 1972). Chiappetta also indicates that Higgens-Trenk and Gaite (1971) concluded that the formal operational level is not reached by most American adults until the age of twenty or so. Other studies seem to reinforce the belief that most American students, both adolescent and young adult, function mostly at the concrete operational level when dealing with abstract scientific material. In some experiments as few as 14 percent were found to be formal operational, while in others as many as 78 percent were at this stage. It was also determined that over half of
formal operational students operate at the concrete operational stage when dealing with scientific concepts that require formal operational levels of reasoning. McKinnon and Renner (1971) using five Piagetian-type tasks found that 50 percent of college freshmen in their sample were concrete operational, 25 percent were transitional, and 25 percent were clearly formal operational.

Realizing that most of the concepts in chemistry, physics, engineering, and mathematics require formal reasoning skills, one would readily come to the conclusion that the research referred to above suggests that these courses as they are typically taught are in some respects believed to be inappropriate for the mental skills possessed by the students. It perhaps suggests also why so many students continue to find some of these courses nearly impossible to master even in spite of the most conscientious efforts of their instructors to make it all clear. In the absence of well-developed formal operational skills, it might be assumed that students typically manage some of the concepts by reverting to memorization and pseudo-formal operational skills at the concrete level (memorizing reasoning patterns, using paradigms and formulas without being able to internalize and understand in the abstract the concepts that created
the relationships).

Though there has been widespread interest in Piaget's developmental ideas and their implementations for education, particularly the formal operational stage, acceptance has not been universal nor has it gone without notice of possible serious deficiencies. Neimark (1979) finds this apparent after reviewing literature on formal operations research:

While there is increasing acceptance of the existence of a level of adult thought qualitatively different in structure and properties from the stage of concrete operations, there is also a great deal of healthy skepticism as to its generality, the methodology of its assessment, and theoretical characterization of its essential ingredients. (Neimark, 1979, p.61)

Care must be taken to use appropriate means to assess developmental stages, and Neimark points out the need for "... a more direct and generally applicable means of assessing formal operations." And this can not be separated from the need to specify what is to be evaluated, and how one is to differentiate competence from performance.

In the framework of this concern, Herron (1978) warns of a possible pit-fall in attempting to use pencil and paper tests alone to determine Piagetian levels of operation. Piaget refers to the process of thinking, and answers alone do not always reveal the mental route
taken by a student to reach a conclusion, even though the conclusion may be correct. It is more in keeping with the spirit of Piagetian theory and technique, Herron suggests, to question students informally during laboratory when there is opportunity to follow the student's line of reasoning. It is most important to establish if they are comfortable with hypothetico-deductive type reasoning (what used to be called scientific reasoning), and specifically (a) if they habitually think in terms of all possibilities, (b) if they systematically examine all possibilities, and (c) if they see the logical necessity of all other things being equal (control of variables), and (d) if they use proportional reasoning and other modes of formal operational thinking (Heron, 1978, p. 166).

There are some misconceptions regarding Piaget's concrete operational stage. This stage is sometimes mistakingly thought of as being typical of the student who only works well with his hands. Herron points out that Piaget is referring to a process of the mind, a mode of thinking, and not a psychomotor operation. This concrete operational stage is a point in the reasoning process at which things must be seen and experienced directly in order to be understood, the student being unable to think in the abstract about something he has
not yet directly experienced. Concrete operational students have to see it happen before they can grasp the concept, but the formal operational student can perform mental experiments, extrapolate from the world that is to the world that might be under certain conditions they can hypothesize outcomes. But it is known that even formal operational students frequently revert to concrete operational behavior when confronted with totally unfamiliar situations. Perhaps this is the normal pattern, for some studies have indicated even for formal operational students, concrete examples help in formal concept formation (Goodstein and Howe, 1978). Herron suggests that examples of abstract ideas are important even for formal operational students, but we are often tempted to leave out these examples in our haste to cover the necessary material because we don't need them to understand. We forget that the students often do. This realization in itself becomes a strong argument for the necessity of well-designed and carefully executed demonstrations in the physical sciences.

Since research reveals that many of our students who study chemistry (and for that matter, other sciences as well) are not formal operational either at the secondary or college level, and most of the concepts that are taught require formal operational sophistication, a
tempting alternative is to reorganize such courses on a purely concrete operational level. But this would rob science of its very essence, and it is very likely also that students who are never required to perform on a higher level will never learn to do so. Herron states the need for research to develop programs and strategies that will help develop skills and insights into formal operational processes. Traditionally, science courses have been taught with the full expectation that students will learn to think scientifically. This is exactly the objective of the program developed by Karplus (1977) and associates at the University of California at Berkeley.

Lippincott (1978) points out that though there is much in the work of Piaget that commends itself to the attention of college instructors, there are problems, and he identifies four of them: (1) tests to distinguish concrete and formal stages seem to be less reliable than Piaget's methods of direct observation and interview, (2) there is yet no way to catalyze or facilitate transition from concrete operational to formal operational behavior, (3) those capable of thinking at the formal level often fail to do so, and (4) concrete models to represent abstract concepts in order to help concrete operational thinkers grasp abstract ideas have proved unrewarding.
But, nonetheless, we are in a better position to understand (and to some degree control) development of the individual student's thinking process, and to organize our courses in such a way as to identify the missing skills and devise appropriate ways to nurture them. Clearly, most students do not come to our classes with the skills that we previously believed all of them to possess.

Bauman (1976) also raises similar questions regarding some of the Piagetian ideas. He believes that research does seem to support most of Piaget, but the age at which formal operational skills appear he holds in question. Research shows that students do develop at different rates, but always in the same invariant order: concrete precedes formal operational development. Two questions yet remain: (a) do we have valid Piagetian measuring instruments, and (b) does the Piagetian model serve a useful role in post-adolescent development, and if not, just where does it fail? Further questions remain to be answered: can post-adolescent intellectual development be changed, or is it dependent upon inherent genetic, environmental, or other fixed variables much beyond our control? Neimark (1979) raises similar questions about our knowledge of this stage of human development.
Once the matter was established of how poorly students seemed to be prepared for secondary school and college science and mathematics courses in terms of Piaget's formal operational stage of development, research turned to developing programs designed more carefully to address the requirements of this level of mental operations. Typical of such efforts were those of Goodstein and Howe (1978), Herron (1978), Karplus and others (1977), and Lochhead and Clement (1979). While some efforts were directed at particular courses, others were more generally conceived to apply to a broad spectrum of endeavor.

Despite the popularity of Piaget's work, some rather serious reservations about formal stage development as devised by Piaget seem to prevail: (1) the supposed chronological age at which the formal stage should appear as the normal mode of adult cognitive operations, (2) failure to account for factors that may affect formal operations development, (3) absence of objective and uniform means of assessment, and (4) lack of consistent predominance of this stage in the normal performance of adults (Neimark, 1979; Flavel, 1963; Lovell, 1961; Chiappetta, 1976).

Some of the first researchers to investigate Piaget's theories of cognitive development were concerned
with the lack of the universality of the formal stage of development at the age expected, and the fact that it was not consistently applied when it was in evidence. Piaget did very little with this stage of development originally, but he did revise his beliefs about it after considering the mounting research findings that were at variance with his original observations and pronouncements. He later stated: "...we cannot generalize in all subjects the conclusion of our research which was, perhaps, based on a somewhat privileged population." (Piaget, 1972, p.6).

Piaget then possesses a more flexible view incorporating three factors that might possibly account for the research findings that seem to be at variance with his original position: (a) a difference in the speed of development of the formal operations stage (the order of stage development being maintained), (b) a diversification of aptitude with age, and (c) progressively differentiating aptitudes. In expansion of this last point Piaget writes:

In brief, our third hypothesis would state that all normal subjects attain the state of formal operations or structuring if not between 11-12 to 14-15 years, in any case between 15 and 20 years. However, they reach this stage in different areas according to their aptitudes and their professional specializations (advanced studies or different types of apprenticeship for the trades); the way in which these formal structures are used, however, is not necessarily the same in all cases. (Piaget, 1972, pp. 9, 10).
Neimark (1979) raises another question regarding the evaluation of the formal operations stage, and that involves task variables, one among them being familiarity with task materials or content. Familiar materials, she says, should be more conducive to formal operations than is arbitrary, abstract, or symbolic material. Task instructions is another variable that may contribute to evaluation variance.

A study by Barnes and Barnes (1978) sought to determine whether or not one semester of introductory college physics could affect the intellectual functioning of students in the Piagetian formal operations sense. Students in this study were enrolled in a two-semester physics course for premedical students, and in a three-semester sequence for engineering students. A Piagetian-type questionnaire was administered to all students at the beginning and at the end of the semester. The courses were taught in the usual manner. Using the Mann-Whitney U Test, pretest and posttest scores were compared for significant difference, but none was found. It is of interest to note, however, that the sum of ranks for the pretest was higher than that for the posttest (pretest scores were better, but not significantly so).

The study by Carlson (1975) was designed to determine the effect an inquiry science course would have
on development of formal Piagetian thought. The experimental pretest-posttest control group design was used with sixty-six students of the total 133 in a college introductory physical science class assigned to the experimental group. This group was trained in formalistic thinking via the Inquiry Role Approach (IRA). The control group received no such training in the course. Three measurement instruments were used: the Piagetian Task Instrument (PTI), Test on Understanding Science (TOUS), and the Watson—Glaser Critical Thinking Appraisal (WGCTA). Findings revealed that: (1) concrete operational students in both groups became more formalistic in their thinking, and (2) formal operational students out-performed concrete operational students on the WGCTA and TOUS tests. In regard to PTI performance, males outperformed females, but females had higher gain scores. There was no significant difference found between those trained in formal reasoning and those that were not. It was concluded that IRA instruction contributed to formal thinking ability. Also concluded was that the high correlation between PTI, WGCTA, and TOUS suggested that these tests all measure the same thing, namely formal reasoning ability.

The work of Lochhead and Clement and others at the University of Massachusetts (Fitzpatrick, 1982, p. 12)
support the contention that only about half of the students who were tested, college freshmen engineering majors, were able to solve problems requiring formal operations. Others were found to rely heavily upon formula memorization and "plug-in" type solutions for their success in managing their mathematics and science courses. Hindrances to success at the formal operations level were recognized as misconception barriers, often generated by blind manipulation of formulas which were not fully understood. The account indicated that improvement in performance at the formal operations level is possible through remedial work in mathematics and science.

**Summary and Implications**

It has been seen that teaching machines can teach; and though various systems and rules for program design have been developed, specific techniques have made only minor contributions, and the design of the machine, and the style of response, matters little. The important elements are found in the program that the machine presents and in the feedback that it provides. Further, machines do have some particular advantages that programs alone do not. Whether or not they can aid in the teaching
process so as to evoke or promote formal operations levels of thinking remains to be demonstrated.

Several leading theories of learning have been examined because of their differences or similarities to the ideas of Piaget. Guilford's Structure of the Intellect, though postulated from multivariate analysis of mental functions, and though lacking a certain practical usefulness, does place emphasis upon a certain order of mental progress, as does also Bloom's Taxonomy of Educational Objectives, and suggests an ordered progression of mental functions which accounts for an array of complexities and variations. Both of these systems include at their higher levels what Piaget would define as formal operations level behavior. Skinner's seemingly mechanistic approach does not necessarily deny the probability or existence of these higher levels, but is merely concerned with how we acquire them, and by what internal or external process they are triggered in the mind. Skinner believes he can account for all mental actions as meaningful responses to meaningful stimuli. Even here, previous experience and encounter's (conditioning) play an important role in the process. Ausubel stresses the usefulness of direct presentation (didactic teaching), but anchors this to the formation of an inward structure of reference and organization. Experience
plays an active part in providing advance organizers, a kind of first encounter wherein only vague and loose associations are made and which prepare the way for more sophisticated levels of understanding later. The most important aspect of Piaget's cognitive development theory to this study lies in his postulation of the various stages of development, and particularly the formal stage of operations. This formal stage deals with a student's ability to think in the abstract. Though this stage should be in evidence in the early teens, research has shown that it is sometimes slow in developing, it may be unique to certain topics of interest, or things familiar, and it is not as universally prominent in the thinking of adults as once believed. Its development does seem to be linked to experience (equilibration) and a progressive shift in thinking ability from a dependence upon tangible, material things to things of the mind: abstractions. This represents the progression from concrete to formal mental operations, and the similarity to other cognitive views is that it does depend upon experience, and a gradual continuum from simple concepts or ideas to complex ones. The main difference between the views of Piaget and those of others regarding this highest stage of mental activity (abstract reasoning or formal operations) is that Piaget contends that it can
not be in evidence until the organism reaches a certain level of mental maturity, somewhat linked with the organism's physiological and psychological development.

The relevance of Piaget's cognitive development theory to this study lies in the ability of a student to deal effectively with abstract ideas (formal operations) and the question of whether or not a simple progression of ideas from concrete to formal (via a teaching machine) can be effective in improving this desired behavior in dealing with one particular troublesome concept: ratio and proportion. Additional experience and contact, and progression from simple to complex ideas are rather common to all of the learning theories once the concern is put aside about how the process of learning is actually accomplished within the organism. The interest here is not how the learning process takes place internally (we will let the learned theorists continue to speculate and struggle over that), but whether or not it can be made to do so in this particular way, at this particular level of abstraction, and at this point in a student's mental development.

There is a strong case for the importance of experience in all of these theories: advance organizers in Ausubel's terms, equilibration to Piaget, operant conditioning in Skinner's view, and a kind of mental
progression from simple direct experience to more complex mental behavior according to Bloom's Taxonomy of Educational Objectives and Guilford's Model of the Intellect. But the traditional approach in teaching has always been a smooth progression from the simple to the complex, from the known to the unknown. And the more one elaborates upon and expands his experience relative to a particular idea or concept (practice, actually—no matter what sophisticated technical term we apply to elevate its meaning and importance). the better one should become at applying it and understanding its fullest meaning. And for want of a better term, sometimes this is referred to as experience. It must be quite important in the scheme of things—this thing we call experience—whatever it is or whatever it does, for we have long recognized its value in society, and have been willing to pay a relatively high price for it in the professions and trades.
Chapter III
Methodology of the Study

An experimental schema is devised in which (1) a hypothesis is formulated, (2) an experimental format to test the hypothesis is devised, (3) materials and an evaluation instrument are developed, (4) a pilot test of materials and procedures is carried out, and (5) a more extensive and formal test of the hypothesis is initiated in an existing physical science class.

The Experimental Plan

Statement of purpose

The purpose of this research project is to see if a teaching machine [5] can aid students in the improvement of formal reasoning skills in a class in college chemistry. Stated in the form of the null hypothesis:

There is no significant difference between the experimental group and the control group in formal reasoning skill gains in a class in General College Chemistry.

Experimental format

During the course of the normal semester, students
from an existing class in general chemistry are randomly assigned to either Group A (experimental), or Group B (control). Both groups have identical experiences in all features of the course except that the experimental group uses a teaching machine for access to programmed course materials on ratio and proportion.

The experimental schema is of the Pretest-Posttest Control Group Design of Campbell and Stanley (1963, pp. 183-195), but without the benefit of true random sampling since the population from which the groups are drawn is in itself a special group (an existing class). A representation of this design is shown in Table 1.

Table 1

CAMPBELL AND STANLEY PRETEST-POSTTEST CONTROL GROUP EXPERIMENTAL DESIGN

<table>
<thead>
<tr>
<th>Group</th>
<th>Pretest</th>
<th>Treatments</th>
<th>Regular Class</th>
<th>Teaching Machine</th>
<th>Posttest</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>0</td>
</tr>
<tr>
<td>B</td>
<td>0</td>
<td>X</td>
<td></td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>

Group selection. The experimental and control groups are established by random assignment from an existing class in general chemistry. A random numbers table generated by an Apple II computer is used for selection, and the first half of the class to be listed
comprises the numbers of the control group. Students are listed and numbered in alphabetical order on the master list from which selections were made according to the random numbers table.

**Group equivalence.** Because of current laws governing confidentiality of student records, the use of personal data of students for the purpose of establishing equivalence of the groups on the basis of certain demographic and personal data is not possible. Instead, the groups will be compared on the basis of such course-derived information as test averages, and pretest and posttest scores.

**Materials development**

The materials to be used by the experimental group via the teaching machine consist of sixteen frames of ratio and proportion problems, explanations, and examples arranged in an increasing order of complexity. In addition to the sixteen main frames of information, the teaching machine also provides thirty-two additional frames of information and examples, plus sixteen multiple-choice questions for which feedback as to the correctness of responses is provided.

Ratio and proportion was chosen as the topic for development because it is clearly recognized as requiring
formal operational level thinking (Karplus et al, 1977), although in its simpler applications ratio and proportion problems can be solved by concrete operational level manipulation of a solving procedure. But in the more abstract applications, ratio and proportion is often found confusing and difficult, particularly when the ratio involves powers of numbers, inverse relationships, or fractional or decimal quantities. But these are precisely the cases one encounters in courses such as chemistry and physics, and it is at this point that students often have difficulty with the concepts.

**Evaluation instrument and procedures**

**Evaluation instrument.** A sixteen-question multiple-choice test on ratio and proportion is used for both pre- and posttesting. Questions range in difficulty from whole number ratios to inverse power ratios. The simpler ones, then, could be dealt with on a concrete operational level, particularly where they deal with familiar relationships. Most of the problems, however, are in a scientific context less familiar to the common experiences of the students, and thus require a fuller understanding of proportional reasoning, and full formal operational thinking. The instrument may be found in Appendix B, p. 151.
Reliability of the measurement instrument. One of the most often used methods to establish reliability of an evaluation instrument is the split-half method. The procedure is to divide the test into two parts (odd and even numbered items, for example). Scores are obtained for the two halves, and these are then correlated. Another method, one that uses test item statistics, is called the Kuder-Richardson Formula 20, (Ferguson, 1966, p. 379), and is the method that is used in this study, details of which may be found elsewhere in this report in the discussion of the results of the Pilot Study, p. 107.

Validity of the measurement instrument. Content validity is often established by subjecting the instrument to evaluation by knowledgeable authorities in the field involved. This is a means of establishing the sampling adequacy of the material: its representativeness is judged. This was done in two instances for the instrument used in this study, and the instrument was judged to be adequate in this regard.

Construct validity—that which has to do with the psychological factors accounting for test variance—is much more difficult to deal with and is quite involved. What factors or constructs account for variance in test performance is the question to be answered in construct validity [6]. If there were other similar measures to
which one might compare the developed instrument, there would be little need to develop it in the first place. However, the fact that an instrument is being used for a specific purpose is, in part, construct validation: in this case, to differentiate between concrete operational and formal operational reasoning in regard to ratio and proportion concepts.

Tests of significant difference. Tests of significant difference will be applied to the mean scores of both the pretest and posttest measures for both the control and experimental group. In regard to pretest scores, the purpose is to establish that both groups are similar in terms of the criterion measure; in regard to posttest scores, one would hope to show that there is a significant difference between the groups, due entirely to the experimental treatment. Since only two groups are involved, a simple t ratio or t test seems appropriate, particularly since large amounts of other information will not be available.

Delimitations

Instructional materials. The programmed instructional materials developed for this study will be limited to ratio and proportion concepts, and will involve applications common to the physical sciences which are
normally encountered in freshman level courses.

**Evaluation instrument.** The evaluation instrument for both pretest and posttest purposes will be a multiple-choice type test similar to the type commonly used in the classes that will participate in this study.

**Random assignment.** Students will be assigned to either the control group or the experimental group from the membership of the classes which are available for participation in the study. Since the hypothesis to be tested is pertinent to, engineering, mathematics, or any of the physical sciences, any of these might serve equally well as the study population. Random assignment will be accomplished by the aid of a random numbers table.

**Programmed materials.** Materials to be developed for the teaching machine, and which constitute the experimental treatment, will be organized to provide a smooth and gradual transition from concrete operational to formal operational thinking requirements within the constraints of ratio and proportion concepts.

**Identification of effective factors.** No attempt will be made to identify exactly which features (if any) of either group might be responsible for any difference in performance; e.g., interactive study aspect of the teaching machine, novelty effect of the teaching machine,
reinforcement feature of the teaching machine, etc.

Generalizability of the study. Since random assignment from existing groups (ongoing classes) is being used rather than true random sampling, the results of the study will be generalizable only to similar groups under similar circumstances. Further, since topics in the physical sciences differ considerably in regard to their complexity, abstractness, and prerequisite knowledge, results of this study may not necessarily apply equally well, or to the same degree to other, but similar, areas of study.

Pilot Study

Purpose of the pilot study

In order to accomplish certain objectives, an informal experiment with the teaching machine program and the evaluation instrument was carried out in a setting similar to the one in which the formal study will take place. These objectives are to (1) estimate the effectiveness of the teaching machine and its program of instruction; (2) establish the best working procedures and schedule; (3) check the program for errors; (4) examine the system for possible appropriate modifications; and (5) determine the validity and the
reliability of the evaluation instrument.

**Experimental materials**

**Teaching machine program.** Sixteen four-frame sets of material were prepared, photographed, and made into 2 x 2 color slides for the teaching machine [7]. The subject of the teaching machine program is ratio and proportion, a topic typically troublesome to chemistry and physics students at the introductory level of study. The material is presented in an ascending order of complexity, involving both direct and inverse proportion, some of the problems involving powers of numbers. All of these concepts involve formal operational thinking, although some of the simpler problems could be solved at the concrete operational, or the concrete-formal transitional level.

**Evaluation instrument.** Used for both pretest and posttest, the evaluation instrument consists of sixteen multiple-choice ratio and proportion problems [8]. Some of the problems are merely general math problems which deal with familiar situations, while the more difficult and abstract problems involve problems such as are commonly encountered in the physical sciences (Boyle's Law gas problems for example). Students are required to write their work and answers in the space provided.
Sufficient time is allowed (one-half hour) to complete the test without racing against the clock, and calculators are used.

Content validity was established by having two experts in the field examine the instrument to judge its content relative to formal reasoning and ratio and proportion concepts. It was found to be adequate for the study.

Reliability of the instrument was established by means of the Kuder-Richardson Formula 20, using test item statistics. The reliability coefficient is given by

\[
 r_{xx} = \frac{n}{n-1} \frac{S_x^2 - \sum_{i=1}^{n} p_i q_i}{S_x^2}
\]

where \( n \) = the number of test items, \( S_x^2 \) = variance of scores on the test, defined as \( \overline{x}(x-\overline{x})^2/n \), \( p_i q_i \) = product of proportion of passes and fails for each item, \( i \), and
\[ \sum_{i=1}^{n} p_i q_i = \text{sum of these products for } n \text{ items} \]

This formula yields a measure of the internal consistency or homogeneity of the test material. (If the popular split-half method of establishing reliability coefficients were to be applied to all ways of splitting a test, and the average of these taken using the Spearman-Brown correction, then one would obtain the KR Formula 20 value) [9].

The instrument developed for this study was administered to three classes, and the following results were obtained for the reliability coefficient, using the KR Formula 20:

- Chemistry 101 \( n = 84, \ r_{xx} = 0.70 \)
- Physics 101 \( n = 22, \ r_{xx} = 0.50 \)
- Electronics 101 \( n = 11, \ r_{xx} = 0.81 \)

With all groups combined and \( n = 123, \ r_{xx} = 0.70 \).

Many factors such as test length, testing conditions, time given, and other testing variables can cause considerable fluctuation in this value. The values obtained here are taken as acceptable for the purpose of this study, since this measure is subject to a great deal of variation. The higher the reliability coefficient \( r_{xx} \), the more likely that test items are measuring the same attribute. Its value can range from zero to
one, one being possible only if all the test items have the same difficulty (Ferguson, 1966, p.381).

**Experimental setting and procedure**

A class in Introductory Electronics at a small New England Community College served as the pilot study group. Originally there were seventeen students in the group, but four of these were also members of the physics class that was to be used in the formal experiment. Four of the remaining thirteen in the class were lost during the semester through normal attrition, leaving only nine students to take part in the pilot study. Four of these students used the teaching machine and the programmed materials, while the other five students did not. All other aspects of the course were the same for both groups. The students were listed randomly, numbered consecutively, then the first four students to appear by number on a random numbers table were assigned to the experimental (teaching machine) group. Students were given several weeks to complete the routine on the teaching machine, though all but one used it early within the first week. The average time to complete the teaching machine sequence was one-half hour, and none used the machine more than once. Students in the class were told that some attempt was being made to provide
extra mathematical help for the course, and that their opinion as to the effectiveness of the program was needed. They were also told that all would eventually use the materials, but since there was only one teaching machine, a schedule and controlled use was required.

**Results and evaluation of the pilot study**

Approximately one month elapsed between the administration of the pretest and the posttest (the same instrument was used for both). The time span had to be long enough to effectively minimize recall from the pretest experience, yet not so long as to increase the influence of extraneous events. A summary of the results of the testing is found in Table 2.

<table>
<thead>
<tr>
<th>Group</th>
<th>Pretest</th>
<th>Posttest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control Group X</td>
<td>53.3</td>
<td>67.5</td>
</tr>
<tr>
<td>Experimental Group X</td>
<td>47.0</td>
<td>50.3</td>
</tr>
</tbody>
</table>

| Test of significant difference between means | t  | 0.43 | 01.58 |

For the test of significant difference between means, the t test was used [10] where
\[ t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{s_1^2}{N_1} + \frac{s_2^2}{N_2}}} \]

and

\[ s^2 = \frac{N_1 \sum (x - \bar{x}_1)^2 + N_2 \sum (x - \bar{x}_2)^2}{N_1 + N_2 - 2} \]

For the pretest, the \( t \) value of 0.43 was not significant, meaning that, to begin with, the groups were alike in terms of the criteria measurement. The posttest \( t \) value of 1.58 could be considered significant at less than the 0.2 level (not highly significant), but nonetheless favoring the control rather than the experimental group. Here it becomes clear that, with such small samples as \( n = 4 \), just one questionable performance can seriously affect the results. A tabulation of the actual test scores is found in Table 3.

<table>
<thead>
<tr>
<th>TABLE 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>PILOT STUDY PRETEST AND POSTTEST SCORES OF EACH STUDENT</td>
</tr>
<tr>
<td>Control Group</td>
</tr>
<tr>
<td>Student</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
</tbody>
</table>
Overall conclusions from pilot study

Though the effectiveness of the teaching machine cannot be determined from these data, verbal responses of the students indicated that it was a helpful experience to use the teaching machine program. Statistical support for its effectiveness remains to be established through further investigation. Revised procedures will call for more strict and specific commitment on the part of the students who are assigned to the treatment group. A mandatory assignment plan will have to be implemented as part of the course requirements so that each student will participate consistently and conscientiously. The treatment phase (use of the teaching machine) should be completed within a month's time, even with greater numbers of students involved, so as to reduce the likelihood of extraneous factors influencing the outcome. Corrections in the programmed materials and improvements in machine performance were outcomes of the pilot study.

Formal Experiment

Three physical science classes were available for participation in this study: an electronics class with seventeen members, a physics class with twenty-four students, and a chemistry class with eighty-three
113

students. Normal attrition rates are high in these
classes, so the chemistry class was chosen in order to
assure the highest possible numbers for the study.

The Pretest-Posttest Control Group Design was used
as the experimental format, and procedures similar to
those used in the pilot study were followed (see previous
section). A pretest was administered late in the Fall
semester in each of these classes and served as a basis
for establishing the reliability of the test instrument.
The same pretest was used as the pilot study pretest in
the electronics class.

Early in the Spring semester the chemistry class,
now numbering forty-five, was randomly divided into an
experimental group and a control group by means of the
random numbers table. The experimental group was
assigned the use of the teaching machine containing the
programmed learning materials on ratio and proportion,
and a schedule for its use was maintained and supervised
by the laboratory technician. Within two weeks all the
assigned students had completed the teaching machine
assignment.

At the time the posttest was given a large number of
students were absent, and it took several weeks more to
obtain all the make-up tests. Finally, of the original
forty-five students, only thirty-two students, fifteen in
the experimental group, and seventeen in the control group, had complete sets of data. Thirteen students were lost to the study due to extended absence, or incomplete data due to other reasons. Nine students dropped the course.

Results of the study, analysis of data, and conclusions will be found in subsequent chapters.
CHAPTER IV
RESULTS OF THE STUDY

The experimental group consisted of fifteen students, while the control group numbered seventeen students, both groups' members having been selected at random from a class in general college chemistry at a small New England community college.

The experimental group treatment consisted of the use of a teaching machine program on ratio and proportion, the same program as was used in the pilot study (p. 105). Students were allowed to schedule the use of the teaching machine at their convenience. Most students cooperated well, with only a few having to be reminded to schedule a time and complete the program.

The most problematic aspect of the experiment routine was obtaining the posttests. The study was carried out during the winter months, and there was a high absentee rate at that time. Make-up tests had to be arranged several times in order to obtain all the posttests.

A summary of the results of the pretest and posttest for both the Experimental Group and the Control Group may be found in Tables 4, 5, 6, and 7 in Appendix D. Students are numbered sequentially from one to fifteen in
the Experimental Group, and from one to seventeen in the Control Group. The letter f or m designates sex of the student. The x's indicate the questions that were answered wrongly, while the dash indicates questions not answered. Correctly answered questions are indicated by the letter c. The r and w columns indicate the number of questions counted as right and wrong, questions not answered being counted as wrong since it was felt that unanswered questions were indications of inability to answer. The percent column is the percent correct score based upon a total of sixteen questions. At the foot of each column is the percent of that group that answered that particular question correctly.

Table 8 is a summary of pretest, posttest, and gain scores. The course grade for each member in both the experimental and control groups, and the arithmetic mean of each of these, are also indicated.

Using the data from Table 8, the t test was used to determine whether or not significant differences existed between the means of the experimental and control groups. Table 9 is a summary of these results. There were no significant differences found between any of the means, although one might wish to consider the fact that the pretest value of 1.7 was significant at the 0.1 level in favor of the experimental group. On the basis of the
final course grade, both groups had about the same course performance (81,83). Though the experimental group scored higher on the posttest (51,45), they also scored higher on the pretest (47,38); but the differences were not significant. Gain scores were compared in several ways because there were so many negative and zero scores (40% of the experimental group and 47% of the control group). By using the gain scores of both, the means of 3.5 and 7.4 were obtained, but were not significantly different. When only gain scores of students with course grades of 85 or less were considered, means for the two groups were calculated to be 10.6 and 8.4, still not significantly different. When only positive gain scores were used in the calculations (zero and negative gain scores considered spurious) means are again not significantly different at 12.2 and 15.3. Male gain scores of both groups were 5.14 and 12.5 using all scores and 12.2 and 21 using only positive scores, but again they did not differ significantly. Female scores of 2.1 and 5.9 for all scores, and 12.2 and 16.8 for only positive scores were also compared. It was found that these, too, were not significantly different.

On the basis of the foregoing data, no statistical significance can be attributed to the difference in means between the experimental and control groups taken
collectively, and the null hypothesis (Chapter Three, p. 97) then must not be rejected. A fuller discussion of these results and their implications will be found in the next chapter.
Summary

It has been seen that teaching machines, regardless of their specific design, can teach. Though various rules and specific techniques for program development have been proposed, these differences seem to have contributed only minor differences in results. Thus the design of the machine, the style of the program, and the mode of response all seem to contribute only minor variations in terms of teaching outcomes. The more important elements are found in the program itself that is, how well it is conceived and presented, and the amount of feedback that is provided (Lumsdaine, 1964, p. 401; Pressey, 1964, p. 362). Whether or not programmed learning via a teaching machine is effective in improving formal operations level thinking was the object of this study. While students apparently understood the material which was presented in this way, there was no statistically significant support for the belief that it had any cumulative effect on their formal operations thinking process in regard to the topic presented.
A number of different learning theories were presented that have had a strong part in bringing us to our present state of understanding about the learning process, and among them now the more recently considered cognitive theory of Jean Piaget. This is not to say that his work has been fully accepted without question or controversy: it has not. But this is also true of the other theories that have been proposed over the years to account for the complex and varied operations of the human mind in its development. In discussing variations in the kinds of teaching which are implied by the different learning theories, Gage concludes:

The various kinds of learning have not been embraced successfully by any single learning theory. And this failure may well stem from the false belief that a single term, "learning," guarantees that a single, universally applicable theory of learning can be found.

(Gage, 1964, p. 274)

It is not the intent, then, of this study to defend or try to establish the likelihood of one theory being more correct than another. Rather, the various popularly-held learning theories were considered for their insight into the process of learning, and for their mutually-supportive ideas, regardless of the terms in which they were couched. Yet there is still strong appeal for the basic idea that Piaget was right in suggesting that development occurs in stages, and that
the final stage, which he calls the formal operations stage, is one which is most important for development of abstract ideas, but is the stage most often not fully developed to deal with the content of high school and college science and mathematics courses.

Regardless of the actual mental process involved in learning, and in particular the inner phenomena that gives rise to it, all of these views of learning can lend direction to what is done in the classroom to further the process of learning. Seemingly consistent with these theories, the following considerations can be made in designing a learning routine: (1) a point of prior knowledge should be considered; (2) a smooth and easy transition should be provided from what is known to what is to be learned; (3) what is to be learned should be well-defined and should be arranged in logical order; (4) there should be some means of acknowledgment of accomplishment or achievement so that the student knows when he or she has arrived at the desired outcome; (5) some system of value or reward should be directly or indirectly applied to the desired achievement so that accomplishment remains more desirable than non-accomplishment; and (6) it should be taken into account that ability to function at a particular abstract level depends in part upon prior experience and development.
The use of a teaching machine and its program in this study was believed to be consistent with these views.

Conclusion

The application of a simple $t$ test to posttest means for the experimental and control groups revealed no significant differences in the groups because of the treatment. This required, then, that the null hypothesis not be rejected:

There is no significant difference between the experimental group and the control group in formal reasoning skill gains in a class in General College Chemistry.

This is not to say that there was no benefit to be gained by the experimental treatment, only that there was no statistical evidence to support that belief.

In the spirit of true scientific research, experiments should always be considered successful even when they do not yield the expected or desired results, provided of course that they have been well designed and skillfully executed: they yield information that was previously not available. Yet disappointment often attends a project that results in NSD, particularly when the researcher was fired by a persistent "gut" feeling at variance with the results. This is apparently not an uncommon occurrence in social, behavioral, and educational
studies. Some of the conclusions that can be drawn in such cases are: (1) there were truly no significant differences (NSD), disappointing and perhaps unexpected though that may be; (2) the experiment was faulty; (3) the experiment was poorly conceived and executed; (4) the results were confounded by factors not controlled by the experiment, and (5) some or all of these. But it is also possible that the reason there is so much research ending in NSD is that individual differences tend to average out in the gross statistical treatment. If each individual case were to be considered on its own merits, examined separately, one might find a significant difference here and there. Perhaps we will eventually see the value in small increments of progress as being worthy of experimental endeavor, even though just a few individuals seem to benefit from it. We must begin to move away from the expectation that we will eventually discover the one, the only, the all-embracing system of learning that will bring the expected results in every case, under every circumstance, to every kind of student regardless of mind-set, ability, background, readiness, or motivation. There is also the strong possibility that the increments in learning that we continue to try to measure are very small, occur over very long periods, and require continued and extensive reinforcement throughout all exper-
iences—not just isolated ones. If this is the case, only longitudinal experiments, run over relatively long periods of time, and involving the total learning spectrum would be likely to yield measurable results.

Implications

Perhaps what the research has shown is not that there is a pattern of cognitive development, but that there are patterns of cognitive development, perhaps as varied, complex, and interdependent as the biological, physiological, and psychological processes of the human organism. There is probably no such thing as a definitive theory of learning.

Certainly, though, the cognitive epistemology of Jean Piaget has given some direction to the learning process that previously did not exist. Whether or not one accepts all the aspects of Piaget's ideas is really not all that important except to the professional theorists. What is important to the classroom teacher is that Piaget's theory is in harmony with much of our teaching experience and is parallel in its practical applications to that of other theories of learning. These features may be summarized as follows: (1) there is a progressive nature to the learning process from
simple to complex (regardless of what particular internal mechanism accounts for it), from tangible to abstract; and (2) tangible, concrete aspects of physical reality must be experienced and thoroughly understood before their abstractions can be mastered. The changes in learning maturity can be anticipated, tests can be devised to detect the emergence of developing skills, and appropriate learning experiences can be accordingly provided. To a measure, it has been done in the past. In the laboratory and science classroom, experiments and demonstrations are intended to ease the transition from the material to the abstract, to demonstrate the principle with its real and material manifestations. As the learner becomes more experienced, he needs less direct contact with the material world and begins to develop an ability to relate to its abstractions such as pictures, schematics, graphs, equations, and other paradigms. The trick is to know when these transition abilities are operating (concrete operational to formal operational in Piaget's terms) so that appropriate learning activities can be provided. But this transition from concrete to formal does not seem to be constant as originally thought, for it is probably dependent upon many still unknown variables (Neimark, 1979). It is now believed that the transition from concrete to formal
operations is at least partially concept-related, for the process seems most efficient when similar ideas are dealt with (Piaget, 1972). But it is still recognized that the process of formal operations can not take place until the individual develops such skill. Individuals sometimes find it hard to frame an idea "in the mind's eye" without additional concrete examples and experience, even when they have shown formal operations level thinking in other areas. It seems that perhaps the formal operations mode of thinking may not be as common as it was once thought, except in some highly specialized or technical areas. Some adults never arrive at this stage, and those that do are inconsistent in performing at this level even when it is appropriate that they do so. That this level of thinking can be mastered is suggested by the fact that science and engineering students more consistently operate at this level than do students in other fields. This could be due to the fact that (1) they are experienced at operating at this level, or (2) they had the skill or aptitude to develop at this level. Students failing to develop formal operations skills would not be able to succeed for very long in these fields, or would be marginal performers at best (Lochhead and Clement, 1979).

One need not adopt wholesale any one particular
theory of learning to call his own, for none exists without its challengers. The real value of a theory of learning lies in the realization of its contribution to our insight as to how people learn. Many theories have similar, parallel, and complementary features, and no one theory seems to be sufficiently satisfying. To the extent that they offer insight, understanding, and direction, and make one more aware of the potential of the human mind, and inspire us to new efforts toward greater educational accomplishment, they are all valuable contributors to the process of education. Certainly Piaget's work has contributed greatly toward these ends.

One should avoid, however, strict adherence at every point to a particular theory, especially if it seems to go contrary to nature or evidence. And especially one should avoid taking any position that if wrong would render the educational experience totally and irrevocably inappropriate and unrewarding. Hilgard (1956) in dealing with the nature of learning theories stated:

Science ought to be systematic, not eclectic, but a premature systematic position is likely to be dogmatic and bigoted just as an enduring eclecticism is likely to be superficial and opportunistic. It is possible to have systematization of knowledge as the goal without permitting the desire for system to blind the seeker after it to the truths unearthed by those with views unlike his own. (Hilgard, 1956, p.14).

Implications from the study, then, are: (1) the
experiment was a reasonable venture, and expectations were consistent with current learning theory and previous research; (2) lack of positive results may have been due to (a) factors beyond the control of the experimenter or (b) lack of adequate exposure to the treatment; (3) this study may have relevance for similar studies in computer-assisted instruction.

**SUGGESTIONS FOR FURTHER RESEARCH**

Continued to be needed is research about some of the following issues:

1. To what extent can formal operations skills in one area or discipline be transferred to other areas or disciplines?

2. Can teaching machines and/or microcomputers aid in the development of formal operations skills at the early high school level?

3. Does the length of exposure to the experimental treatment have any influence on the results of either (1) or (2) above?

4. Is it possible to teach concrete operational students to perform at the formal level in regard to certain principles or areas of study?

5. What effect on total formal operations
performance does formal operations training in all disciplines concurrently have compared to training in only one discipline or field of study?
ERIC is an acronym for Educational Research Information Center. There are several centers, each one responsible for collecting, abstracting, cataloguing, and disseminating information about a particular segment of education.

"The 8086 Family: Helping to Solve the Software Crisis of the 80's." Intel Innovator, Intel Corporation, Santa Clara, California, Spring, 1980.

A manometer is a partially liquid-filled tube which is used for the measurement of pressure. Connected to the trigger of a rifle, the movement of the liquid column indicated the manner in which the trigger had been moved.

PLATO is an acronym for Programmed Logic for Automatic Teaching Operations, a CAI (computer-assisted instruction) system originating at the University of Illinois.

For a description of the teaching machine used (the Harvey Technitutor), see Appendix A.


The teaching machine program on ratio and proportion may be found in Appendix C.

A copy of the evaluation instrument may be found in Appendix B.


Ibid., pp. 167-168.
REFERENCES


APPENDICES
A visual teaching device which comprises a first and second rotatable and a first fixed plane front surface mirrors which provide for the display at any time on a screen of a selected quadrant portion of an image from a projector.

15 Claims, 7 Drawing Figures
BACKGROUND OF THE INVENTION

Any device that aids in an instructional process is often referred to as a teaching machine. The oldest U.S. patent issued for such a device is that belonging to H. Chard, Feb. 16, 1809 (see Lumadina, A. A. and Robert Glaser, Teaching Machines and Programmed Learning, A Source Book, Washington National Education Association, 1960). Today, there are hundreds of patents relating to teaching and education, but many of the older ones represent outmoded and now useless devices.

Modern interest in teaching devices as they are now conceived probably had its origin in the work of S. L. Pressey, who, around 1926, developed an automatic mechanical testing device. In this instance, and in the efforts of educational researchers that followed, there was an attempt to relate the operation of the teaching device to known theories of learning. The principle involved in Pressey's device was to test a student (multiple-choice-type questions) and to provide immediate feedback to the student's responses, thus providing reinforcement of learning. Over a period of time, Pressey continued to work with such devices, and was able to show that they had value as instructional aids as well as testing.

It was not until World War II that interest in teaching machines was renewed, and various devices developed for military use. Up to this time, most of the machines involved presentation of material that was best dealt with by rote learning. With the advance of electronic technology, greater demands being made of our educational institutions, and greater knowledge of the learning process, interest in teaching machines in the post-war period has continued to rise. Much of the renewed interest in teaching machines was due to the experiments of B. F. Skinner. Programmed learning, apparently, naturally resulted from attempting to write material for machine presentation. Programmed learning is a system of presentation of material in small increments, requiring student interaction (usually overt) with a statement or question. It may be presented by machine or book, and some provision is made to indicate to the student the correctness of his responses. Today, there are many different devices for teaching, ranging from simple programmed books to computer-operated systems which not only respond to student answers, but correct them when necessary. Ideally, a teaching machine should present instructional content to the student, require some means of student response or interaction, and offer immediate feedback to the student information as to the correctness of his responses. Some systems also provide alternate routes through the program, such routes determined by the student's responses.

Most commercial systems or devices are expensive, and require the user to purchase, commercially prepared software or programs; e.g., tape cassettes, microfilm, carriers, etc. Often programs desired are not commercially or readily available for the system or device. Few systems provide an acceptable means by which the user, a student or teacher, may prepare his own materials.

Teaching devices are not absolutely necessary for program presentation, although such devices do offer certain distinct advantages over book-type programs. Cheating is less likely; the element of novelty may contribute to student interest; psychologically, devices differ from books, and thus, the use of a device may reduce student anxiety, and further, devices provide an opportunity for supervised, forced student concentration.

Thus, a need exists for a visual teaching device and system described herein which has the advantages of low cost, great flexibility of use and provision for instructor-prepared materials.

SUMMARY OF THE INVENTION

My invention concerns a teaching device and teaching system and a method of displaying instructional material and of instructing students by a programmed teaching method. In particular, my invention relates to a visual teaching device and a programmed teaching system employing such device, wherein instructional material prepared by the user or teacher may be displayed at any time on a screen in selected quadrant portions of the total image.

My visual teaching device provides for the display of only selected portions of a total projected image on a display screen to be observed by the student, so as to provide for the display of portions of the image in a desired teaching sequence. My device may be employed as a teaching device alone or in combination with a student response device which operates with the teaching device to control the teaching sequence and displays the response provided by the student. My teaching device and system is relatively simple and economical to manufacture, and permits the use of instructional material prepared by the student or teacher.

My visual teaching device comprises in combination a means to receive and to display an image, such as a screen, means to project an image containing instructional material, such as instructional material on a transparent slide, the image so projected to be directed through an optical system, all or a portion of the image to be displayed on the receiving screen means, and the optical system positioned between the image-receiving means and the means to project. The optical system comprises a first mirror means to receive an inverted reversed image from the means to project, means to rotate the first mirror means about an axis, a second mirror means to receive the image projected from the first mirror means, the second mirror means mounted at an angle on the optical path of the image projected from the projector means, means to rotate the second mirror means about an axis, preferably at 90° to the axis of the first mirror means, and a third mirror means to receive the image from the second mirror means, and to project the image so received onto the means to receive and display the image; that is, the projector screen; and control means to rotate the first and second mirror means so as to display on the image-receiving means only a selected portion, such as a quadrant portion, of the total image which is projected into the optical system, whereby instructional material from the total image on the slide may be displayed on the image-receiving means in a desired or controlled teaching sequence for viewing by the student.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic illustrative block diagram of my visual teaching device and system.
FIG. 2 is a perspective view of my assembled visual teaching device.

FIG. 3 is a perspective schematic view of the optical path system of my visual teaching device.

FIG. 4 is a schematic illustration of the electrical circuit of my visual teaching device.

FIG. 5A is an illustrative view of the individual components of the response device of my system.

FIG. 5B is an exploded view of the components of the response device.

FIG. 5C is an assembled view of the components of the response device.

DESCRIPTION OF THE EMBODIMENTS

FIG. 1 is a schematic illustrative block diagram of my visual teaching system 10 which includes a slide projector 12, an optical system 14, a control panel 18 and a visual display screen 20, which, in combination, comprise my teaching device. Prepared programmed materials in one or more of a series of slide transparencies 22 are employed in my teaching device as illustrated, while a student response device 24, the use of which is optional in my teaching system, is employed to provide student response to the teaching sequence when the student is using my visual teaching device.

FIG. 2 is a perspective view of my assembled visual teaching device with the sides and top removed, and illustrating the components of my visual teaching device as assembled. My teaching device, as illustrated in FIG. 2, includes a base 30 supporting a frame 34, and a visual display screen 20 within the frame 34 which includes the visual display screen 20 and a control panel 18. Within the frame 34 are positioned the slide projector 12, such as a commercially sold transparent slide projector like a Kodak Carousel projector, and components of the control circuit 16 which comprise, as illustrated, power cord reel 36, relays 24, wiring harness 28 and a solenoid 48 for adjustable first surface mirror 40 (see FIG. 3) and a vertical alignment adjustment control 46 for the projector 12.

FIG. 3 is a perspective schematic view of the optical path system of my visual teaching device. The optical path shown is from the 35 mm transparent slide in the projector 12 through the display of one of the quadrants B on the display screen 20. The optical system then includes a transparent slide containing the total instructional material to be displayed on the screen 20, the slide, when placed in the projector 12, providing an image in the focal plane of the projector lens.

My optical system includes a first plane front surface mirror 40 adapted to receive an inverted reversed image from the slide 54 from the projector 12, the first mirror being mounted at an angle of about 45° from the horizontal axis which is at right angles to the optical path of the projector 12. The first mirror 40 is variable about its horizontal axis at a right angle to the optical path of the projector through the use of opposing electromechanical solenoids 48 and 50, and which opposing solenoids operate through relays from the control panel 18 in the teaching device.

My optical system also includes a second plane front surface mirror 42 which is positioned to receive the image from the first mirror 40, the second mirror being mounted at an angle of approximately 45° on a horizontal axis parallel to the optical path of the image from the projector. The second mirror 42 is larger than the first mirror 40, and like the first mirror 40, is variable about a 45° position on a horizontal axis which is parallel to the image path from the projector. The second mirror is varied by means of opposing electromechanical solenoids 54 and 56 which control the movement of the mirror.

The optical path system also includes a fixed plane front surface mirror 44 larger than the second mirror 42 adapted to receive the image from the second mirror 42 and to project the image so received, or a quadrant portion thereof, onto the display screen 20. In the optical system, any projector of suitable dimensions or reversed by the projector lens 12 and the image projected onto the surface of the first mirror 40. The mirror 40 is a first surface mirror which is mounted about its axis as illustrated by the activation of the solenoids 50 and 48, whereby motion of the mirror 40 controls the horizontal shift of the image frame. For example, boundary C-D of the image would move toward the left of the device when mirror 40 is tilted forward.

Mirror 42 receives the image from mirror 40, and its position is controlled by means of opposing solenoids 52 and 56 which, as the other solenoids, are operated through relays from the control panel 18, so that motion of the mirror 42 controls the shift of the image in the vertical direction. Rotation of mirror 42 about its axis clockwise, that is, facing the device front as illustrated in FIG. 2, causes the boundary line of the image A-D to move upwardly.

The clockwise rotation of second mirror 42 brings either quadrant C or D onto the viewing display screen 20, depending upon the accompanying position of the variable mirror 40. Thus, in operation, through altering the positions of mirrors 40 and 42 about their respective axes through the use of the solenoids, any one of the four quadrants A, B, C or D in the 35 mm slide contained in the projector 12 may be displayed on the display screen 20 and viewed by the student, while the shift from one to the other quadrant is easily and rapidly accomplished; for example, in less than 2 seconds.
Mirror 44 is a fixed first surface mirror, but is adjustable (not shown) for minor image alignment, while each movable mirror 40 and 42 is also adjustable (not shown) for the desired alignment of the image received by each mirror.

In operation of my teaching device, the image displayed on the display screen 20 on the front panel 32 of my teaching device originates typically in a 35 mm transparency slide and is placed within the slide insert of the projector 12, such as a Kodak Carousel projector fitted with a three-inch focal length lens. The projector 12 operates the reverse R and forward F modes by means of switches mounted on the control panel 18. The image displayed on the screen 20 represents one quarter of the slide as illustrated, the slide being divided into quadrants.

Typically, quadrant A may be used for the main line of material for a teaching sequence, and is preferably the quadrant automatically displayed whenever the forward or reverse mode switches are activated. However, this feature (automatic display of quadrant A) is optional, and may be by-passed by means of an internal switch if desired. The instructional material contained with the quadrants B, C and D of slide 54 may be used for parallel material, review or adjunct material, for testing, or may be used as part of the main sequence material. The quadrants are selected for viewing by the student or the teacher by activation of one of the four quadrant switches which are labeled A, B, C and D on the control panel 32, or if desired, the switches can be activated in a predetermined time sequence through the use of a suitable timer.

Material for my teaching device is prepared on sheet material, such as cards, having a dimension of approximately the same size as the display screen 20, and then photographed, with, of course, the actual arrangement and dimensions variable depending upon the type of copy equipment used. The particular arrangement of the material and the order in which the quadrants are to be viewed by the student or teacher depend upon the design of the instructional program, and the capacity of the slide tray employed in the particular projector. Instructional material may be typed, drawn, pasted or written or otherwise illustrated, and may be photographed in color or black and white as desired.

The projector 12 is wired through plug-in-type connectors through the control panel 32. The projector is then aligned into the optical path system, with horizontal alignment being made by means of a vertical elevation control on the projector base, while a vertical alignment is made by motion of the projector about a vertical axis by means of its rotating support platform which is controlled by an adjustment control 46 on the projector support platform. The projector 12 is positioned on the platform base 30, with the projector feet resting in indentations to maintain the projector position.

In operation, the student or teacher operates the switches on the control panel 18, such as switches A, B, C and D, in the particularly desired sequence to energize relays which activate the solenoids which in turn operate the solenoids in proper combination so as to tilt the movable mirrors about their respective axes 40 and 42 as described for the selection of any one of the four quadrants to place their images onto the display screen 20. Operating the slide change switches in either the forward or reverse mode as shown automatically shifts the mirrors in the optical system to display the first quadrant A, but this is an optional feature, and may be switched off by means of an internal control.

FIG. 4 is a schematic diagram of the electrical circuit of my visual teaching device. Power is provided for the machine from a conventional 110-120 volt 60 A.C. outlet through a power cord disposed on a reel 36, which cord terminates at a terminal block within the device. One side of the line is fused (see FIG. 4, /), the other is switched by means of a s.p.s.t. switch (T1). A neon indicator signals when the electrical power is on.

The projector 12 is left in the on position so that it is on when the power switch is closed. The six s.p.s.t. momentary contact switches (T2, T3, 2, T5, T6, 3) located on the front panel of the teaching device control all functions of the machine in association with their respective relays R1-R6, Sw1 (projector reverse) indicated as R activates relay R1, connecting the leads from the remote control cable connector of the projector (terminals 1 and 5, Kodak Carousel model 650H), thus causing it to change slides in the reverse direction.

Any quadrant of the slides may be displayed, depending upon the last quadrant selection. Sw1 is the projector slide advance indicated as F, and through its relay R1, connects the leads of the remote control cable (terminals 1 and 5), causing normal slide change in the forward direction. Simultaneously, relay R2 also activates relay R3, which sets the optical system for display of quadrant A automatically each time a slide is changed.

This feature is optional and may be switched off by opening switch T1, which is located inside the machine on the access door. Sw2 is the quadrant A switch, and operates R2, and energizes solenoid B (mirror number 1 to the forward position, ccw facing the right side of the device as shown in FIG. 2), and solenoid C (mirror number 2 downward, or ccw facing front of the device). Sw3 is the quadrant B switch and operates relay R4, which energizes solenoid C and solenoid A (mirror number 1 to backward position or cw from right side of the machine). Sw4 is the quadrant C switch, operating relay R5 and solenoids A and D (mirror number 2 upward position or cw from front of machine). Sw5 is the quadrant D switch, and energizes solenoids D and B through relay R6. In addition to operating the solenoids for quadrant D, relay R6 may also energize relay R7 when quadrant D is selected (this is an optional feature controlled through sw6, located inside the device on the access door). Relay R8, is a holding relay, and once energized, will not release until relay R9 interrupts the other side of its supply. Relay R9 is used when my response device is being used and functions to cut off supply to relays R7, R8 and R10 which control slide change. Thus, if this feature is being used, once quadrant D is selected (this quadrant would contain a multiple-choice question, or would be the last quadrant observed before slide change if the responses were contained on a sheet), slides cannot be changed (through quadrants A-D could be reviewed) until relay R9 is energized. This function is accomplished through a low-voltage circuit that is completed by the probe of the response unit when the correct answer to the multiple-choice question is selected. The probe can make contact with the backing plate only through a hole in the Correct Answer Template (see FIGS. 5A, 5B and 5C). When contact is made, relay R9 is energized, breaking the circuit to relay R9, and causing it to release and restore op-
eration of slide change switches $s_w$ and $s_{w'}$. When a
wrong answer is punched with the probe, a hole is left
in the answer sheet, thus indicating a wrong choice or
wrong choices. Selections are made until the red indi
cator light goes out (it comes on when quadrant D is
selected and a response is to be made), and the green
light glows, indicating that a correct response has been
made and that the program may be continued.

The response device circuit incorporating a low-vol
tage circuit, relays $R_1$ and $R_2$, and one contact of
relay $R$ may be bypassed merely by opening $s_{w'}$, in
which case, all functions may be selected at any time
desired without interruption.

Optionally, a response device 70 as shown more par
ticularly in FIGS. 5A, 5B and 5C may be employed in
combination with my visual teaching device.

In use, my response device 70, as shown more partic
ularly in the assembled condition of FIG. 5C, is con
nected with the teaching device, the teaching device set
for its use through the operation of an internal switch
$sw$, (see FIG. 4). For example, quadrant D of each slide
may be a multiple-choice question to test the student
on the information previously displayed in quadrants
A, B, and C, or if desired, the questions can be con
tained in a booklet or sheet to follow the teaching pro
gram sequence displayed, thus, conserving viewing
space on the teaching device. In either case and as an
illustrative example, once quadrant D has been se
lected for posing the questions to the student, a re
sponse is required by the student before the sequence
or the further display of quadrants in my teaching de
vice can be continued.

FIGS. 5A, 5B and 5C are views of my response de
gice 70 which consists of a base 68, a frame 66, such
as, for example, a hinged locking frame approximately
6½ inches by 9½ inches. The frame 66 and base 68 are
adapted to hold four sheet elements to comprise, and
as illustrated more particularly in FIG. 5A, a multiple
choice answer sheet 58, an answer sheet support 60, a
correct answer template 62 and an electrical conduc
tive sheet 64. The answer sheet 58 is illustrated as containing space for thirty responses by the student.
The answer support sheet 60 has the answer choices
punched out so that holes from the answer template
will not show through, so that the answer sheet 60 is
raised so that holes may be punched therethrough eas
ily by the student. The correct answer template 62 is
composed of a nonconductive material, such as an an
swer sheet, with correct answer choices punched out.
The punch out holes provide means by which a mark
ning stylus 74 can reach the conducting surface of the
conductive sheet 64, so as to complete the low
voltage circuit providing for tripping the teaching de
vice and permitting the slide to advance to the next
quadrant, thereby indicating the correct choice by the
student which may also be indicated by a visual signa
t such as a green light.
The answer sheets 58 are mimeographed or printed,
and consist of half sheets of standard 8½ × 11 paper
two answer sheets are printed per page of master copy
They provide four choices per question (A, B, C, D) and
contain space for 30 responses. The response spaces are
so arranged on the sheet that the Answer Template
may be turned over and inverted to change correct an
swer locations for questions 31–60, 61–90 and 91–120
without having to make additional templates. Each
time a student completes a 30 question sheet, the re
sponse device 70 is unplugged and returned to the in
structor for examination and reloading. A low-voltage
circuit (6 v. DC.) is used for the response device in
order to eliminate electrical hazards.

My response device provides a means by which a stu
dent may check his understanding of the material pre
sented by the visual teaching device, and to provide im
mediate feedback as to the correctness of the responses
selected by the student to, for example, questions pro
posed in any one of the quadrants on the display
screen, such as responses to multiple-choice questions
displayed. My response device also provides a means
by which the instructor is provided with a record of stu
dent responses which permits the instructor to acquire
knowledge as to areas in which the student has been
trained or is unfamiliar. My response device used in
combination with my teaching device also serves to
force concentrated attention to the programs being dis
dplayed, since it requires student interaction with the
displays on the visual teaching device. Of course, my
visual teaching device may be used alone or in com
bination with other known response devices, and my
response device may be employed in combination with
a timing means so as to provide for the sequential or pre
determined time displays of the particular quadrants of
the slide in the projector, thereby providing a measure
of the student's knowledge by his rapid response to in
structional material so displayed.

What I claim is:

1. A visual teaching device, which device comprises
in combination:
   a. an image-receiving and display means;
   b. a means to project an image onto the display
      means through an optical system;
   c. an optical system between the display means and
      the means to project comprising:
      i. a first plane front surface mirror adapted to re
         ceive the projected image, the first mirror
         mounted at an angle of about 45° from the hori
         zontal on an axis which is at right angles to the
electric path of the projected image;
      ii. a second plane front surface mirror adapted to re
         ceive the image from the first mirror, the second
         mirror mounted at an angle of about 45° from the ver
         tical on an axis parallel to the optical path of the pro
         jected image;
      iii. a first means to rotate the first mirror about its
          axis;
      iv. a second means to rotate the second mirror about its
          axis;
      v. a fixed plane front surface mirror adapted to re
         ceive the image from the second mirror and to
         project the image onto the display means, and
      d. control means to control the first and second means to
         rotate the first and second mirrors so as to
      e. a means to rotate the first mirror about its axis;

2. The device of claim 1 wherein the first and second
   means to rotate the first and second mirrors are elec
   tromechanical solenoids.
3. The device of claim 1 wherein the means to project
   comprises a projector having a short focal length lens, and
   adapted to project an inverted reversed image onto the
   first mirror.
4. The device of claim 3 wherein the projector is adapted to receive and project an image from a transparent slide containing instructional material in quadrant portions of the slide.

5. The device of claim 1 wherein the means to display the image is a flat display screen, and which device includes as the control means four control switches, the activation of each switch providing the display on the screen of a selected quadrant of the projected image.

6. The device of claim 5 wherein the screen and control switches are positioned in a control panel for viewing by the user.

7. The device of claim 1 wherein the first, second and fixed mirrors are each progressively larger in image-receiving surface from the preceding mirror.

8. A teaching system which comprises in combination:
   a. a teaching device of claim 1, and
   b. a response means adapted to be employed by the user to respond to information displayed as an image on the display means, and to prevent the display of the next sequential image, unless a correct response is made in the response unit, the response means in electrical communication with the electrical circuit of the control means.

9. The teaching system of claim 8 wherein the response means comprises in combination:
   a. a base element;
   b. an answer sheet with choices of multiple answers displayed thereon for selection by the user;
   c. an answer support sheet with perforations thereon corresponding to all the choices of the answer sheet;
   d. a nonconductive correct answer template sheet with perforations therein corresponding to the position of the correct answer on the answer sheet;
   e. a sheet having an electrically conductive surface;
   f. a signal cable electrically connecting the sheet with the conductive surface with the teaching device control means.

10. The teaching system of claim 9 wherein, the image received is a reversed image from the projector about its horizontal axis.

11. A teaching system which comprises in combination:
   a. a teaching device of claim 10;
   b. a response means to permit the user to select responses related to information or questions displayed on the teaching device, the response means electrically communicating with the control means; and
   c. an electrical control means to prevent the advance of the quadrant displayed on the teaching device until a correct response is selected by the user and entered into the response means.

12. A method of teaching, which method comprises:
   a. providing a slide for display containing four separate quadrant display image areas on the slide;
   b. placing the slide in a projecting means;
   c. projecting the total image of the slide onto an optical system containing a series of plane front surface mirrors, the mirrors directing the image displayed onto a screen a quadrant at a time;
   d. adjusting the mirrors in the optical path of the displayed image by rotating at least one mirror about one axis and another mirror about another axis at right angles to the one axis; and
   e. controlling the adjustment of the mirrors so as to display on the screen only a selected quadrant portion of the slide in the projector.

13. The method of claim 12 which includes adjusting the mirrors by employing an electromechanical system of solenoids.

14. The method of claim 13 wherein the mirrors in the optical path from the projected image include sequentially a first variable mirror, a second variable mirror and a fixed mirror.

15. A teaching system which comprises:
   a. displaying in a programmed sequence quadrant portions of an image as claimed in claim 12;
   b. providing for the user to select responses relative to the information displayed in any quadrant at any one time;
   c. preventing the display of the next sequential quadrant, unless the user selects a proper response; and
   d. providing for the display of the next sequential display on selection of the correct response by the user.
Appendix B: Evaluation Instrument

Ratio & Proportion - General Applications

1. What is the price per gallon of gasoline if it is selling at the rate of 6.0 gal. for $1.14?

2. A tree which is 70.0 ft. tall casts a shadow which is 40.0 ft. long. What is the ratio of tree height to tree length of shadow?

3. Gold has a density of 19.6 grams for every cubic centimeter it takes up in space. How many grams would 500 cubic centimeters weigh?

4. If gasoline costs $1.34/gal., how many gallons could be bought for $5.00?

5. If it takes 40 minutes to cut 1/5 of the lawn, how long will it take to do the whole lawn?

6. A large graduated cylinder has a diameter of 4.0 cm. and is filled to a depth of 25 cm with a particular liquid. If the liquid is then poured into a cylinder with a diameter of 2.0 cm, then the depth of the liquid will be how many centimeters?

7. A machine has a capacity to turn out 40 pieces of material per minute. How many pieces could then be produced by 4 machines in 1 hour?

8. The resistance of a wire varies inversely with the square of its diameter. If a certain wire has a resistance of 0.83 ohms when its diameter is 0.001 millimeter, then what is its resistance in ohms if its diameter is 0.005 millimeters?

9. The speed of a falling body increases with the square of the time of fall (within certain limits). Starting from rest, how much faster will a body be falling after 5 sec. of fall than after 3 sec. of fall?

10. A pump can deliver 5.6 gal./minute of a certain liquid. How long will it take to fill a 4 ft. x 3 ft. x 6 ft. tank if there are 7.5 gal. per cubic foot?

11. A gallon of water weighs 8.3 pounds, while gasoline weighs only 0.67 as much. How much, then, would 20 gallons of gasoline weigh?

12. One quart is only 0.946 metric liters. There are 4 quarts to every gallon. If gasoline now costs $1.43 9/10 per gallon, what would be the price per liter?

13. One inch is equal to 2.54 centimeters. There are how many cubic centimeters in a cubic inch?

14. The density of lead is 11.3 grams per cubic centimeter. What is the density in grams per cubic inch?

15. Gas volumes are inversely proportional to their pressures. Thus, if the pressure on 2.0 liters of a gas changes from 2.5 atmospheres to 1.49 atmospheres, what will the new volume be?

16. In a certain chemical reaction, 75 grams of reactant yielded 35 grams of product A. How many grams of reactant would be required for every kilogram of product A?
The numbers 1 and 4 would be written
\[ 1 : 4 \]
but often it is preferred to write the larger number first:
\[ 4 : 1 \]
this is read "four to one"

RATIO (pronounced ra-she-oh)
A comparison of any two numbers
For instance, the numbers 1 and 2 would be written as
\[ \frac{1}{2} \quad \text{OR} \quad 1 : 2 \]
The first one would be read "one-half" but the second one would be read "one-to-two"

The numbers 4 and 16 would be written as
\[ \frac{4}{16} \quad \text{OR} \quad \frac{16}{4} \]
but this could be reduced to
\[ \frac{4}{1} \quad \text{OR} \quad 4 : 1 \]
(read "four-to-one")

Which one of the following number arrangements is a ratio?

a. \( 4 \times 10^{12} \)
b. \( x = 2y^2 \)
c. \( 1 : 6 \)
d. \( 2 = 4x \)

(mark your answer on the TECHNITUTOR answer response unit)
Reducing fractions or ratios is usually accomplished by dividing the denominator into the numerator (by dividing the bottom number into the top number):

\[
\frac{2.5}{5} = \frac{5}{1}
\]

and then putting the quotient (result) over one.

This is really the process of dividing both the numerator and denominator by the same number (this then is the same as dividing by 1- which then does not change the mathematical value, only the form (looks) of the ratio.

The meaning of larger ratios is sometimes hard to see, so when it is possible these large number ratios are reduced to simpler equivalent ratios.

For example: \(4:16\)

CAN BE REDUCED to the simpler ratio

\(1:4\)

The ratio \(4:16\) IS the same as the ratio \(1:4\)
(The ratio four-to-sixteen is the same as the ratio one-to-four).

Dividing the denominator of a fraction (or ratio) by itself makes it equal to one, and dividing the numerator by the same number (the denominator) changes the numerator to a correspondingly smaller number:

the ratio \(24:16\) can be reduced to \(1.5:1\)

by dividing both numbers by \(16\)

\[
\frac{24/16}{16/16} = \frac{1.5}{1} \quad \text{or} \quad 1.5:1
\]

For the numbers 12 and 72, the simplest ratio is

a. \(12/72\)

b. \(72/12\)

c. \(6:1\)

d. \(12:2\)
Reduction of a ratio to smaller numbers can be accomplished by dividing each number of the ratio by the same number:

\[
\frac{6}{36} = \frac{6 \div 3}{36 \div 3} = \frac{2}{12}
\]

but this can be further reduced to

\[
\frac{2 \div 2}{12 \div 2} = \frac{1}{6}
\]

In either case, 4 : 16 or 1 : 4

THE MEANING is that the second number is four times larger than the first number.

Of course, in comparing the two numbers, they could also have been written in reverse order:

\[
16 : 4 \quad \text{or} \quad 4 : 1
\]

THE RATIO MEANING is still that one of the numbers is four times larger than the other (or that one of the numbers is one-fourth as large as the other).

This could have been accomplished directly by dividing by six:

\[
\frac{6}{36} = \frac{6}{6} = \frac{1}{6}
\]

(dividing first by 3 and then by 2 is the same as having divided by 6).

The ratio 15 : 40 can be reduced to the simplest whole number ratio of

- a. 1 : 1.67
- b. 3 : 8
- c. 1.5 : 4
- d. 5 : 13.33
Ratios do not always reduce to whole number integers, but if the smaller number is the denominator, dividing the ratio by that number will always reduce the ratio to some value compared to the number one.

the numbers 64 and 12 could be written

\[
\frac{64}{12}
\]

and dividing both numbers by 12

\[
\frac{64 \div 12}{12 \div 12} = \frac{5.33}{1} \text{ or } 5.33 : 1
\]

(five point three three to one

It is sometimes more meaningful to write the smaller of the two numbers of a ratio as the second number;

\[
12 : 4 \text{ rather than } 4 : 12
\]

then dividing by the smaller of the two numbers, the ratio will take the form of some number compared to one

\[
12 : 4 = 3 : 1
\]

of course, it could have also been written

\[
12 : 64 \text{ or } 12/64
\]

AND THEN BOTH NUMBERS divided by the smaller one

\[
\frac{12/12}{64/12} = \frac{1}{5.33} \text{ or } 1 : 5.33
\]

To reduce the ratio 9 : 54 to its simplest terms would require both numbers being divided by

\[
a, 1 \\
b, 3 \\
c, 6 \\
d, 9
\]
The ratio 3:4 could also be further reduced to a form in which one of the numbers is 1:

\[
\frac{3}{4} \rightarrow 3 \times 1 = 3 \\
\rightarrow 3 \times 1.33 = 3 \times 1.33 = 1.33
\]

(This would be read "one to one point three three")

This is also 1:1 1/3
(one to one and one-third)

HOW DOES THE NUMBER 27 COMPARE TO THE NUMBER 36?

\[
27 : 36 \quad \text{or} \quad \frac{27}{36}
\]

This can be "reduced" to a simpler ratio by dividing both numbers by 9:

\[
\frac{27}{36} \rightarrow 9 = \frac{3}{4}
\]

(of course this could also have been written as 4:3)

The ratio 24:32 should be reduced to 1 : 1.25 by dividing both numbers by

a. 24  
b. 32  
c. 24 and 32  
d. 8
If the numbers 5 and 60 had been written as
\[
\frac{5}{60}
\]
then dividing by the denominator (60), the larger of the two numbers would have given
\[
\frac{5}{60} \rightarrow \frac{1/12}{1} = 0.083
\]
or 0.083 : 1

How do the numbers 5 and 60 compare?
\[
\frac{60}{5} \quad \text{or} \quad \frac{60}{5}
\]
Dividing this ratio by the smallest of the two numbers reduces the smallest one to 1, and the other number to a correspondingly smaller number:
\[
\frac{60}{5} \rightarrow \frac{12}{1} = 12 : 1
\]

Just how numbers are compared often depends upon which of the numbers represents the best standard reference, and what is being compared to it. Also, it often depends on the order in which the numbers are stated.

One car gets 25 mpg (miles per gallon) while another gets 40 mpg. How much better (how many times) is the better mileage car than the other (notice the order in which the comparison is to be made)?

a. 25 : 40
b. 5 : 8
c. 5/8
d. 1 : 1.6 or 1.6 times better
Dividing a ratio by the smallest of the two numbers will reduce the smallest number to 1.

\[ 9 : 27 \rightarrow 9 = 1 : 3 \]

Dividing the ratio by the largest of the two numbers will reduce the largest number to 1, but the other number will be a decimal or a fraction:

\[ 9 : 27 \rightarrow 27 = \frac{1}{3} : 1 \]

or \[ 0.33 : 1 \]

Ratios don't always reduce to simple whole numbers, and in some cases it is preferred to reduce the ratio to some number compared to 1.

The numbers 8 and 30 could be written

\[ 8 : 30 \]

or this ratio could be reduced to

\[ \frac{30 \rightarrow 8}{8 \rightarrow 8} = \frac{3.75}{1} \text{ or } 3.75 : 1 \]

Notice that the ratio \( 1 : 3 \) is the same as \( \frac{1}{3} : 1 \) (that is, they have the same meaning) since

\[ \frac{\frac{1}{3} \times 3}{1 \times 3} = \frac{1}{3} \]

Multiplying by \( 3/3 \) is equal to multiplying by one, and does not change the value of the relationship--only its form (looks).

Which one of the following is a correct form of the ratio \( 7 : 42 \)?

a. \( 1 : 6 \)
b. \( 1/6 : 1 \)
c. \( 3\frac{1}{2} : 21 \)
d. all of these
In 1960 the price of regular gasoline was $0.29/gal. In 1981, it was $1.33/gal. What is the ratio of 1981 gasoline price to the 1960 price per gal.?

\[
\begin{align*}
\frac{1981}{1960} & = \frac{1.33}{0.29} \\
& = 4.586 : 1
\end{align*}
\]

The 1981 price per gal. is 4.6 times higher than the 1960 price per gal.

Ernie Spendmore has only $27.00 in his bank account while his friend Gladys Pursesqueeze has $256.50. What is the ratio of Gladys’ savings to those of Ernie?

\[
G : E = \frac{256.50}{27} = 9.5
\]

G : E = 9.5 : 1 Therefore, Gladys’ savings is 9.5 times that of Ernie.

100 grams of calcium oxide, CaO, contains 28.5 grams of oxygen while 100 grams of calcium carbonate, CaCO₃, contains 48 grams of oxygen. What is the ratio of oxygen (by weight) in CaO to that in CaCO₃?

\[
\begin{align*}
\text{wt. in CaO} & = 28.5 \text{ g} = 0.59 \\
\text{wt. in CaCO₃} & = 48.0 \text{ g} = 1
\end{align*}
\]

so the ratio of oxygen in CaO to that in CaCO₃ is about 0.6 : 1 (or the ratio of CaCO₃ oxygen to CaO oxygen is 1.4 : 1)

18 grams of water contains about 2 grams of hydrogen and 16 grams of oxygen. The weight ratio of oxygen to hydrogen is therefore

\[
a. \quad 16 : 1 \\
b. \quad 8 : 1 \\
c. \quad 1 : 9 \\
d. \quad 8 : 9
\]
For sodium and oxygen, the simplest whole number ratio is 23 : 16 (listing the larger first). Reducing the smallest value to unity is often the preferred form, and in this case the ratio was reduced to 1.44 : 1

In the inverse form, oxygen to sodium,

\[
\frac{0}{Na} = \frac{16}{23} = \frac{16/23}{23/23} = \frac{0.7}{1} \text{ or } 0.7 : 1
\]

In this form we are saying that oxygen is 0.7 as heavy as sodium.

The atomic weight of sodium, Na, is 23, and that of oxygen, O, is 16. What is the weight ratio of sodium to oxygen?

\[
Na : O = 23 : 16
\]

or \( \frac{Na}{O} = \frac{23}{16} \)

(dividing both numbers by 16 yields a simple ratio of 1.44 : 1 That is, sodium is approximately 1.44 times heavier than oxygen)

Atomic weights of the elements are relative weights (comparison or ratio weights), and can therefore be used to find actual weights.

Potassium, K, has an atomic wt. of 39.1

Sulfur, S, has an at. wt. of 32.006

What is the weight ratio of potassium to Sulfur?

\[
\frac{K}{S} = \frac{39.1}{32} = \frac{1.22}{1} \text{ or } 1.22 : 1
\]

The weight ratio of iron, Fe, At. wt. = 55.85 to aluminum, Al, at. wt. = 26.98 is about

a. 26 : 55
b. 56 : 27
c. 0.48 : 1
d. 2 : 1
A proportion, then, is simply a mathematical statement that two ratios have the same value, or are different forms of the same ratio.

for the proportion $1 : 2 :: 2 : 4$,
it can easily be seen that
\[
\frac{1}{2} = \frac{2}{4} \quad \text{because} \quad \frac{1 \times 2}{2 \times 2} = \frac{2}{4}
\]
and multiplying by $2/2$ does not change a value because $2/2 = 1$

If one member of a proportion is unknown, it can easily be found. For instance,
$5 : 8 :: ? : 64$ or $5/8 = ?/64$
The denominator was multiplied by 8 to make it into 64, so the numerator must be multiplied by the same number:
\[
\frac{5}{8} = \frac{?}{64} \quad \text{or} \quad \frac{5 \times 8}{8 \times 8} = \frac{40}{64}
\]
\[
\frac{64}{8} = 8 \quad \text{or} \quad \frac{?}{64} = 40
\]

17 is to 32 as what number is to 128?
$17 : 32 :: ? : 128$

a. 68
b. 17
c. 34
d. 4
In the example given in frame 11A, multiplying by 8/8 does not change the value of the ratio—only its form, because 8/8 = 1.

\[
\frac{6}{27} = \frac{?}{54}
\]

Dividing 54 by 27 reveals the multiplier to be 2.

\[
\text{therefore } \frac{6}{27} \times \frac{2}{2} = \frac{12}{54}
\]

12/54 has the same mathematical value as 6/27.

Often it is desirable to find a new ratio that has the same mathematical value as a particular one which is determined by some condition.

How many 16ths have the same value as one-half?

\[
\frac{1}{2} = \frac{?}{16}
\]

\[
\frac{1}{2} \times \frac{8}{8} = \frac{8}{16}
\]

(denoting 2 into 16 reveals that the multiplier is 8, 1 : 2 :: 8 : 16)

Treating the equation (proportion) algebraically,

\[
\frac{6}{27} = \frac{n}{54}
\]

\[
\frac{6 \times 54}{27} = n = 12
\]

For the proportion

\[
4 : 5 :: n : 39
\]

n must be equal to

a. 156
b. 195
c. 48.75
d. 31.2
Often, actual ratios do not come out to convenient whole numbers. The ratio of carbon to oxygen could have also been given as:

\[
\frac{\text{wt. C}}{\text{wt. O}} = \frac{12}{32} = \frac{12/32}{32/32} = 0.375
\]

\[
\text{carbon/oxygen} = 0.375 : 1
\]

(this is really the same ratio as before, since

\[
\frac{0.375}{1} = \frac{1}{2.67}
\]

So the ratio of carbon/oxygen is either

\[
\frac{\text{Carbon}}{\text{oxygen}} = 0.375 : 1
\]

or

\[
1 : 2.67
\]

But the inverse order,

\[
\frac{\text{oxygen}}{\text{carbon}} = 1 : 0.375
\]

or

\[
2.67 : 1
\]

For the chemical reaction,

\[
\begin{array}{ccc}
12 & 32 & 44 \\
C & O_2 & \rightarrow \ \ CO_2
\end{array}
\]

(numbers above chemical symbols are equation weights, = atomic weights x number of atoms used)

From these, weight ratios can be found:

\[
\frac{\text{wt. C}}{\text{wt. O}} = \frac{12}{32} = \frac{1}{2.67}
\]

Actual weights used will also be in this ratio.

What is the simplest inverse ratio of 6 : 16?

a. 6/16
b. 16/6
c. 0.375 : 1
d. 2.67 : 1
In the previous example, frame 13A, how many grams would be required of oxygen?

\[
\frac{\text{eq. wt}}{\text{act. wt}} = \text{a constant which in this case is established by having only 6 g of carbon:}
\]

\[
\frac{\text{actual wt.}}{\text{equation wt.}} = \frac{6 \text{ g}}{12} = \frac{1}{2}
\]

actual weights should be \( \frac{1}{2} \) the equation weights, therefore

\[
\frac{\text{act. wt. of oxygen}}{32} = \frac{1}{2} = 16 \text{ g}
\]

Since the equation weights called for 12 g, 32 g, and 44 g respectively for C, O\(_2\), and CO\(_2\), but only half as much as specified for carbon was allowed, then all other values will also be in this ratio of \( \frac{\text{eq. wt.}}{\text{act. wt.}} = 2/1 \) or the inverse, \( \frac{\text{act. wt.}}{\text{eq. wt.}} = \frac{1}{2} \)

\[
\begin{array}{ccc}
12 & 32 & 44 \\
C & O\_2 & CO\_2 \\
6g & 16g & 22g
\end{array}
\]

The nature of chemical reactions is that the weight ratios are constant for a particular reaction.

\[
\begin{array}{ccc}
12 & 32 & 44 \\
C + O\_2 & \rightarrow & CO\_2
\end{array}
\]

equation weights

\[
\begin{array}{ccc}
6g & ? & ?
\end{array}
\]

actual weights

How many grams of CO\(_2\) would be formed from 6 grams of carbon?

\[
\begin{array}{ccc}
CO\_2 & 44 & ? \\
C & 12 & 6g
\end{array}
\]

\[
\frac{CO\_2}{12} = \frac{6g}{6g} = 22 g
\]

For the reaction,

\[
\begin{array}{ccc}
65.38 & 32.06 & 97.44 \\
Zn + S & \rightarrow & ZnS
\end{array}
\]

if 20 g of Zn are used, then the number of grams of sulfur required is approximately

a. 10 g
b. 20 g
c. 30 g
d. 40 g
(the symbol \( \pi \), pi, represents the constant value 3.14)

If circle #1 has a radius of 2, and circle #2 has a radius of 4, the ratio of areas of circle 1 to circle 2 could be easily found:

\[
\frac{A_1}{A_2} = \frac{r_1^2}{r_2^2} = \frac{2^2}{4^2} = \frac{4}{16} = \frac{1}{4}
\]

Notice that though the area ratios are 1:4, the radius ratios are 1:2. It is their squared value that is proportional to their areas, not their actual values.

Often ratios and proportions are derived from simple relationships or definitions. For example,

Area of a circle = \( \pi r^2 \) \( (r = \text{radius}) \)

The area of circle #1 and #2 could be related by using this definition:

\[
\frac{\text{area Circle #1}}{\text{area Circle #2}} = \frac{A_1}{A_2} = \frac{\pi (r_1)^2}{\pi (r_2)^2}
\]

\( \pi \) can be cancelled from each area, then the ratio reduces to \( A_1/A_2 = r_1^2/r_2^2 \)

A ratio of areas using diameters rather than radii could also be developed since \( 2 \times r = d \) (a diameter is equal to 2 times a radius)

\[
\frac{d_1}{d_2} = \frac{2r_1}{2r_2} = \frac{r_1}{r_2}
\]

The diameters of two circles have the same ratio as the radii, therefore

\[
\frac{A_1}{A_2} = \frac{r_1^2}{r_2^2} = \frac{d_1^2}{d_2^2}
\] or \( A_1 : A_2 :: r_1^2 : r_2^2\)

or \( A_1 : A_2 :: d_1^2 : d_2^2\)

If circle II has a diameter three times that of circle I, then the area of circle II is larger/smaller than the area of circle I by a factor of

a. 3 x larger
b. 1/3 as large
c. 1/9 as large
d. 9 times larger
\[ A_1 : A_2 :: B_2 : B_1 \]

(This is read "A one is to A two as B two is to B one"). Let \( A_1 \) and \( B_1 \) be initial conditions for some experiment, and \( A_2 \), \( B_2 \) the final conditions.

\[
\frac{A_1}{A_2} = \frac{B_2}{B_1}
\]

Notice that the order, initial/final, is inverted for the second ratio.

Suppose for this example we let \( A_1 = 1 \), \( A_2 = 2 \), \( B_1 = 6 \). What then is \( B_2 \)?

\[
\frac{A_1}{A_2} = \frac{B_2}{B_1}
\]

\[
\frac{1}{2} = \frac{B_2}{6}
\]

\( B_2 \) is \( 3 \). While the A values went from 1 to 2 (doubled, or increased two times), the B values went from 6 to 3 (halved, or decreased by a factor of two).

**Inverse Proportions**

An inverse proportion is one in which one of the ratios is inverted (changes in the opposite direction). That is, if one ratio increases, the other decreases by the same factor:

\[
\frac{A_1}{A_2} = \frac{B_2}{B_1}
\]

or

\[
\frac{A_1}{A_2} = \frac{B_2}{B_1}
\]

If \( A_1 \) and \( R_1 \) are initial conditions, and \( A_2 \) and \( R_2 \) are resulting or final conditions, and A and R values vary inversely (are inversely proportional), then if \( A_1 = 4 \), \( R_1 = 12 \), \( A_2 = 6 \), \( R_2 \) would equal

a. 3
b. 8
c. 12
d. 18
160 liters of a gas are collected during an experiment at a pressure of 1.03 atmospheres. What is the gas volume at 1.0 atmospheres?

\[ V_1 = 160 \text{ L} \quad P_1 = 1.03 \text{ atm.} \]
\[ V_2 = \text{unknown} \quad P_2 = 1.0 \text{ atm.} \]

so we can write

\[ \frac{V_1}{V_2} = \frac{P_2}{P_1} \quad \text{or} \quad \frac{V_2}{V_1} = \frac{P_1}{P_2} \]

or by "cross multiplication"

\[ V_2 = \frac{P_1 V_1}{P_2} \]

\[ V_2 = \frac{160 \times 1.03 \text{ atm}}{1.0 \text{ atm}} = 164.8 \text{ L} \]

A well known example of an inverse relationship is Boyle's Law. This law states that when the pressure on a gas changes, its volume changes inversely:

\[ \frac{P_1}{P_2} = \frac{V_2}{V_1} \]

Pressure and volume are oppositely related

So, if the pressure on a gas increases, then its volume decreases by the same factor. For example, if the pressure were to double (2 X), then the volume would be half as much (1/2 X).

In working with ratios and proportions, certain operations are mathematically permissible: \( A : B :: C : D \) can also be written \( AD = BC \) \((A \times D = B \times C)\). That is, the product (multiplication) of the two middle terms = the product of the two outside terms. that is the same as "cross multiplication":

\[ \frac{A}{B} = \frac{C}{D} \]

\[ AD = BC \]

\[ A = \frac{B \times C}{D} \]

\[ D = \frac{B \times C}{A} \]

A certain gas has a volume of 200 milliliters at a pressure of 0.95 atm. What will the volume be at standard pressure (1.0 atm)?

a. 200 ml
b. 190 ml
c. 210 ml
d. 10 ml
## TABLE 4

**EXPERIMENTAL GROUP PRETEST SCORES**

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<thead>
<tr>
<th>Student Number</th>
<th>Sex</th>
<th>Test Questions</th>
<th>—Scores—</th>
<th>R</th>
<th>W</th>
<th>%</th>
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Percent of group answering each question correctly.

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Percent of group answering each question correctly
### TABLE 6

**CONTROL GROUP PRETEST SCORES**

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<tr>
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<td>9 7</td>
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<td>f</td>
<td>c x c c c c x c x x c - - - - -</td>
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<td>4 12</td>
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<td>c x c c c x c - - - c x c - - -</td>
<td>7 9</td>
<td>44</td>
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</table>

| 82 83 71 88 76 0 76 0 6 29 33 6 53 12 6 6 |

Percent of group answering each question correctly
### TABLE 7

**CONTROL GROUP POSTTEST SCORES**

| Student Number | Sex | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | R | W | % |
|----------------|-----|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|
| 1              | f   | c | c | c | c | c | x | c | - | x | -  | c  | x  | c  | -  | -  | -  | 8 | 8 | 50 |
| 2              | f   | c | c | c | c | x | x | c | c | c | x  | c  | c  | c  | x  | x  | 7 | 9 | 44 |
| 3              | f   | c | c | c | c | x | x | x | c | c | c  | c  | c  | x  | c  | c  | 9 | 7 | 56 |
| 4              | f   | c | x | c | c | x | x | x | x | x | x  | x  | x  | x  | x  | x  | 4 | 12| 25 |
| 5              | m   | c | c | c | c | x | x | x | c | c | c  | c  | c  | x  | x  | x  | 9 | 7 | 56 |
| 6              | m   | c | c | c | c | x | x | x | c | c | c  | c  | c  | c  | x  | c  | 10| 6 | 63 |
| 7              | m   | c | c | c | c | c | x | x | c | c | c  | c  | c  | c  | c  | x  | 11| 5 | 69 |
| 8              | f   | x | c | x | x | c | x | c | - | - | x  | x  | x  | x  | x  | x  | 4 | 12| 25 |
| 9              | f   | c | c | - | x | x | x | x | c | - | -  | -  | -  | -  | -  | -  | 3 | 13| 19 |
| 10             | f   | c | c | c | c | c | x | x | x | c | c  | x  | x  | x  | c  | c  | 9 | 7 | 56 |
| 11             | f   | c | - | x | c | x | x | c | x | - | x  | -  | -  | -  | -  | -  | 5 | 11| 31 |
| 12             | m   | c | c | c | c | c | x | x | x | c | c  | c  | c  | c  | x  | x  | 9 | 7 | 56 |
| 13             | f   | c | c | c | c | c | x | c | - | - | x  | c  | c  | c  | x  | x  | 9 | 7 | 56 |
| 14             | f   | c | x | c | c | c | c | x | x | x | -  | -  | -  | c  | x  | -  | 6 | 10| 38 |
| 15             | f   | - | - | x | c | x | c | - | - | - | x  | x  | x | x  | x  | -  | 2 | 14| 13 |
| 16             | f   | c | c | c | c | c | x | c | c | c  | c  | c  | c  | x  | x  | x  | 10| 6 | 63 |
| 17             | f   | c | c | c | c | x | x | x | x | c | x  | x  | - | x  | -  | -  | 7 | 9 | 44 |

Percent of group answering each question correctly

[88 76 82 76 88 0 94 6 6 29 59 18 35 0 6 52]
## TABLE 8

Summary of Experimental Group and Control Group Scores

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<td>Posttest Scores</td>
<td>Gain Scores</td>
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<td>3 m</td>
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<td>8 m</td>
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<td>56</td>
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\[
\bar{X} = 46.9 \quad 50.5 \quad 3.5 \quad 81
\]
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$^1$Gain scores of students with course grade of 85 or less.

$^2$Negative and zero gain scores have been eliminated from this computation.