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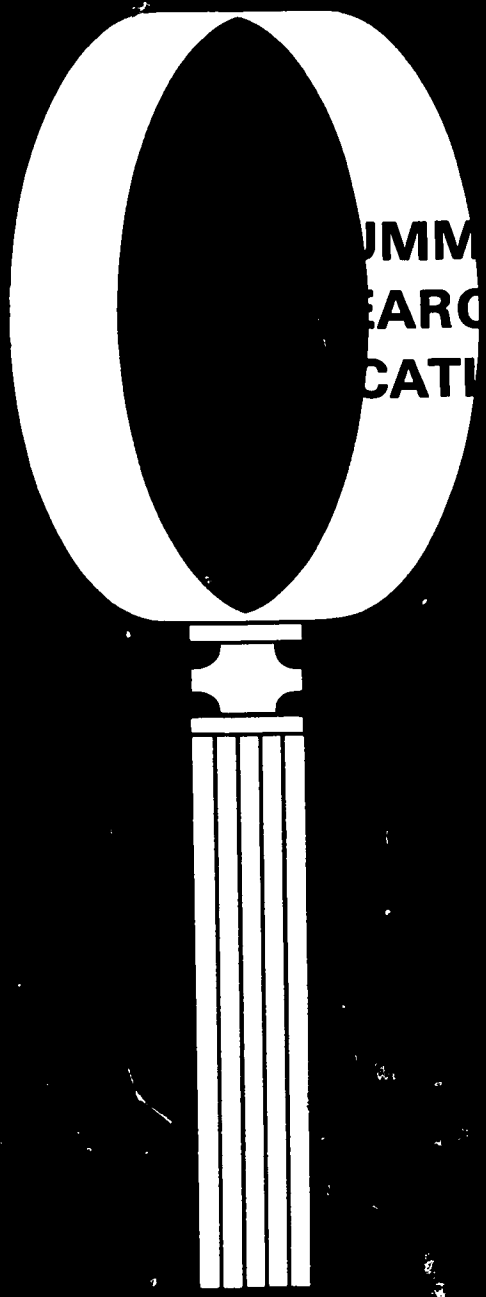
ABSTRACT

A summary of the 231 research articles in science education reported in 1972 is presented in this book through a review of over 400 studies. The content is classified into 18 categories: Learning Theory; Student Achievement; Instruction; Studies Related to Piaget's Work; Evaluation and Testing; Curriculum Studies; Computer Assisted Instruction; Attitudes Toward Science and Science Values; Bloom's Taxonomy; Interaction Analysis; Inquiry, Discovery Learning and Problem Solving; The Teacher; Enrollment; Environmental Education; Science Consultants; Research Methodology; History and Philosophy; and Foreign Studies. A special section is incorporated to deal with unpublished articles. Many of the research articles are related to the theoretical framework of Ausubel. Survey type studies are not dealt with in this summary, although titles appear in the bibliography. A total of 440 entries is contained in the bibliography. (CC)



SCIENCE EDUCATION INFORMATION
REPORTS

# SCIENCE RESEARCH REVIEW SERIES
# A SUMMARY OF RESEARCH IN SCIENCE EDUCATION
# FOR 1972

By
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## SCIENCE, MATHEMATICS, AND ENVIRONMENTAL EDUCATION INFORMATION REPORTS

The Science, Mathematics, and Environmental Education Information Reports are being developed to disseminate information concerning documents analyzed at the ERIC Information Analysis Center for Science, Mathematics, and Environmental Education. The reports include four types of publications. Special Bibliographies are developed to announce availability of documents in selected interest areas. These bibliographies will list most significant documents that have been published in the interest area. Guides to Resource Literature for Science, Mathematics, and Environmental Education Teachers are bibliographies that identify references for the professional growth of teachers at all levels of science, mathematics, and environmental education. Research Reviews are issued to analyze and synthesize research related to science, mathematics, and environmental education over a period of several years. The Occasional Paper Series is designed to present research reviews and discussions related to specific educational topics.

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RESEARCH REVIEWS - SCIENCE

Research Reviews are being issued to analyze and synthesize research related to the teaching and learning of science completed during a one-year period of time. These reviews are developed in cooperation with the National Association for Research in Science Teaching. Appointed NARST committees work with staff of the ERIC Center for Science, Mathematics, and Environmental Education to evaluate, review, analyze, and report research results. It is hoped that these reviews will provide research information for development personnel, ideas for future research, and an indication of trends in research in science education.

Your comments and suggestions for this series are invited.

Stanley L. Helgeson
and
Patricia E. Blosser
Editors

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Without the encouragement and assistance provided by these good people, the task of sifting and abstracting over four hundred research reports would have been much more onerous.

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# SUMMARY OF RESEARCH IN SCIENCE EDUCATION FOR 1972

## METHODS AND CRITERIA USED

The review of research in science education has been a tradition since the first publication by F. Curtis in 1926 (241). This review continues the tradition in that numerous papers and abstracts have been perused and selected studies have been summarized. It departs from traditional reviews of research in that a strong editorial position is asserted not only for so-called experimental studies purporting to test the comparative value of alternative instructional techniques or teacher preparation regimes but also for "ethological" type studies where careful observation of phenomena hopefully may lead to identification of factors causing or influencing these phenomena (e.g., studies of teacher-pupil interaction).

In some respects 1972 was a productive year; more than 400 different studies and reports were identified through ERIC and in our library search. To proceed in our review, these studies were classified into twenty-five categories. As the review of studies in each category progressed, sufficient overlap was identified to reduce the total number of distinct categories to eighteen. However, some of these groupings; i.e., Studies related to Piaget's work, contained a variety of studies and subcategories were subsequently identified. Table I shows the number of studies in each category.

Our procedure was to check all studies against bibliographies for earlier research reviews and to cross-check Research Reports obtained through ERIC with Dissertation Abstracts to eliminate duplicate studies. New studies identified were added to the bibliography. References are presented in four groupings: (1) Reports Abstracted, (2) Unpublished Reports, (3) References Cited, and (4) Additional References. All studies were alphabetized and final bibliographies were prepared with a total of 440 entries. Although we undoubtedly missed some reported research, this bibliography should contain most science education research studies reported in 1972.

Earlier reviews of research used a variety of category systems for grouping research reports. One approach has been to group studies according to the type of curriculum involved; e.g., BSCS, PSSC, CHEMS, etc. However, only about one-tenth of the 1972 studies specifically indicate consideration of one of the national curriculum projects and many of these studies were not an appraisal of the curriculum *per se*. Several Nuffield project reports are grouped together, since these may be less familiar to American students and the Nuffield Foundation in England is continuing to support new

TABLE I

Categories Used in this Review and Number of Studies Abstracted in Each Category

| | Category | Number of Studies Abstracted |
|---|---|---|
| 1. | Learning Theory | 5 |
| 2. | Student Achievement | 21 |
| 3. | Instruction | 36 |
| 4. | Studies Related to Piaget's Work | 24 |
| 5. | Evaluation and Testing | 10 |
| 6. | Curriculum Studies | 15 |
| 7. | Computer Assisted Instruction | 5 |
| 8. | Attitudes Toward Science and Science Values | 13 |
| 9. | Bloom's Taxonomy | 2 |
| 10. | Interaction Analysis | 10 |
| 11. | Inquiry, Discovery Learning and Problem Solving | 13 |
| 12. | The Teacher | 25 |
| 13. | Enrollment | 3 |
| 14. | Environmental Education | 3 |
| 15. | Science Consultants | 2 |
| 16. | Research Methodology | 3 |
| 17. | History and Philosophy | 6 |
| 18. | Foreign Studies | 9 |
| 19. | Unpublished Studies | 26 |
| | Total | 231 |

instructional materials development and evaluation. Most studies dealing with National Science Foundation supported curriculum projects will be found either in our Instruction or Evaluation categories.

In spite of the repeated assertion that survey type studies have limited value and are of dubious value as doctoral research projects, and other types of research have been recommended [Atkin (234), Cooley (240), Hurd (249), Novak (255), Watson (262)], many surveys were reported in 1972 as doctoral studies. As with most surveys, these studies typically were limited in that they dealt with a population or with issues that were highly local in character, had limited response percentages with no attempt to obtain information from non-responding individuals, used questions with ambiguous interpretations and/or dealt with issues that have expired. For these and other reasons, none of the survey-type studies were included in our review, although titles appear in the bibliography. As in past years, survey research in 1972 has again found that students prefer warm, sensitive teachers, more and better in-service education is needed, science facilities are below desired levels, disadvantaged students suffer in school achievement and science instruction in general could be better. In fairness we should point out that a few survey studies were strikingly well-done, but even in these the findings generally represent local interests or situations identified by earlier surveys of a similar nature. Since the subject of the survey study is usually explicit in the title of the study, citation in our bibliography should provide access to survey information that may be needed.

Of the non-survey studies, many were not reviewed for one or more of the following reasons: poor experimental design and/or statistical treatment; data had limited bearing on hypotheses tested; sample size was too small for issues being studied; evaluation instruments lacked validity and/or reliability; issue studied was of strictly local interest or peculiar to a specific local setting; conclusions did not follow from data reported; or insufficient information was available for review.

In reading the numerous abstracts and reports, a pattern appeared to emerge that suggested a trend in science education we view with optimism. Many researchers were trying to base their work on some theoretical or methodological framework. The work of Flanders (245) and others continues to provide an approach for analyzing verbal interaction, but even more encouraging, in our view, was the frequent leaning on clinical interview methods and strategies of Jean Piaget. By a wide margin, Piaget's works provided the major intellectual props for more studies than the work of any other theoretically oriented scholar. A few studies related to the theoretical framework of Robert Gagné and David Ausubel. This reviewer is strongly biased in favor of research that attempts to frame hypotheses and research issues associated with an explicitly stated theoretical

position. In our view, intellectual advance in the sciences has been most rapid when research proceeded on the basis of some kind of paradigm (to use Kuhn's term) even though these paradigms may be altered or discarded by succeeding generations. In his book, The Structure of Scientific Revolutions, Kuhn (252) describes paradigms as the conceptual frameworks that guide the research methodologies and interpretations of research results in science. He indicates that paradigms are conceptual inventions, for example, evolution or Newtonian mechanics, which can be modified over time, but also may be discarded and displaced by new paradigms (e.g., Einsteinian relativity), thus effecting a "scientific revolution." This review, therefore, presents studies and attempts to relate each to some theoretical framework wherever possible; this is done even when the research did not attempt such an association. We have indicated elsewhere [Novak, et al. (256)] that this approach to organized research reports has hazards, but without such risks we do not hold optimism for the usefulness of research reviews as a positive influence on the quality of future research.

## LEARNING THEORY

In sharp contrast to reported research in psychology and related fields, less than a dozen studies reported research in 1972 directly related to learning theory. In most of these studies, the theoretical work of David Ausubel (235) was used.

Although it is beyond the scope of this paper to describe Ausubel's theory in detail, some basic elements are necessary for the reader to understand salient issues described in this review. Ausubel's paradigm could be briefly stated as he presents it in the introduction to his 1968 book (p. vi):

> The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly.

Simple as his statement may appear, some profound issues are hidden in it. To ascertain what a learner already knows is no easy task, at least not if one seeks to learn what relevant concepts a learner has to which new information can be related, as required for meaningful learning. In rote learning, new information is arbitrarily incorporated in cognitive structure without specific association with previous learning. Unfortunately, too much science instruction has been of this type. In meaningful learning, new knowledge is learned by association with prior relevant concepts in cognitive structure. In other words, to facilitate new, meaningful learning, we need to plan instruction in such a way as to increase the probability that learners will have or develop those concepts needed to assimilate the information to be presented, thus expanding or differentiating these concepts further. Moreover, larger, more inclusive general concepts should provide the basis for meaningful learning of a wider array of knowledge, since more diverse bits of information can be associated with a broad concept (e.g., conservation) than with a narrow concept (e.g., torque).

To enhance meaningful learning in subject matter areas where the learners have limited or no relevant concepts from prior learning, Ausubel has proposed the use of advance organizers. Advance organizers are more general, more abstract statements that precede a a segment of learning and thus provide some cognitive "anchorage" for the new learning. Ausubel suggests that advance organizers may serve as a kind of "cognitive bridge" to assist the learner in meaningful learning. The idea of a cognitive bridge implies, however, that some relevant knowledge or concept must already exist in the learner's cognitive structure. In this case, advance organizers could be expected to facilitate meaningful learning only to the extent that some related concept (perhaps only weakly developed)

already exists in the learner's cognitive structure, and effectiveness also would be dependent on the organization used to present new knowledge. Ausubel's advance organizer concept is, in this reviewer's judgment, the weakest element in this theory, but most research reported in science and other fields has jumped on this notion. To design a research study presenting the same materials with or without advance organizers is an obvious problem derived from Ausubel's theory, but it ignores the most fundamental tenet of Ausubel's theory. To "ascertain what a learner knows" and to "teach him accordingly" means that we cannot arbitrarily prepare an advance organizer or "cognitive bridge" without careful attention to salient aspects of our learner's existing cognitive structure.

Graber et al., (66) found no effect of advance organizers when provided either prior to or after instruction with chemistry students. They used the same "organizers" as originally developed by Ausubel with only minor wording changes to fit their setting. If any assessment for the chemistry students' existing cognitive structure was attempted, no mention of this is made in their report. Hence, we might assume that the so-called advance organizer was not a cognitive bridge and predict the results obtained. Lucas (113) used three types of advance organizers with seventh-grade biology students. Again, no mention is made of attempts to assess the students' existing cognitive structure and we can assume none were made. The results--no significant differences between audio, visual, and written advance organizer groups or between these and a control (no organizer) group.

Talisayon (188) studied achievement of physics students on programmed units dealing with concepts of work and energy. In contrast to the studies of Graber et al.(66) and Lucas (113), careful analysis of the learner's existing relevant cognitive structure preceded design and use of the instructional material. Talisayon found that relevant cognitive content in the learner's cognitive structure facilitated the new learning in an increasing, non-linear manner, the facilitating effect being greater in the presence of more antecedent concepts. She also found that students who began instruction with some initial concepts not only learned more but also retained information longer as shown in posttests given three to four months after instruction.

We will see in research reported in other sections of this review how the results obtained support the basic learning paradigm of Ausubel even though the studies were not designed explicitly to test for facilitating effects of relevant concepts in learner's cognitive structure or for the influence of cognitive bridging (as might be obtained through careful specification of learning objectives) and appropriate sequencing of hierarchically-organized subject matter.

Although not specifically designed to test aspects of learning theory, Billeh and Pella (17) studied pupil-achievement in knowledge, correlation and theoretical categories. One would expect that with similar instruction, as was given, grade six pupils would achieve more than grade three, four, or five pupils, since older pupils generally have more relevant concepts to facilitate new learning. Moreover, ability (as indicated by GPA) should influence achievement both as a function of accelerated learning during instruction and as an influence on past learning in providing relevant anchorage concepts. Billeh and Pella obtained F values in their analysis of variance of 3.32 to 17.45 for grade effect on achievement and F values of 35.04 to 43.22 for ability variance components. This study does suggest that over the long term, nature is more influential than nurture in science achievement under present instructional regimes.

In another theoretically oriented study by Muller (129), third-grade children were instructed with SCIS materials and their success in solving problems dealing with the concept of interaction in physical systems was assessed. He found properties of the context of the learning more related to conceptualization than the child's intellectual ability. Muller's study appears, then, to contradict the findings of Billeh and Pella. However, Muller was concerned with achievement of specific problem solving tasks presented in a specific sequence of experiences, whereas Billeh and Pella tested for students' concept achievement without reference to instructional experience. In a study with eighth, ninth and tenth-grade students, we have found that initial concept learning is primarily dependent on "ability" whereas subsequent achievement in sequenced learning is primarily dependent on success on early tasks [Gubrud and Novak (248)]. According to Ausubel's theory, we would expect general ability (the extent of overall cognitive structure differentiation) to contribute most in the initial stages of learning new materials, but subsequent instruction on related materials would be primarily a function of the degree of mastery of earlier specifically relevant concepts. The studies cited above all support this contention.

## STUDENT ACHIEVEMENT

In this group we have placed studies in which the focus was on pupil achievement, either as a result of some "experimental" treatment or to examine correlations between achievement in science and other parameters. Although more than 20 studies fell into this category, none of the studies were designed or interpreted in terms of learning theory. It might be concluded that theories of learning have no relevance to studies of achievement in science; alternatively, one may conclude we have a long way to go before research on science achievement will be based upon and contribute to theories of learning. Personality and sociological variables were considered in some studies, but again, in these areas no reference to theoretical views was made.

Among the most common studies reported in the 1920's and 1930's were studies of pupil achievement under alternative instructional regimes. Most of these early studies, as well as most studies cited in this review, concluded that no significant differences in achievement were found. We now have more sophisticated statistical tools, more resources for support of research and many more studies completed each year, but no significant progress has been made in fifty years of science education research in this category. Hence, once again we appeal to our colleagues to examine the potential value of learning theory in the design of future studies of achievement.

A common type of achievement study has been to relate college achievement in science to high school performance. We have summarized the results of this kind of study elsewhere (256). Bajah (6) found that students' percentile rank in high school had the highest correlation with achievement in college freshman chemistry. High school grade in mathematics had a slightly higher correlation with achievement in freshman chemistry than did high school chemistry grade. One might conclude that the abilities indicated by high school math grade (for the students in this study) were more important to achievement than the concepts of chemistry that were learned. However, several sources of misinterpretation exist: (1) the high school chemistry course may have focused on rote learning of information and thus provided few concepts to facilitate achievement in college chemistry, (2) low correlation between high school chemistry grade and college freshman chemistry achievement would occur if high school chemistry grades were all comparatively high (as is common for college-bound students) whereas college chemistry grades were variable, and (3) instructional objectives and evaluation approaches differed markedly between high school chemistry and college chemistry. According to Ausubel's theory we need information on the adequacy of <u>specific</u> concepts relevant to the college chemistry

course in order to predict achievement or learning efficiency. This information was not obtained by Bajah and most investigators working in this area.

McCall (123) studied achievement of freshman biology students and found several factors significantly related to achievement: number of science courses completed in high school, high school grades, completion of high school biology, students' interest in taking college biology, and science ability (ACT science scores).

Williams (203) studied achievement in college biology and found some obvious results; e.g., students in the upper half on ACT performed better than students in the lower half; and some less obvious results; e.g., students who viewed college general biology as "process" oriented achieved significantly better than those who viewed the course as "content" oriented. We might surmise that the latter students were more inclined toward rote learning schemes, which should have resulted in progressively less adequate performance, whereas the "process" oriented students should also show greater retention and better transfer to novel learning tasks, according to Ausubel's theory, but these questions were not studied.

Studies by Economos (59), DeKock (50), and Lescarbeau (109) examined student achievement in the physical sciences. Economos found no significant relationships in time spent in teaching an IPS unit and achievement, but did find that classes with the highest past science achievement required significantly less teaching time. In a laboratory-oriented, individualized high school physics course, DeKock (50) found I.Q. correlated with performance. Lescarbeau (109) tested five fine motor manipulative abilities and found no predictive value for achievement in an IPS course. What can one conclude from these studies? There is evidence that indicators of specific relevant cognitive structure better predict the rate and amount of learning than do general ability indicators or non-cognitive variables.

The use of behavioral objectives to orient students toward learning tasks and to guide evaluation has received increasing recognition since Mager's (254) book in 1962. Studies by Olsen (139) and Payne (141) compared achievement under instructional treatments with and without the use of behavioral objectives. Olsen (139) found significant differences in favor of classes studying physical science (IME) with behavioral objectives provided in advance; whereas Payne (141) found no significant differences between chemistry classes, although mean scores increase somewhat more for classes using behavioral objectives as instruction proceeded. On theoretical grounds, we would expect well-written behavioral objectives to serve as advance organizers and to facilitate growth of concepts. Payne's "control" classes also were provided instructional objectives, but these were not behaviorally stated. As indicated earlier, the crucial factor in facilitating meaningful learning is the extent to which cognitive bridging is provided. Well-written non-behavioral

objectives might sevve as advance organizers as well as good behaviorally stated objectives. The crucial issue in studies of the use of explicit instructional objectives is whether meaningful learning, rather than rote learning, is enhanced and the crucial test requires evaluation with transfer to new areas of study and long-term retention measurement.

Connor (45) used instructional modules for some eighth-grade classes and "usual" science teaching methods for other classes. Both groups were provided with the same behavioral objectives, laboratory instruction and audio-visual aids. Connor found no differences between modular and regular classes on achievement or attitudes, nor on cognitive retention tests. The study results follow theoretical expectations, assuming instruction was paced slow enough to allow most students in regular classes to achieve instructional objectives.

Smith (173) studied fourth, fifth and sixth-grade achievement in science and compared gains on the Educational Development Series test for science. Using data from 2,000 students in sixteen different schools, and sixty-eight different teachers, Smith found students using traditional textbook programs made greater gains than students in "modern" elementary science curricula. Students in SAPA classes achieved significantly higher if their teachers had fewer than ten hours of science training, whereas other classes did better when their teachers had ten or more semester hours of science teacher training. The results suggest a possible relationship between instructional objectives and achievement.

Smythe (175) compared achievement in BSCS biology for classes in 55, 70 or 145 minute periods. He found no significant difference between the 55 minute and 70 minute class means. He concluded that the teacher's difficulty in adjusting to a period just 15 minutes longer may have been responsible. On theoretical grounds, the length of study periods should be important only to the extent that efficient learning can be sustained, assuming instruction is of equal effectiveness.

Bethune (16) studied ninth-grade science achievement of 198 students and compared achievement of various reading ability groups. He found science scores increased with reading ability. Comparing achievement of students tested on a revised test form with an easier reading index, Bethune found no differences. Kindler (97) compared achievement of ninth-grade students on two passages of a science textbook, with one group receiving the expository textbook passages and another receiving "narrative" passages of the same length prepared by the investigator. He found a significant difference (.05 level) in favor of students using the "narrative" material. Nevarez (133) used three approaches to teach elementary science (COPES) to Spanish-speaking fourth grade students. Comparing groups taught by (1) English only, (2) Spanish only, (3) Spanish and English, he found students in group (3) achieved more (.05 level) than students

in groups (1) or (2). Kraemer (99) compared achievement gains of Oklahoma City high school students bused into "cluster" schools with gains of students not bused into their schools. She found significant differences in favor of students bused into "cluster" schools. Riley and Westmeyer (157) compared gains in reading scores for one class taught ISCS science and another taught with traditional science materials. They found somewhat more gain in reading scores for the ISCS class than for the traditional science group (no statistical analysis reported). The above studies all suggest some connection between achievement and the degree to which instructional input is matched to student's existing cognitive structure, but the type of analyses done leaves such a conclusion in the realm of conjecture.

Humphrey (78) compared achievement of slow learning fifth-grade students who were taught lessons on electricity with (a) traditional methods or (b) physical activity methods. The latter method involved the children in physical activities, such as rolling a ball between legs of a row of students to simulate electric current, with the rules or procedures for the game serving to define the science concepts. After two weeks of instruction, Humphrey found a significant difference in favor of the physical activity group (mean of 69.9 on a 100 item objective test) over the traditional group (mean of 50.2). After a three-month interval during which no science was taught, the group differences had increased with means of 50.3 and 73.3 for the traditional and physical activity groups, respectively. Although only twenty students were involved in the study, the results lend support to the importance of motor activity to achievement by slow learners.

Creative thinking has been a subject of interest for decades. Eichenberger (61) developed a Judging Criteria Instrument (JCI) to assess the creativity of students through the products they create. He found the JCI to be reliable and to correlate significantly with scores on the Torrance Tests of Creative Thinking. Eichenberger concluded that student creativity can be validly assessed using the products the student creates.

An exception to the general lack of theory-based research in science education is the scholarly effort of Professor O. Roger Anderson and his students of Teachers College. Professor Anderson has developed a theoretical framework for analyzing the structure in teaching. His two recent books, Structure in Teaching: Theory and Analysis (232) and Quantitative Analysis of Structure in Teaching (233) present both the theory and empirical evidence indicating the importance of organized structure in teaching for transmitting knowledge. "Kinetic structure" in teaching derives from the organization inherent in the instruction either (1) by spatial ordering with contiguous elements discussed successively, (2) by chronological ordering achieved by sequential presentation of elements identical to the order of their occurrence in time or (3) by an instructional series that has common symbolic elements in contiguous units.

Browne (34) studied pupil achievement in biology as a function of "kinetic structure" in lessons and found that student achievement was directly related to the degree of structure in lessons on the life cycle of Rhizopus bread mold. Browne found that ninth-grade students in the three groups (high, intermediate, and low kinetic structure) did not recognize the difference between high and low kinetic structure even when two samples were provided to them. However, after rudimentary training, students could discriminate kinetic structure levels. Trindade (195) in a related study with eighth-grade students also found significant differences in achievement on three units of instruction favoring the group instructed with materials with high kinetic structure. Sharp (167) studied the degree of kinetic structure in college physics lectures. He found significant differences in the degree of structure between professors lecturing on the same topic, but not for the same professor presenting different topics. However, he did not study comparative student achievement under alternate instructors. These studies support Anderson's theory that indicates reception of information will be a function of the degree of serial order in material presented. The results support Ausubel's model of progressive differentiation of concepts in cognitive structure as a primary mechanism for facilitating new learning.

Anderson's theory is based on his broad perspective of organismal data processing resulting in part from basic research he has conducted with protozoans and in the field of cell ultrastructure. Although his theoretical framework applies only to a limited sphere of instruction, we applaud his efforts to tie science education research to general theoretical issues in organismal data processing and information transfer.

We conclude this section with the observation that research on student achievement in general has not progressed much in the past half century, but some hopeful, theory-based research is appearing. There is reason to believe that a review of research considering this issue ten years from now can spell out some specific parameters involved in student achievement in science and specific educational practices to optimize achievement.

## INSTRUCTION

Another "classic" research area has been the study of instructional methods. A common type of study during the 1920's and 1930's was to compare achievement of students with or without laboratory or demonstration instruction. Some early research in science education also explored the value of forms of individualized instruction, but we found this to be one of the most popular research topics reported in 1972. Individualized instruction received a strong impetus with Bloom's (237) paper in 1968 in which he urged that instruction be designed to allow most students to master an explicitly defined set of materials by allowing students varying amounts of time to achieve mastery. Together with the rapid increase in the use of behavioral objectives, the "mastery learning" concept has had increasing influence on educational innovation. [For discussion of mastery learning see Block (236).] It is appropriate that this should be reflected in current research studies.

### Individualized Instruction

Individualized study has a range of meanings. The ideal form would be to have a Socrates caliber teacher tutoring a student, planning each new lesson segment with wisdom and sensitivity. Usually, individualized instruction is much less than this; sometimes only the pace at which the student can progress is "individualized" or perhaps some alternate routes to common learning objectives are provided. Technological aids may include complex computer facilities with visual displays or simply prints or slides to aid in presenting information.

Various forms of student-paced instruction have appeared under the label of Audio-tutorial (A-T) instruction [see Postlethwait, et al. (258)] wherein audio-tape is used to guide students in study of materials together with printed study guides and other audio-visual aids. The use of audio-tape can allow simultaneous study of science materials or illustrations together with didactic input in the voice of the teacher. Since the tape can be stopped, reversed and segments repeated, some measure of student pacing is provided. Moreover, unlike the traditional lecture or laboratory exercise, students can usually choose their favored times for study and alternative programs for various students or groups of students is possible. Usually a staff tutor is available for counsel whenever students need personal assistance. Unfortunately, a poor audio-presented lesson is much more deadly than a poor lecture, and trivial subject matter is not enhanced through audio-tutorial presentation.

A common question raised regarding A-T instruction is the value of audio guidance over printed material, especially with high school or college students. Simons (171) used students in a college biology A-T course, with sample groups receiving audio or written scripts to

guide their study. One group received audio first and then written scripts, and another group received the reverse treatment. Students in the two groups were switched on a second unit of instruction. He found a significant difference in favor of the "script" group for the "developmental" unit. Both groups needed significantly less time to complete units using script guidance, and each group preferred the method of instruction they had for the first part of the study. This study provides some evidence that, at least for some subject matter areas, college students (Syracuse University) do better with printed study guides than with audio guidance and also complete study units more rapidly. This study suggests what we recommend--use audio-tape guidance in instruction only when there are some particular advantages to audio over printed material. In a related study with engineering students, Harris (72) found no difference in achievement for students in an A-T course who received printed lecture transcripts and a group that received audio-taped lectures. Johnson (83) found no significant differences between students using (a) an "audio-mechanical mode of study," (b) a "literary mode" using a self-contained booklet and diagrams, and (c) a conventional laboratory approach. However, the physics students used significantly less time with methods (a) and (b) than with (c). Anderson and Artman (4) found that nearly all students using cassette tape recorders for problem solving in physics reached mastery (75% correct) and showed a positive attitude toward the instruction.

Wheatley (201) studied cognitive and affective changes in college biology students (Ohio State) under two regimes: (1) regular audio-tutorial program and (2) regular program plus additional activities designed to teach for "higher levels" in the cognitive and affective domains. On one posttest, he found significant differences for the latter group both on immediate and delayed posttests. Other cognitive and affective test means were not significantly different. In a study by Jenkins (81), one group of students received regular A-T instruction (at Purdue University) and another received the regular program plus participated in small (six students and leader) group discussions. Jenkins found mean scores for the latter group consistently higher, but no significant differences at the .05 level. We may conclude from these two studies that some "enrichment" of regular A-T instructions probably will increase cognitive gains.

Nussbaum (136) using audio-tutorial instruction with second grade students found improvement in the children's "notions" of the planet Earth over uninstructed children (who received only incidental instruction and no audio-tutorial program). The study also showed areas where the A-T instruction needed revision, and the results were consistent with Ausubel's theory of learning. An obvious advantage of A-T methods with young children is that their cognitive growth capacity is much greater than can be reached through printed materials, given their limited reading skills. A-T methods provide a useful research tool for study of cognitive learning in children since instruction is constant for all students and many extraneous

variables (e.g., reading skill) are circumvented. Netburn (131) used an audio-tutorial approach with fourth-grade children studying Conceptually Oriented Program in Elementary Science (COPES) materials. He found no significant differences in achievement for students taught with A-T methods as compared to a group taught conventionally, although the A-T group spent significantly less time in study.

In addition to audio-tutorial kinds of instructional approaches, a variety of other forms of individualized instruction have been attempted. An increasingly popular approach to individualized instruction at the college level is the so-called Keller Plan. This system includes careful preparation of learning objectives, unit exams as pretests and posttests and student-paced, individualized instruction. Audio-visual support is usually limited, but carefully prepared study guides are used. Philippas and Sommerfeldt (145) compared student performance in physics under conventional and Keller Plan approaches. They found no differences in achievement on common course exams, but almost twice as many students withdrew from the course under Keller Plan as with conventional instruction. However, ninety percent of the students in the Keller Plan preferred this method over conventional instruction. Braly (28) compared achievement of four classes studying CHEMS material, one group receiving lecture-laboratory instruction essentially as outlined in the teacher's manual and the other using independent study with the teacher serving as a tutor. He found no significant differences in achievement between the groups. Blackwell (19) compared attitude changes of students taught drug abuse concepts by (a) self-directed, multi-media learning activities or (b) conventional lecture-discussion. A significant difference in favorable attitude change occurred for group (a) but not for group (b). Bolin (24) developed an auto-instructional approach for teaching Harvard Project Physics and found that class averages "slightly" exceeded national norms on posttests, though they were "slightly" lower on pretests. Ketchum (94) used an "individual progress approach" in which students had access to laboratory materials and worked at their own pace, and conventional instruction with a second group of ninth-grade students studying Introductory Physical Science. He found no significant differences in cognitive achievement between the two groups, although a locally constructed Student Attitude Survey showed positive gains for the "individual progress" group. Dawson (48) found that students who had three years of individualized junior high school science (ISCS) favored this method over group-centered classroom instruction.

Kuhn (101) used an open laboratory arrangement whereby students could study materials dealing with a survey of the plant kingdom at times of their choosing. He found, as would be expected, that achievement was a function of the length of study time. However, students rated as "high analytic" achieved greater mean scores in 140 minutes of study time than did "low analytic" students in 240 minutes. Analysis of variance for achievement gave F values of $F = 8.59$ (1,97df) for study time and $F = 19.09$ (1,97df) for analytic ability.

These data also support Ausubel's theory in that they suggest well-organized cognitive structure (as indicated by high analytic ability) significantly influences the rate of acquisition of new information. Kuhn's study also showed that students in the high analytic group retained more information two, four and six weeks after learning, as would be predicted. Barry and Carter (11) found that college chemistry students using carrel "slide-audio" programs learned more with greater study time and that students with low ACT scores gained most from the program. This study suggests that when students lack relevant cognitive structure, they need flexibility in study time or they will be continuously at a disadvantage in learning in the subject area.

## Other Studies of Instruction

Shymansky (169) observed students under "student structured learning" and "teacher structured learning" and found significantly greater use of inquiry skills by children in the "student structured learning" classes. Strozak (187), however, found no differences in achievement or attitudes when college freshmen were taught under "directive" or "non-directive" methods.

Over the years, numerous studies have explored the value of visual aids or laboratory activity to cognitive and attitudinal development. In 1972, several reported studies continued this line of inquiry. Townsend (194) compared achievement in biology with and without the use of microscopes. Using 35mm slides, handout sheets with photographs and direct projection with a group of students, he found these techniques superior to "conventional procedures." McIntyre (125) used three types of visual devices with elementary school children to teach basic concepts of electrostatics and found no difference in achievement. Yolles (205) used various "multiple image" and "narrative" formats with fourth, fifth and sixth-grade children. He found a simultaneous pattern of three-screen presentation to be significantly better for grades four and six but no significant differences for grade five. Moore (127) used video tape to present two science lessons at four different paces. He found significant differences between the most rapid and slowest paced instruction, with the latter favored. Bland (20) compared three methods of instruction in teaching electricity concepts to eighth-grade students. Group (A) used an interactive mode verbally to reinforce lesson objectives, group (B) received a summary at the end of lessons to reinforce objectives and group (C) did not have lesson objectives reinforced. Bland found significant differences in achievement and retention favoring groups (A) and (B) over (C). Working with college chemistry students, Talley (189) compared achievement of students who used three-dimensional models of molecules with achievement of students taught by didactic methods. He found significant differences in favor of the former method on measures of analogy, knowledge, comprehension, and analysis and evaluation. Tauber (193) used (a) cassette tapes

and (b) limited comment, (c) written comment and (d) no comment as feedback on laboratory exercises with the high school students. In general, he found no significant differences, but a CHEM Study class achieved more with method (a) and a PSSC class achieved more with method (d). In a unit on genetics in high school biology, Johnson (82) compared instruction with (a) programmed materials, (b) BSCS materials and (c) traditional material. He found differences in favor of group (a) over group (b) and (c). All of these studies show results generally consistent with Ausubelian theory--enriching cognitive input, allowing for variation in learning rates and clear specification of learning objectives (cognitive bridging) should enhance cognitive learning. The studies may have had more power in elucidating relationships if they were designed to focus on these learning parameters.

Several other studies explored instructional issues. Knapp (98) compared achievement of high school chemistry students using Scientific American articles with or without annotation prepared by the investigator. He found no significant differences in achievement, although achievement in English was positively correlated with understanding of Scientific American articles for high-ability students (e.g., for those who probably had reasonable entry cognitive structure[1] for these assignments). Kampwirth (87) compared conventional and project laboratory methods of teaching biology and found no significant differences in achievement. Gunsch (68) compared a laboratory and a non-laboratory approach in general education physical science classes. Students in the laboratory course (PSNS) achieved significantly better than students taught in a traditional lecture-demonstration course. Ivany and Oguntonade (80) studied teacher's verbal explanations. They found that "constructs" and lecturing were the most frequently used tools and modes of explanation, with "universal laws," analogies, and historical accounts used infrequently. Kilburn (96), working with seventh-grade students, found no significant differences in student achievement when (a) guided discovery with maximum emphasis on individual laboratory experiments and field work instruction was compared with (b) guided discovery with demonstrations and films, etc. in lieu of field work or laboratory study. Shanlin (165) used "self-instruction booklets" in which (a) "picture-rule" booklets stated the principles involved and (b) "picture-only" booklets presented situations only. He found no significant differences in achievement, but a "plateau of achievement" with the test instrument may have been responsible for the null results. Shepley (168) compared achievement of students in

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[1]In accordance with Ausubel's theory, the extent of relevant concepts or knowledge a student has in an area of learning will facilitate new, related learning. We refer to this as relevant "entry cognitive structure" in our research work.

earth science who (a) undertook field studies of soil before laboratory work or (b) after laboratory work and found that group (a) achieved significantly better. Did the field study serve as an advance organizer? Richter (156) used two methods to teach a seven-week section on heat and sound to technical institute students. The Individual Progress Rate method allowed students to perform laboratory work in pairs and also receive tutorial aid; in the Even Front method, all students received lectures, demonstrations and the same laboratory instruction on the same time schedule. He found students in the Even Front method better achieved course objectives. Working with general college chemistry students, Hunter (79) used five methods of instruction wherein one group received lectures and the other groups received a "systems approach" which consisted of group orientation, individualized learning, small group seminars, and unit tests. As with other studies cited in this section, we see a general tendency for enhanced performance when learning objectives are clearly indicated and when learning materials are targeted at these objectives.

Along a somewhat different line of inquiry, Byrne (39) studied two issues with instruction in sixth-grade science. Classes were taught partly by regular teachers together and partly by student teachers (eighth graders) trained to instruct on the units of study. Some classes were taught with the "process or discovery" approaches and others were taught by "receptive" methods. She found students achieved equally well under both methods and no significant differences between student-taught and teacher-taught pupils.

Most studies of instruction focus on very broad questions. If we are to understand the learning process better, we must begin to focus our research on specific instructional issues. But there are hundreds of discrete issues involved in instruction, how do we select issues and design our studies? Here is where working from a learning theoretical framework can be of value. We have found Ausubel's theory to be useful and our work has led to some modifications of his theory. For example, our studies and studies cited in this review, indicate that "advance organizers" such as objectives provided prior to instruction will facilitate learning only to the extent that "cognitive bridging" is provided, thus assisting the learner to identify relevant concepts in his cognitive structure which can facilitate learning or guiding him in the development of new concepts that have power for associating new information as it is received in ordered succession. We repeat the plea of Hurd (249):

> A much neglected factor in science education research is a theory base.** Because we tend to operate on an atheoretical basis every research effort is a separate problem, instructional fads go unchallenged, and education buffs who criticize our efforts cannot be answered. Within the profession there is a minimum of dialogue and when it exists the deliberations are on means or

operations and not on purposes. We talk about what we do and not what we ought to do. We get caught up in the "here and now" and seldom consider the "there and then," or the "where and why." Our lack of education theory keeps us from ever seeing the "whole" of our enterprise. We have no way to relate the accumulated insights and experiences of the classroom teacher with the results of our research. Without an underpinning of theory, research findings are dissipated in a fog of contradictions, are labeled impractical, and have small impact on educational decision making.

**"A theory covers and formulates the regularities among the things and events it subsumes." Joseph J. Schwab, School Review, 78, (November 1, 1969).

## STUDIES RELATED TO PIAGET'S WORK

The extensive work of Jean Piaget and co-workers in Geneva, Switzerland, has had increasing influence on science education in the past decade. This is clearly evident in studies reported in 1972, with more than 24 studies directly related to Piaget's work in child developmental psychology. Piaget has been active in this field for more than five decades, but much of his early work was not published in English and his influence on educational thought has grown substantially over the past decade.

Although Piaget's work has been extensive, his studies have been restricted to a comparatively narrow segment of human learning and he has not formulated a general learning theory. Nevertheless, the developmental stages that Piaget has described [cf. Flavell, (246)] for cognitive growth do provide an intellectual framework to which research and curriculum practices can be related. This reviewer strongly endorses this approach, for Piaget's developmental structures provide a useful paradigm for development of researchable hypotheses and for interpretation of data; it is a paradigm that can be used by various researchers and one that encourages cross-interpretation between research studies.

The 24 studies reviewed in this section can be grouped into four categories: (1) studies that replicate or extend the analysis of cognitive structures described by Piaget; (2) studies of the effect of instruction on cognitive development; (3) studies of cultural or hereditary influences on cognitive development; and (4) studies that correlate school achievement or other abilities with Piagetian stages of cognitive growth.

### Replication and Extension

The late Professor Robert Buell and his students at the University of Toledo had focused their research efforts almost exclusively on Piagetian learning tasks and implications for science education. A study by Lengel and Buell (107) published in 1972 showed an expected improvement in ability to predict the velocity of a pendulum bob from grades seven to nine to twelve, with only the latter group reaching 80% success in identifying the crucial factor in the velocity. Sex and I.Q. were not found to be significant independent variables in achievement on this Piagetian task. One might conclude from this study that grade eleven or twelve would be the best time to teach the law of the pendulum, as intimated by the authors. However, 10% of the seventh-grade students and 35% of the ninth-grade students correctly predicted the crucial variable of pendulum length. This study and others by Buell and his associates add evidence to a view of

cognitive development which suggests that the extent of an individual's cognitive development in a specific relevant area is the primary determinant of performance, not general abilities or non-cognitive aptitudes. Science education research lost a good worker with the death of Professor Buell.

At State University of New York - Buffalo, Professor Ronald Raven focused his attention on Piagetian-studies with the result that he and his students are contributing to our understanding of cognitive development in selected areas. Two papers by Raven (151), (152), and one by Popp and Raven (146) were published in 1972. In these studies, careful analysis of children's cognitive growth in concepts of classification and acceleration showed patterns generally in agreement with findings of Piaget. Implications for grade placement of science lessons involving the concepts are suggested. Although the studies of Buell, Raven and their associates focus on basic Piagetian issues, both groups have looked to application of their findings to science curriculum development.

Ward (197) studied children's understanding of a particulate model of matter and found that children under age ten could not interpret demonstrations given in a way that would indicate an understanding of a particulate model, and that eleven and twelve year old children were at an "interstage" which suggested that not until Piagetian formal operations stage can children explain demonstrations of particle mixing, gas diffusion, etc. Ethnic background, sex and type of school community were not found to be significant variables in students' performances. Stone (185) used three approaches to assessing five to twelve year old children's concepts of conservation of weight. She found no sex differences but did find that a test approach using visual cueing resulted in significantly higher performance than a test using a kinesthetic modality. Lewis (111) studied age, sex and school size as variables influencing formal operational thought. He found age (as one would expect) to be the most important variable, sex significant and second, and school size least important in students' performances. Weybright (200) used a classification system based on behavioral components for Piagetian "equal arm balance" task and "clear and colored chemicals" task. It was found that subjects displayed a wider variety of behaviors than reported by Inhelder and Piaget and that the behavioral components filled in significant gaps in description of transition from concrete to formal operations stages.

## Studies of the Effect of Instruction on Cognitive Growth

The above studies in general show correspondence between the cognitive development for American children and that reported by Piaget for Swiss children. An issue which Piaget calls the "American question" is whether or not children can be accelerated in the cognitive growth by appropriate instruction. Eight studies were reported

in 1972 that considered the influence of instruction on students' cognitive development in terms of Piagetian categories.

Studies by Schafer (161), Bass and Montague (12), Breidenbaugh (29), Dial (53), Espejo (62), Hilliard (76), Hale (71), and Reeves (154) show a general pattern: instruction in specific science areas does lead to students performing at a higher level of Piagetian stage when assessment is specific to the area of instruction, but transfer to new tasks or general Piagetian tasks does not appear to be significantly enhanced. It might be concluded that the time scale for general cognitive development in children cannot be altered, as suggested by Piaget, but this does not preclude the value of instruction in specific concept areas. An Ausubelian interpretation of the results is that instruction in specific science areas can lead to concept development in these areas, but well-differentiated, functional concepts across broad areas of science require extensive concept learning and hence years rather than weeks or months of learning time.

## Cultural or Hereditary Influences on Cognitive Development

Three studies appeared in 1972 in which cultural or hereditary factors were related to achievement along Piagetian dimensions. Sharp (166) found that conservation tasks were not functional for identifying retarded children. Boland (23) found that chronological age was the best predictor for conservation of continuous quantity tasks and the mental age best predicted success in conservation of a substance. Davis (47) found no significant relationships between Afro-American and Anglo-American children on four "time conservation" tests. These studies in general confirm the hypothesis that cognitive development tends to follow Piagetian stages across broad differences in heredity or culture.

## Correlation of School Achievement or Other Abilities with Piagetian Stages

A group of studies was identified in which comparisons were made between school achievement or other measures and Piagetian level of cognitive development. Hathaway (75) found a moderate positive relationship between twenty-one traditional psychometric (e.g., I.Q.) variables and ten Piagetian tasks. Ball and Sayre (9) found a significant relationship between achievement in science of eighth, ninth, tenth and eleventh-grade students and their performance on a Piagetian Task Instrument (a test devised by the authors). The correlation coefficient between PTI scores and I.Q. was .28 for junior high school students and .51 for high school science students. Sliker (172) used a Piagetian test and Torrance Tests of Creativity Thinking with adults and found significant positive correlation in the range $r = .21$ to $r = .78$. Rubley (159) used Rokeach's Dogmatism Scale and interviews with Piagetian formal operations type tasks with eleventh and twelfth-

grade students. She found a significant difference (.05 level) between low dogmatics and high dogmatics on the flexible rods task, but not on the three other tasks. It might be interesting to speculate on the meaning of the above correlations; no obvious conclusions are apparent to us.

Buell and Bradley (36) found that chemistry students who might be expected to be at the formal operations stage did not perform separation of variables or express relations between variables after instruction in chemical solubility. Lang (103), using physics examination results for eleventh-grade students in Australia, found that on items dealing with volume, mass, weight, levers and proportion, speed and velocity, acceleration and relative speed, many students did not appear to succeed at Piaget's formal operations level even though they were above average students. While the results are difficult to explain with a Piagetian paradigm, they are easily explained with an Ausubelian paradigm--the students had not acquired sufficient elemental concepts in chemistry or physics to solve new problems at higher levels of abstraction. In short their specific relevant cognitive structure was not adequately developed, whatever their general stage of cognitive maturity may have been.

The value of Piaget's classification scheme for cognitive development is evident in the studies reported in this section. With common threads in research methodology and interpretations, it is possible to group studies and to pool evidence. While we do not regard a Piagetian framework as the most powerful intellectual model available, it is evident in the quantity and quality of studies reported herein that the work of Piaget is contributing importantly to science education.

## EVALUATION AND TESTING

Problems of assessing pupil and teacher characteristics and aptitudes continue to be important in science education. Many of the studies reported in other sections have included substantial efforts to solve evaluation problems as well as to research educational issues. The studies reported here have as a principal thrust the study of evaluation issues.

There are relatively few standardized tests that can be used for research in science. Most tests employed are "teacher-made" for use in specific courses and inappropriate for measuring achievement in courses taught by other teachers. The result is that generalizing from the findings of several studies is usually not possible since each study used different tests as criteria of achievement. Some efforts to develop and standardize tests of general aptitudes or abilities have been attempted, but these have not been unqualified successes. A widely used test in science research (and other fields of education) is the Watson-Glaser Critical Thinking Appraisal (WGCTA), designed to measure a kind of general problem solving or "critical thinking" ability. Ennis (244) in 1958 raised serious issues as to the validity of this test, but its use has continued. Lucas (112) found in his study (1972) that taking the WGCTA as a pretest "inflated" posttest scores substantially more between grade eleven and twelve than the apparent "real" gains. He found Australian students who took both pretests and posttests had a mean score of 71 and those who took only posttests averaged 65. Using a 135 item Welch Science Process Inventory (WSPI) with Israeli students, Tamir (190) studied gains in students' understanding of science processes as a function of their experience with new curricula, BSCS, PSSC and CHEM Study. He found that only the biology program showed a significant gain in students' scores on the WSPI, although mean scores increased at each grade level from 94 at the end of grade nine to 105 at the end of grade twelve. With such small gains over four years, one must conclude that the new curricula have little success in teaching the nature of science or that the WSPI is of questionable validity.

On the positive side Soh (176) used a modified form of the Reed Science Activity Inventory (RSAI) with English students and found factor loadings similar to those obtained by the test authors. Soh also found that correlations for subscales on the RSAI were consistent with "science career" ratings on another instrument, correlating positively with expressed interest in science and negatively with interest in a non-science career. Doran (57) devised a test for elementary school students' "misconceptions of science concepts." He found that mean scores on the 77 item test increased from 39.7 for grade two to 48.1 for grade six, with reliability of $r = .37$ to $r = .56$ for second and sixth grades, respectively. Correlations with reading ability, I.Q., sex and mathematical ability were

essentially zero, hence Doran's test was not just another indicator of general ability. Burns (37) developed a 48 item, five response, multiple-choice test "science process" test involving (1) formulating hypotheses, (2) defining operationally, (3) controlling variable, (4) interpreting data, and (5) experimenting. Testing 428 advanced undergraduate students majoring in elementary education, she obtained a Kuder-Richardson reliability coefficient of 0.81 and a score range from 0 to 46.

Donovan (56) used computer-generated repeatable tests with college chemistry students. One group received these tests throughout the semester and a second group took single unit exams for half of the semester and computer-generated repeatable tests for the second half of the semester. He found no difference in performance on a final course examination, although students preferred the repeatable testing format.

Haindl (70) studied science concept retention six months after completion of BSCS biology, CHEMS chemistry and PSSC physics. Retention was correlated with variables of I.Q., sex, Science Achievement scores, Natural Science Development, Reading Comprehension, Quantitative Thinking, Delay Avoidance, Work Methods, Teacher Approval, Educational Acceptance, Student Perception of Teacher Student Interaction (I/P) and Teacher Indirect to Direct Ratio (I/D). He found high correlation with the cognitive variables and low correlation with affective variables. Combinations of variables led to multiple correlation coefficients for concept retention scores of .72 for physics students, .87 for chemistry students, and .88 for biology students.

Baker and Talley (8) developed a test of students' "visualization abilities" to assess chemistry students' aptitude for some kinds of learning in chemistry; e.g., molecular models. They found a larger correlation between visualization ability and senior chemistry status than between general ability and status.

Stevens (183) used measures of various teacher effective characteristics (for 32 teachers) and pupil affective characteristics and achievement in the junior high program, Interaction of Matter and Energy. He found no significant correlations between pupil affective characteristics and achievement nor between teacher characteristics and pupil achievement.

Landauer (102), working with sixty third-grade boys studied their ability to solve classification problems (class inclusion questions) as a function of the tendency to "stop and think" or their "impulsivity." She found significant differences in solving class inclusion problems in favor of those boys who "stop and think."

We see in the above studies the manifest difficulty in measuring cognitive and affective traits and interpretating the meaning of

these measures for instructional practices. In this reviewer's view, the basic difficulty lies in a lack of learning theory foundation for much of instructional practice and for the design of evaluation instruments. It is difficult to be optimistic regarding progress in evaluation as long as we have little more than the "artificial taxonomies" of Bloom (238) and Krathwohl, et al. (251) to guide our work.

## CURRICULUM STUDIES

Over the years we have seen numerous studies in science education in which one program (or curriculum) was compared in effectiveness to another program. On the whole, these studies have provided little information that could be generalized, since tests or other evaluative criteria did not necessarily apply with equal validity to the programs being compared. In general, studies that compared the effectiveness of program A in contrast to program B gave little useful information. Although results from such studies have "political" value for those involved in decision making, they give little insight into relationships between instructional practices and expected learning outcomes.

One of the most carefully done curriculum evaluation studies of the past decade was reported in 1972 in two papers by Welch (198, 199). Supported by a grant from the National Science Foundation, Welch compared affective and cognitive achievement in twelve colleges where Physical Science for Non-science Students (PSNS) and conventional programs were offered. Welch succeeded in obtaining random assignment of students to either the PSNS course or the local variety of "conventional" physical science course. Over 1,000 students in the study were given pretests and posttests. Both groups made significant gains over the school year with PSNS students doing somewhat better on most affective posttests. Welch (199) concludes:

> Do the course [PSNS] developers have some glimmer of hope that their six years of effort have produced a new physical science course that is capable of achieving their objectives? The information gathered in this study cannot provide yes or no answers to these questions, but only contribute further to the storehouse of information available to each decision maker (p. 155).

Welch led the evaluation group for Harvard Projects Physics during the years that this program was under development. He and his colleagues conducted an extensive evaluation program for HPP, easily the most thorough and comprehensive of evaluation programs associated with federally supported U.S. curriculum projects. This leadership is evident in the large number of evaluative studies reported during 1968-71 related to HPP and summarized in earlier research reviews. A continuation of this work was reported by Aikenhead (1) who studied students' knowledge about science and scientists, comparing HPP and "control" groups. He found that students in the HPP program greatly exceeded their control counterparts in understanding (1) the tactics of science, (2) its values, (3) its institutional functions,

and (4) the interaction of science and society. Since these were learning objectives for the HPP program, Aikenhead's study provides a positive "summative" evaluation for HPP.

Drawing on the data pool from the HPP evaluation program, Ste-Marie (182) studied physics classroom social climates. He used data obtained with a Learning Environment Inventory, administered in 1967, and again in 1970 to samples of HPP teachers and non-HPP physics teachers. Ste-Marie found HPP classes shared more responsibility with the teachers' organization of class activities, worked more freely as individuals or in small groups and had greater access to learning materials. However, work pace and difficulty of the course were not different for the two sample groups. He concluded that the type and variety of materials in the HPP program were primarily responsible for differing classroom social climates rather than the teacher's understanding of course objectives and methods of implementation, for little teacher "growth" was observed over three years.

In a study by Reeder (153), the content involving scientists in forty-five textbooks of biology, chemistry and physics, including both "new" and "traditional" curricula was analyzed. Using word counts for sections dealing with scientists, Reeder found that the attention given to scientists increased during 1957-1970 with much more space given to scientists in the new curricula. Green-Version BSCS biology and PSSC physics had the lowest word counts for the new curricula. Most scientists mentioned worked in the period 1916-1950, and relatively few from the 1951-1970 period were cited.

In England, the Nuffield Foundation (a private foundation unlike NSF in this country, which is federally supported) has been the major source of funding for new curriculum programs during the 1960's. Curriculum materials for elementary, secondary and college students have been developed with Nuffield support. There has been a much greater interest in evaluation in Nuffield supported projects than in NSF supported projects. Among the most carefully done evaluation studies are those reported by Kelly (89, 90, 91, 92, 93). In a series of five papers, Kelly's reports on the Nuffield A-Level Biology program include (1) overall achievement of students, (2) evaluation of specific objectives, e.g., handling quantitative information, (3) student characteristics and achievement, (4) school characteristics and achievement and (5) post-trial student characteristics. Kelly's reports are comprehensive and cannot be reviewed in detail here. However, his general findings are consistent with the usual patterns, e.g., the new program was successful in achieving learning objectives, students with better backgrounds in science did better, class size did not influence achievement, and students saw objectives of the course varying in importance approximately in direct proportion to their achievement of these objectives.

Crossland (46) reported on a subjective evaluation of the Nuffield Foundation Primary Science Project. Schools were visited during 1966-1967 and classes were observed, conferences were held with headmasters and teachers, and problems were identified. Teachers not oriented to informal, activity-based instruction had more difficulty in teaching the program.

Nieft (134) used data from 900 ISCS students and 200 non-ISCS students on three scales--Student Inventory, Classroom Activity Checklist and Scientific Attitude Inventory. He found that ISCS classes had significant differences in "teacher's role," and student participation and laboratory activities, with differences favoring ISCS classes in flexibility. However, no differences between groups were found on the Student Inventory or the Scientific Attitude Inventory, even though ISCS course objectives stress more intimate teacher-student interaction and scientific attitude development.

Jungwirth (86) conducted a longitudinal study of Israeli students' development of understanding of science. Using the Test on Understanding Science (TOUS) developed at Harvard University, he found that student scores improved from grades nine to twelve, but some test items continued to be missed extensively. He attributes some of the poor performance to "semantic confusion," resulting partly from translation into Hebrew but also inherent in the type of questions included in TOUS.

Mueller (128) developed a set of procedures to guide local school systems in evaluation of new curriculum programs. Using Earth Science Curriculum Project installation in the Carmen School District (Flint, Michigan) as a model, he obtained data on affective and cognitive growth of students from fall to spring. Mueller found significant cognitive gains but a deterioration in attitudes toward science which appeared to be directly related to overemphasis of "textbook" teaching.

Using a more theoretical approach, Presseisen (147) analyzed the intellectual roots of the curriculum revolution of the 1960's from the viewpoint of structure as developed in Piaget's work. Structure as a problem of organization, the contributions of various psychological theorists and the uses of structure in curriculum theorizing were investigated. Implications for curriculum development stress the important role of structure in design of materials.

There is little one can conclude for the above curriculum studies except perhaps that student achievement of curriculum goals is a mixed bag. Even the best planned programs sometimes show modest results and some programs fail to achieve stated goals, especially in the affective area. We see the primary difficulty residing in our poor understanding of cognitive and affective learning processes with the result that most curriculum development and curriculum research continues to be based on the intuition or biases of writers, for better or worse.

## COMPUTER ASSISTED INSTRUCTION

The use of computers as a means to instruct students is now well into a second decade of experimentation. However, most schools have no computer facilities for instruction and most teachers at all education levels are not aware of the potential values of computer assisted instruction. In part, the general apathy toward computer assisted instruction (CAI) derives from experience with early computers that were severely limited in data storage and processing capability, difficult to program and awkward for student use. With new developments in computer technology, new programming techniques, and new terminal hardware that is easy for students to use, the continuing limited use of CAI must be explained in other ways.

Evidence to indicate that computers can be effective instructional devices has been established by numerous studies, including several reported in 1972. Boblick (22) devised a computer program to teach students to write chemical formulas. Comparing a CAI instructional group with a group taught by traditional lecture-discussion methods, he found that the CAI group achieved significantly more (92.1%) correct responses on posttests than the traditional group (86.2% correct) and the CAI group accomplished this in approximately half as much instructional time as the traditional group. In another study, Boblick (21) compared achievement of students on a unit dealing with conservation of momentum. High school physics students taught by CAI made significantly greater gains than students performing laboratory experiments and discussing results.

Lunetta (116) compared three groups studying PSSC physics where group I received film loops and computer interactive dialog, group II used film loops and simulated data and problem sheets and teacher discussion and group III used real laboratory materials and teacher discussion. The concepts of force and motion were the subject of study for all three groups. Lunetta found that group I achieved significantly higher scores than groups II or III; moreover, group III spent 3.2 times as long in study as group II and 8.2 times as long as group I. For the concepts studied, it was evident that students were learning significantly more through CAI and simulation methods than through direct instruction in significantly less time.

Jones (84) used computer simulated experiments in high school physics and chemistry. One group did a series of ten experiments by use of computer simulations and the other group carried out investigations with traditional laboratory equipment. No significant differences in achievement or in attitude toward the subject were found, although student attitudes toward the computer as a laboratory aid improved significantly in the group using the computer.

Denton (51) used a computer to produce individually prescribed instructional guides for high school physics students. Using the content from two chapters of PSSC physics, he compared achievement of a class using traditional group methods with that of classes receiving a computer individualized program. He found no significant achievement on posttests administered to the classes.

We see from the studies reported here that computers can be used effectively in science instruction. Carefully prepared CAI materials can generally be more effective for teaching knowledge and application of principles than conventional instruction. The problem is, however, that much preparation time and skill in program writing are needed. CAI can save time, especially for students, but school budget structures and assignment of teacher loads take no account of the time we save for our students and hence this significant positive aspect of CAI does not serve to promulgate use of computers in instruction. Perhaps as students gain more awareness of the potential of CAI and become aggressive in demanding more effective, less time-consuming instruction, the force needed to expand CAI to its present and future potential will exist.

## ATTITUDES TOWARD SCIENCE AND SCIENCE VALUES

Thirteen studies dealt with attitudes toward science and science values, for the most part focusing on student attitudes. The volume of work concerned with the affective (reviewed in this and other categories) reflects a continued interest in this area. Few studies have attempted to correlate affective with cognitive growth, and the conclusions of such studies have not always been in agreement. That mutually dependent relationships between the two areas exist is a focus for research deserving more critical attention.

The change in student attitude toward science as a function of the science program was the research outline for eight studies. Four of these focused on instructional method used as a variable influencing student attitude.

No statistically significant differences in attitude toward science were found between junior high school students taking an individualized science program (Intermediate Science Curriculum Study, ISCS) and non-ISCS students [Mann (119)]. The three specific attitudes assessed were: 1) interest in science, 2) the nature of scientific knowledge, and 3) the value of science. Larger numbers of ISCS students showed interest in the science activities, viewed scientific knowledge as temporary and changing, and viewed the intellectual value of science as being greater than the practical value of science.

Two studies focused on inquiry or process education. An inquiry approach to teaching a college chemistry laboratory program was shown to be neither more nor less effective than a structured approach in improving intellectual or emotional attitudes towards science, though the inquiry approach was more effective in the development of laboratory skills and gains in critical thinking skills [Allison (2)].

A report by Simmons and Esler (170) on the effect of a Process Approach science program on science attitudes of sixth graders, as opposed to a textbook oriented program, indicated a generally higher attitude toward science for students in the process program. Though no statistical analysis was performed on the data, a higher percentage of students in the Process program indicated a preference for their science class; they also reported comparatively more ease and sense of fun and accomplishment with regard to science activities. The authors contend that "answers to questions such as 'What is science?' or 'How do you like science?' may reveal more of greater and lasting importance to the future of the children than considerations of content alone." We have commented on this issue in the section Inquiry, Discovery Learning and Problem Solving.

Several studies were evaluations of student attitudes toward science as a function of a specific science program. Martin (121) found no significantly different change in scientific attitude among students using Blue, Green and Yellow versions of BSCS biology. The effectiveness of a course titled, "Man and His Environment," in changing attitudes of ninth graders toward science was analyzed by Starring (180). He found teacher effect to be more influential than various student characteristics in changing student attitudes toward science and scientists.

Downs (58) studied attitudes of students in grades nine to twelve. The instrument used to measure attitudes was designed using Thurston's technique and the first four categories of the affective domain from Krathwohl,et al. (251). Findings from the analysis included the following: the affective ratings of most science students changed in the unfavorable direction, though students enrolled in physics and chemistry (grades eleven and twelve) showed a more favorable affective response toward science than did the biology and Introductory Physical Science students (grades nine and ten, respectively). Males generally showed a more favorable affective set toward science than did females. It appears that the student's reasons for taking a science course would probably correlate highly with his affective response (i.e., was the course required?).

Correlations between cognitive knowledge and attitudes were analyzed in two studies. Sorenson and Voelker (177) investigated attitudes of secondary school students toward the U.S. space program in an attempt to determine the relationship of the direction and intensity of these attitudes to selected cognitive and personal characteristics variables. Attitude, defined by the authors as a "predisposition toward action in a given direction," was measured by three different types of instruments: the alternative response type (yes-no), a Likert-type agree-disagree scale, and a semantic differential. The authors concluded that the students' attitudes toward the U.S. space program are influenced by the knowledge they possess about the program as well as the educational background of their parents. In the areas related to social and product outcomes of the space program, attitudes were strongly positive and the greatest number of significantly greater than zero correlations were obtained between the expressed attitude and the amount of knowledge possessed about these areas. The authors recommend their research methodology as one from which reliable attitude data may be obtained.

Hartman (73) developed an instrument for measuring attitudes toward science of high school students based on the model of attitudes proposed by Martin Fishbein. The Fishbein model assumes that a person's attitude toward an object is determined by his beliefs about the object (the cognitive component) and his evaluation of these beliefs (the affective component). The psychometric properties of the instrument were determined acceptable at criterion levels based

primarily on guidelines currently available for achievement tests. The instrument was judged to be adequate on internal consistency (Hoyt r = 0.78) for the measurement of levels of group attitudes and adequate for measurement of differences or changes in group attitudes (r = 0.83). The instrument was judged reliable for measurement of level of individual attitudes for certain applications. The author's conclusion was that the Fishbein model of attitudes is applicable to the measurement of attitudes toward science held by high school students.

The remaining students in the attitudes category are concerned with diverse topics. Hackett (69) found a high correlation between teacher-observed and student-self-reported interests, appreciation, attitudes, and values for eighth-grade students. Two instruments were developed for the study: an "Observed Affective Behavior Checklist" (OABC) and "Affective Self-Report Instrument"--a Likert-type scale with the same behaviors as those on the OABC. Ramsaur (150) investigated the question of whether personality differences exist at a statistically significant level between persons who have made a vocational choice prior to college and those who made their decision after enrolling in college. The author also investigated possible differences in personality--as measured by the Edwards Personality Preference Schedule--of college senior science majors and non-science majors. The author was able to conclude that no personality differences as measured by the EPPS existed at the .05 level of confidence between seniors classified as having made an "early choice" and those seniors classified as having made a late choice. The study found statistically significant differences in personality between females who chose a science major and those who chose a non-science area.

Systematic analysis of non-verbal behaviors was the subject of a study by Eggen (60). The author developed an instrument based on video-tape analysis for the measurement of non-verbal behaviors exhibited by junior high school and high school students. A significant positive correlation was found between positive and negative behaviors of the students and their attitude toward their teacher and/or class. All kinetic variables (such as head shakes, frequency of yawns, frequency of hand raising) were significant at .05 level and most were significant well beyond .005 level of confidence.

The interaction between student personality and teacher behavior was investigated by Stellwagen (181). Special focus of the study was investigation of possible interaction between test anxiety and grading procedure. Subjects for the investigation were sixty college freshmen, prospective elementary school teachers, in a turn-taught science course using physical science for non-science students. The author found that the grading procedure by test anxiety interaction was significant when the criterion variables were the score on the standardized physics test and the subscores and the total score on the TOUS test.

Neumann (132) investigated the role of humor in the science classroom and found that the trend of test scores indicated that the non-humorous lessons was not significantly superior to the humorous lesson in its capacity to increase lesson content retention. The author also found some preference, mostly among female students, for classes where cartoon humor was included in instruction.

What can we conclude from the above studies on student attitudes? We lack a theoretical framework for the definition and elucidation of attitudes and attitude growth. Important as affective dimensions of school learning may be, we are not likely to make substantial progress in understanding attitude measurement and designing instructional practices for positive affective growth on the basis of research unless and until some better theoretical framework or paradigm is elucidated to guide our work. Krathwohl's, et al. (251) taxonomy not withstanding, we have a long way to go to surpass what insights warm, sensitive people have to offer at this time.

## BLOOM'S TAXONOMY

There were two studies based on the theoretical structure of Bloom's Taxonomy of Educational Objectives (238).

Scott (164) described a modification of the Taxonomy code system to take into account the variables of teaching techniques and student cognitive background. The non-programmed instructional material in Science--A Process Approach served as the basis of the Scott modification, which was to assign to an activity the code number for the lowest cognitive behavior required and to add next to this a coding for a possible higher level of behavior. Attention is called in this way to the fact that what may be a comprehension (2.20) or (2.10) activity for one student is an application (3.00) activity for another, depending upon the operative variables cited above.

Fast (63) compared analysis of the 12 ACS-NSTA High School Chemistry Achievement tests (1957-1971), the method of analysis being that of test item coding according to Bloom's Taxonomy. His findings included the following: the knowledge category contained 40.2 percent of all test items; comprehension, 25.6 percent; application, 24.8 percent, analysis and/or higher categories contained 9.3 percent; the six most recent tests contained a greater percentage of higher cognitive level items (13.7 percent analysis items). He found also that the difficulty of items increased with the hierarchy of the Taxonomy levels, verifying that there is some degree of validity of the Taxonomy. Application (3.00) level items were the most discriminating--they were most frequently omitted.

A unified learning theory should be able to explain how the variables cited as "problems" in the Scott study fit into a total picture of the individual's cognitive structure as it approaches an interface with the material to be learned. Such a theory would eliminate the need for using a modifying taxonomy in these circumstances. The Ausubelian model explains the "past experience" variable quite well--relevant cognitive anchors from the past provide ready acceptors of new information and thus facilitate assimilation of the new material. Knowledge of relevant aspects of the students' cognitive structure should provide the framework for choosing teaching strategies and learning content. Individualized instruction would then seem to be the best mode of teaching because it can be based on the individual student's available cognitive store.

## INTERACTION ANALYSIS

Analysis of verbal interaction between student and teacher in the classroom was the topic of ten doctoral theses. Flanders' Interaction Analysis Method (245) was used for various purposes of investigation in seven of the theses; among the interaction measurement instruments used in the remaining three theses was Parakh's (257) System for analyzing student classroom talk.

The assumption underlying the study of pupil-teacher interaction in the classroom is that there are patterns of teaching behavior that characterize effective teaching--effective in the sense that the learning situation results in relatively high student achievement. The construction of category systems of teacher and student behaviors in such a way that temporal behavior patterns can be analyzed is the primary intent of interaction analysis. Flanders projects the use of interaction analysis as a tool to train teachers to perform behaviors which reliably produce certain student achievement results (1970). We have chosen to review in some detail the studies which focus on these topics and to comment only briefly on those remaining.

Two doctoral theses dealt specifically with the relationship of student achievement to mode of classroom interaction. The relationships among verbal interaction, student background, student achievement, and student attitude toward the course and teaching in selected two and four year college general chemistry classes were studied by Cangemi (40). Taped sessions of classes were coded and analyzed according to Flanders. Within each of the four schools, sections were grouped into higher and lower I/D groups based on the Flanders categorization. (I/D = the ratio of indirect to direct plus indirect teacher behavior as categorized by Flanders.) Comparison between high and low I/D groups was made by analysis of covariance, using the variables achievement, attitude toward the course and attitude toward the teacher. Success in the general chemistry course (determined by final grade and posttest score on the ACS-NSTA) was correlated with chemistry background, post teacher attitude, and high school average; chemistry background and pre-course attitude were also correlated. Among the general conclusions of the study was that higher I/D classes produced students with higher achievement and generally more favorable student attitudes toward the course than lower I/D classes.

The implications Cangemi derives from her research are of interest particularly with regard to educational counseling, with suggestions for mapping an individual student's educational route according to the best predictors of his success in a course. The 1969 ACS-NSTA High School Chemistry Exam was found to be the best predictor of success in general chemistry with high school chemistry

course grade, with high school New York State Regents chemistry grade and high school average following as good predictors of success. Educational counseling based on this research data is exemplified by several of the specific recommendations made in the study: that poorer students attend tutorial sessions in which I/D ratio is higher, and that students whose career goals require college general chemistry be encouraged to take high school chemistry. The second recommendation makes good sense within an Ausubelian model of learning. The availability of relevant cognitive structure for accepting new information can make the college course easier to assimilate after completion of a high school course. Increased verbal expression within a tutorial group would seem to enhance meaningful rather than rote learning in that students are encouraged to clarify concepts in their own words.

Significant positive correlation between student achievement and classroom verbal response was noted in research by Mancini (118). The study examined the relationships among student self-concept of academic ability, his/her achievement and his/her classroom verbal behavior. Seventh-grade biology students served as subjects for the research. Parallel versions of the Michigan State General Self-Concept of Academic Ability Scale were used to measure student self-concepts--both general academic self-concept and science academic self-concepts. Parakh's system (257) for analyzing student classroom talk was used to code student verbal behavior. In addition to yielding information about the frequency of types of student responses (volunteer, reply, questioning, etc.), the verbal response analysis revealed, unsurprisingly, that 17 percent of the students were responsible for 60 percent of all student talk measured in the investigation. The verbal response category of "volunteering" showed the highest correlations between student self-concept and achievement.

It seems imperative to examine critically the common mode of classroom teaching, lecture, in light of the results of studies such as these and to consider modes of learning which keep open channels for greater student verbal communication in the learning setting--settings that encourage student-initiated communications from all students. An individualized content program in combination with tutorial sessions would be consistent with research findings.

Teacher training was the concern of five researchers. Flanders Interaction Analysis Method served not only as a training device, but also as the instrument of evaluation and comparison of control and experimental groups of teachers in a study by Beam (13). The study was designed to determine the effect of interaction analysis training with or without feedback upon a teacher's displayed, perceived, and ideal teaching behaviors. The two experimental groups received a training session in the interpretation of interaction analysis; one of the groups received feedback on their actual teaching behavior. Results indicated that teachers receiving the training and feedback tended to reduce the difference between displayed and

intended classroom behaviors. All three groups were subjected to pre-test analysis consisting of audiotapes of classes, and both teacher and student ratings of ideal, perceived and actual teacher behavior. But the fact that the Flanders instrument was used in the study both for evaluation and as part of the experimental treatment casts some skepticism on the validity of the results. Flanders (245) cautioned that "establishing proof of treatment differences is a research problem in its own right, a subproject within the larger design."

A similar project was done by Baker (7) who found an increased I/D ratio with teacher training in Interaction Analysis.

Southerland (178) reported an increased indirect teaching approach (in keeping with SCIS objectives and philosophy) as well as increased scores on TOUS and SAI for teachers having received in-service teacher training.

Contradictory findings were reported by Lerner (108) who found no differential modification of behavior in teachers who received interaction analysis feedback (Classroom Observational Record was the technique employed). He inferred also that this mode of feedback had no differential effect on the subjects' attitudes toward various aspects of the teaching situation.

A training program for new teaching assistants in freshman chemistry was developed and conducted by Murphy (130). Training for the experimental group consisted of seminars, video-taped micro-teaching sessions, and in-class observations by and individual conferences with the author. The verbal behaviors of both control and experimental teacher groups were coded according to the Flanders Method. The results show an increased quantity of verbal response from students in the recitation groups of trained teaching assistants. However, the investigator concluded also that the training program did not appear to produce a change in the ability to elicit a greater proportion of correct responses. Results such as these and contradictory results found by Lerner point out the real need for a comprehensive learning theory, rather than a strictly behavioral model on which to base experimental work designed to show measurable changes in the cognitive growth of individuals.

Research methodology was the focus of researcy by Albert Bosch (25). Based on the Flanders interaction analysis matrices, the author found two indices to be valuable in distinguishing between teachers with similar I/D ratios; no significant relationships between these more sensitive indices and common teaching patterns were found.

The relationship of verbal interaction patterns of ASCP teachers and teacher-student rapport was analyzed by Roth (158). He recommended more indirect influence by teachers on students' motivation and control techniques, utilization of student ideas, and avoidance of criticism and justification of authority. A principal finding in

his study was to show a high correlation between the results of coding behavior with Flanders Method and the Minnesota Teacher Attitude Inventory (MTAI).

The determination of teaching patterns as related to content development over a four-day period of investigation was discussed in a study by Stoess (184). The category system employed was the Content Analysis System for Chemistry. Stoess found that the pace of discussion was brisk, averaging three content events per minute and that teachers generally sought predictable, factual responses from students.

## INQUIRY, DISCOVERY LEARNING, AND PROBLEM SOLVING

The hope that methods could be found by which we could teach students to solve problems more readily has been with man perhaps for as many millenia as there have been teachers. Nevertheless, this hope has continued over the years under various titles: training the faculty of reasoning, critical thinking, problem solving, inquiry training, discovery learning and most recently, process education. To be sure, definitions of each of the latter vary widely from educator to educator, but they all have the same elements of hope--that students will emotionally favor and become successful at some kind of autonomous question asking and question answering procedure. The symposium report by Schulman and Keislar (259) and a recent analysis by Kaufman (88), agree that definitions of inquiry or discovery learning vary widely, but do contain some common elements. Kaufman found that while there is an agreed upon "inquiry method" in learning, "inquirying methods of teaching vary substantially, depending on the priority given affective or cognitive objectives."

In terms of Ausubel's model of learning, improving inquiry skills requires improving the cognitive structure relevant to a <u>specific</u> problem area. Although some general strategies for forming hypotheses and for solving problems may be learned (much as one might learn to favor meaningful over rote leaning strategies), the <u>primary</u> determinant for successful inquiry or problem solving performance is a well differentiated, hierarchical set of concepts relevant to the problem. On this issue Robert Gagnés' views are close to Ausubel's and indicated in his 1970 <u>Conditions of Learning</u> (247):

> Obviously, strategies are important for problem solving, regardless of the content of the problem. The suggestion from some writings is that they are of overriding importance as a goal of education. After all, should not formal instruction in the school have the aim of teaching the student "how to think"? If strategies were deliberately taught, would not this produce people who could then bring to bear superior problem-solving capabilities to any new situation? Although no one would disagree with the aims expressed, it is exceedingly doubtful that they can be brought about solely by teaching students "strategies" or "styles" of thinking. Even if these can be taught (and it is likely that they can), they do not provide the individual with the basic firmament of thought, which is a set of externally oriented intellectual skills. Strategies, after all, are rules that govern the individual's

> approach to listening, reading, storing information, retrieving information, or solving problems. If it is a mathematical problem the individual is engaged in solving, he may have acquired a strategy of applying relevant subordinate rules in a certain order--but he must also have available the mathematical rules themselves. If it is a problem in genetic inheritance, he may have learned a way of guessing at probabilities, before actually working them out--but he must also bring to bear the substantive rules pertaining to dominant and recessive characteristics. Knowing strategies, then, is not all that is required for thinking; it is not even a substantial part of what is needed. To be an effective problem solver, the individual must somehow have acquired masses of organized intellectual skills. (pp. 232-233)

Piaget's writings also stress that strategies children use for problem solving depend on years of cognitive accomodation and assimilation. But the dream of finding techniques to teach global problem solving strategies is too beautiful to abandon; we will likely see this type of hope pursued for decades to come.

Jones (85) used lessons from Suchman's Inquiry Development Program with seventh-grade students. Two groups were taught with comments such as "right" or "that agrees with what most scientists believe at this time," when correct answers were given; two other classes were given no acknowledgement of correct suggestions to inquiry problems. He found that the latter groups achieved significantly more (.05 level) on the Cooperative General Science after fourteen weeks of instruction and that all four groups gained significantly on the TAB Science Test, a presumed measure of problem solving ability. Working with sixth-grade children, Mark and Salstrom (120) used with one group an inquiry approach similar to Suchman's and a "game board" inquiry approach with a second group. In the game board approach, students chose question cards which had "yes" or "no" answers on the reverse side. They found this approach superior to the class discussion method as measured by a test of conceptual understanding. Starr (179) used Schwab's Invitations to Enquiry with tenth grade, (BSCS) biology students, twice each week for eight weeks, and a control group with only regular BSCS materials. He found the students using the Invitations to Enquiry gained significantly more on the Watson-Glaser Critical Thinking Appraisal as a result of some eight hours of instruction. If the WGCTA was valid [See critique by Ennis (244) in which he argues that this test is not valid; see also the study by Lucas (112)] and if results obtained were stable, this would have been a significant achievement. Lehman (106) presented a demonstration to junior high school students and then asked for free response written questions from them. Questions were classified as

concrete, abstract or creative; number and type of questions asked were treated as independent variables and I.Q. and scores on Torrance Test of Creative Thinking (TTCT) were independent variables. His analysis showed that higher I.Q. students asked more questions than low I.Q. students, and high creatives asked more than low creatives, especially questions in the "abstract" or "creative" categories. Inquiry teaching strategies are recommended partly to foster creative thinking. Since "high creatives" (as measured by the TTCT) ask more questions when given an opportunity, Lehman's results suggest these students would get more positive reinforcement under inquiry teaching strategies where question asking is encouraged. Peterson and Lowery (144) found that teachers do tend to rate children as "curious" depending on their question asking, but they found negative correlation between extent of students' motor activity and curiosity ratings. The results suggest that activity on the part of students engendered by some inquiry methods may not be productive.

Smith (174) used a "structure of intellect" protocol analysis system to investigate problem solving processes. She found that students differed in problem solving processing modes when comparisons were made by professional interest, degree of quantitative orientation, and stability of patterns over time. If problem solving is primarily a function of available relevant cognitive structure of an individual (as Ausubel contends) we should expect the results Smith obtained. Butzow and Sewell (38) used a Test of Science Processes (TSP) with eighth-grade students studying Introductory Physical Science. Pretesting in October and posttesting in January, they found some significant gains for the processes of observing, comparing, classifying, quantifying, measuring, experimenting, inferring and predicting. When scores were compared by I.Q. ability group, the highest quarter showed the least gain and the lowest quarter showed the most gain. On theoretical grounds we would expect gains to be positively correlated with ability, unless a "ceiling effect" occurred; since no data on item difficulty or discrimination were given, we can only speculate on the meaning of the results.

Cheong (42), using 293 high school biology students with two subgroups, taught "general underlying rules of inquiry" for four consecutive class periods. One instructed group made greater gains than a control group and Cheong concluded that the lesson materials "did induce a set to learn and improved student ability to carry out inquiry tasks" (and all this with less than four clock hours of instruction!).

Deane (49) worked with fourth grade children using an experimental group taught with Science--A Process Approach and a control group taught with traditional science materials for eight months. He found highly significant differences in posttest scores on a "science process skills" test and also on a "social science process skills" test in favor of the experimental group. Atwood, et al. (5)

found similar results under similar circumstances. At issue here is what do the process skills tests measure--the enormous differences in mean scores between experimental and control groups in both social sciences (where traditional instruction prevailed) and science suggest that the experimental group learned what kind of responses were needed for "process skills" type of questions, rather than that a major reorganization of their cognitive processing structures had occurred.

If "inquiry" strategies are good for students, then we should train teachers to impart these strategies, if possible. Golmon (65) found that an inquiry oriented science methods course resulted in teachers moving in the direction of high level inquiry science teachers, as determined by the Science Teaching Assessment. In the section on Teacher Education we have described other studies that report similar changes in teacher characteristics after some training regime.

Lawfer (104) compared student attitudes on science achievement when taught either by (1) lecture-demonstration or (2) inquiry methods where the instructor served as a resource person. He found no significant differences between the two groups.

Although "inquiry" approaches to science have been much heralded through the 1960's, especially with federally funded programs, there continues to be no convincing evidence that general problem solving strategies can be taught. This reviewer recommends that at least our research energies should be channeled in other directions.

## THE TEACHER: EDUCATIONAL BACKGROUND, TRAINING, ATTITUDES AND BEHAVIOR

Over twenty studies were devoted to research on the teacher. This category has been broken down into four subcategories: 1) educational background and cognitive characteristics of the teacher, 2) teacher training programs, 3) teacher attitudes and behavior, and 4) development of interaction diagnostic schema.

More than half of the studies in this broad category centered on teacher affective characteristics, this interest appearing in each of the four subcategories. Noticeably lacking, however, is research based upon a paradigmatic framework relating affective variables to cognitive development. Hence, the conclusions reached by most of the researchers in this area are limited to narrow application. Schemes such as those of Krathwohl, et al. (251) in the "Taxonomy" (affective domain), and Flanders (245) in his Analyzing Teaching Behavior are cited here as calling attention to the affective as a vital component of the individual in the teaching-learning situation, but neither attempts to resolve the problem of integrating affective and cognitive structures.

### Educational Background

Six studies are included in the subcategory of Teacher Background. Dieter (54) reported that items concerning teacher intrinsic personality characteristics and teacher-student interaction were most often used by judges in choosing a candidate for Outstanding Biology Teacher Award. Of the twenty-three items rated high, fifteen related to those factors, while six related to skills and proficiencies as a science teacher. Of no significance were factors related to the academic background and professional experiences and accomplishments of the teacher.

Cognitive skills were the foci of reports by Schafer (162) and Schilling (163). Schafer correlated critical thinking ability (as measured by Watson-Glaser Critical Thinking Appraisal) with the following teacher characteristics: 1) sex, 2) years of teaching experience, 3) teaching location (urban-suburban) and 4) type of college attended (state college - liberal arts college). Significantly higher scores were achieved by females, suburban teachers, and those from liberal arts colleges. Years of teaching experience was not a significant variable. Schilling investigated the type of test questions employed by junior high teachers, attempting to correlate this information with elements of the teachers' backgrounds. His conclusion was that teachers, regardless of their years of teaching experience, college degrees, or years of science teaching experience, asked questions requiring only the skills of recall in 75 - 85 percent of the cases. Questions challenging students at the highest cognitive

levels according to Bloom's Taxonomy were omitted completely [see Fast's study (63) for similar conclusions on national standardized tests]. Looking at the studies of Schilling and Schafer, one can conclude that whatever the teacher's ability to use higher level cognitive processes may be, this type of thinking is not stimulated in students.

Two studies focused on the academic preparations of college teachers. Dollmann (55) found that many more physicists entered into liberal arts college teaching if they had earned their undergraduate physics degrees from a liberal arts college. The largest productivity was found in the small non-public liberal arts colleges, in contrast to "the large well-equipped physics departments of the prestigious institutions of higher education," which were the poorest producers of liberal arts teachers. One might speculate that affective variables are guiding the career choice and that a teaching career requires an affective development which is possibly stifled in the larger institutions where a strong research orientation is emphasized in departments.

A study of community college physics teachers conducted by Ohm (138) revealed that current teachers of physics varied little in their attitudes toward their professional preparation compared with those surveyed three years previously.

Brown and Brown (32) used semantic differential scales to study scientific values possessed by professors in the sciences and the humanities. The rank orderings of values for thirty science professors and thirty humanities professors at California State Polytechnic College was: for science--(1) curiosity, (2) integrity, (3) intellectual and procedural honesty, (4) creativity, (5) open-mindedness, (6) commitment and persistence, (7) objectivity, (8) experimental verification, (9) cause and effect, (10) skepticism; for humanists the values as listed were ranked respectively, (5), (1), (6), (2), (3), (4), (7), (8), (10), and (9). On the whole, they felt differences in values for the two groups were not significant.

## Teacher Training Programs

Ten studies came under the subcategory Teacher Training. Graeber (67) and Lestingi (110) analyzed teacher training programs designed to develop a positive attitude toward science teaching in elementary school teachers. The experimental program in each case consisted of learning progressively differentiated material in a specific area of science. The aim of the experimental program described by Graeber was to prepare teachers to teach children investigatory type science. The experimental approach concentrated on investigations "related to one conceptual scheme in science" based on activities in COPES Teachers Guide for a Conservation of

Energy Sequence. Prospective teachers were involved in the same type of investigations as recommended for use with the children. A "semantic differential" was used to assess student teachers' attitudes toward science and a form of "interaction analysis" used to assess teaching ability. Comparison with a control group showed that wherever significant differences were found they were in favor of the experimental program. Lestingi found that teachers' attitudes and general understanding of the nature of science improved after exposure to a program based on imparting knowledge related to "the nature and processes of science by means of a historical treatment of the development of ideas which led to the heliocentric view of the universe."

These two studies--those of Graeber and Lestingi--seem to indicate that the development of a positive attitude toward a subject area is a function of the extent to which science concepts are learned. A clear tie to Ausubelian theory is apparent in the conceptual organization of the two programs.

The development of interpersonal relations skills in teaching and their effect on student teacher attitudes was the focus of research by Buchanan (35) and Yaghlian (204). In the Buchanan study, experimental trainees were subjected to a program (Research Utilizing Problem Solving--RUPS) designed to improve interpersonal relations skills as well as problem solving tactics. Results showed improvement in certain of the problem solving skills and an increased use of interpersonal relations skills in the verbal interactions of midterm conferences between the trainees and their advisors. However, experimental subjects improved only in the areas of verbal skills called paraphrasing and not in skills called feedback and process communications. In this respect the results of other studies (see studies in Flanders' category) are in accord. That problem solving ability is a function of the extent of relevant cognitive differentiation has been discussed earlier in this report.

Yaghlian (204) analyzed an in-service program focusing on the development of interpersonal aspect of teaching by use of workshops and teaching with videotape feedback. Among the conclusions from the analysis were that change in attitude toward teaching seems to be related to a reconsideration by trainees of the relative advantages and disadvantages in teaching; and change in description of self appears to be related to perception of potential for an interpersonal style that is characterized by the more intense use of such traits as being helpful to, supportive and encouraging of others.

The relationship between verbal interaction of elementary science teachers and their students' creativity was measured by Puranajoti (149). The research instruments employed were Flanders' Interaction Analysis Technique and Torrance Test for Creative Thinking. The author found significant positive correlation at the .05 level between the student scores on TTCT and the following:

a) indirect teacher behaviors, b) percentage of time spent in accepting feeling of students and praising and encouraging students, c) percentage of time spent in accepting student ideas, d) percentage of time teachers spent in asking questions and e) percentage of time spent in student talk-initiation. Creativity in girls was found to be influenced to a greater extent by teacher behavior than was creativity in boys.

The remaining five studies in this subcategory focus on divergent topics. Brown (33) found that student teachers who participated in a one quarter pre-service program emphasizing classroom participation were more likely to change their views significantly about the types of science classroom activities which should be used in urban or suburban classrooms as compared to student teachers without the pre-service participation. Types of activities differed between project and non-project student teachers, but neither group exhibited significant changes in their attitudes toward or knowledge of culturally deprived students following the two quarter sequence of student teaching.

Lucy (115) investigated variables associated with students enrolled in a secondary science methods course in order to evaluate the Laboratory Science Program component of the course, designed to improve the understanding of science through individualized activities emphasizing either the processes or the products of science. Student gains in understanding the nature of science (as measured by the Wisconsin Inventory of Science Processes) were predicted primarily by two factors: the number of Higher-Order Processes of science activities performed and the science field of concentration grade average. We again refer to Ausubelian theory as explanatory for the increased "understanding" scores.

Clark (43) found that science teaching did not lead to higher levels of language usage among elementary school students as expected. Significant differences in level of language within science context were found. Teachers in the experimental group followed a course of training in use of science materials and concepts, along with training in questioning techniques. Again, the results can be explained in terms of Ausubelian theory: the number and kind of specific subsumers (in this case, scientific terms and concepts) is a predictor of usage in the specific area in question.

That teachers allow too little "think-space" as they ask questions served as the impetus for a study by Garigliano (64). The problem of the study was to subject SCIS teachers to "wait-time training" and to determine the effects of the training on certain dependent, pupil variables, such as length of student response, content-oriented student solicitations, inflected responses, "I don't know" responses, and pupil-pupil interactions. The author concluded that "with the exception of longer student responses, dependent variables did not reach statistically significant levels under the slightly slower paced schedule." More refined training techniques were suggested.

Thelen and Litsky (192) found that students of teachers selected for attendance at a summer institute on water pollution control performed better on an achievement test at the end of the following school year than did students of non-attending teachers. One might interpret this result in light of the speculation that attending teachers probably were committed, interested teachers, and that these affective attributes together with better differentiated cognitive structures result in superior teaching ability (as witnessed by student achievement scores).

## Teacher Attitudes and Behavior

Six studies are included in the subcategory Teacher Attitudes and Behavior, two of which deal specifically with teaching style as related to student achievement.

Barnett (10) and Stothart (186) found that certain aspects of teaching style and affective characteristics showed a relationship to student cognitive preference and curiosity. Barnett's study of a population of high school biology students showed the following results: students who perceive their teachers as non-directive tend to indicate a preference for application and tend to be higher achievers than students of teachers perceived as being directive. The latter also tend to prefer memory to application. However, using the entire sample there appeared to be no correlation between biology achievement and questioning preference. A possible explanation for this last finding may be that the measure of achievement (Nelson Biology Test) does not discriminate between the rote memorizers and students who use higher cognitive processes.

Stothart (186) reports a significant relationship between pupil control ideology of the teacher and changes in student curiosity. A significant relationship was found also between teacher dogmatism and pupil control ideology and the diversity of problems chosen for study in class. No significant relationship existed between the instructional systems used (Laboratory Exploration in Biology) and changes in student curiosity.

Two studies dealt with analysis of teacher objectives. A study of teaching practices in introductory college physics courses was conducted by Whitaker (202), who analyzed data concerning types and purpose of questions asked by the teacher in terms of the goals stated by the instructors for teaching introductory physics. Bloom's Taxonomy of Educational Objectives was used to identify question purposes. Israeli teachers using the BSCS program were the focus of a study by Tamir and Jungwirth (191). The authors investigated the relationship between the teacher's stated priorities of teaching objectives and their stated expectations of achieving those objectives. Among the main disparities between teacher-priorities and teacher-expectations were the following: 1) for the objective "critical thinking," 61 percent gave top priority, yet only 24 percent

expected top achievement, 2) for the objective "accumulation of knowledge," 54 percent of the teachers gave a "no importance" tag, and 36 percent actually did not expect achievement in this sphere. In the discussion it is suggested that teacher training include actual demonstrations of ways and means of attaining objectives connected with "science as a process," as this area received a low priority marking. This was read as an indication that misunderstanding exists about the meaning of this objective--one which is fundamental to the BSCS philosophy. The authors interpreted the low priority marking of "accumulation of knowledge" as stemming from the teacher's assumption that "an emphasis on process must bring about less achievement on content"--an assumption having no empirical validation. Remarks concerning process education have been made elsewhere (see Inquiry Learning).

A study by Collea (44) on the intentions, perceptions and verbal behavior of first year science teachers was based on the supposition that objective information about these attributes would contribute to an evaluation and a revision of present teacher preparation programs. As in many of the studies reviewed in this section, there is an emphasis on interpersonal relations development.

Teachers of BSCS were the subject of investigation in a study identifying ideological orientations and personality characteristics of teachers who "accepted" BSCS and those who "rejected" BSCS biology. Hoy and Blankenship (77) postulated that "acceptors" of BSCS will be significantly more humanistic in their pupil control ideology and will have a significantly greater capacity for independent thought and action than "rejectors" of the program. Findings of the study tended to support the underlying assumptions from which the hypotheses were developed--namely, that the BSCS program requires of teachers a cooperative interaction with the students and independence of thinking.

## Development of Interaction Diagnostic Methods

Two studies were descriptions of diagnostic instruments, developed to assess teaching skills [Kuechler (100)], and to analyze science department head supervisory styles and their affective correlates [Peruzzi (143)]. Kuechler (100) advocated a training program for selected teaching skills with an adequate assessment instrument in order to strengthen pre-service experiences of teacher candidates by 1) providing them with a number of specific instructional techniques and 2) permitting them to follow through the training program in an individualized instruction mode. The author selected the following teaching skills: lesson orientation, verbal and/or written reinforcement and lesson conclusion.

A Science Supervisory Style Inventory (SSSI) and a Science Teacher/Science Department Head Questionnaire (ST/SDHQ) developed by Peruzzi (143) were used to identify three major types of supervisory

styles which were then correlated with such variables as teacher involvement in activities beyond normal expectations, department head satisfaction with job rewards, teacher satisfaction with teacher/department head working relationships. Among the major conclusions Peruzzi lists was that science teachers indicate strong negative feelings toward nomothetic department heads (those emphasizing institutional expectations) and strong positive feelings toward ideographic department heads (those emphasizing individual expectations). He recommends the use of an instrument such as SSSI to identify problems in the working relationships between science department heads and teachers, hoping that feedback would lead to group-desired change.

Researchers interested in teacher education should examine the excellent review of science teaching by Schulman and Tamir in the Second Handbook of Research on Teaching edited by Travers (261). Their review is critical and illustrates ways in which studies on science teaching might be improved.

## ENROLLMENT

Three studies were reported in 1972 which focused on questions of enrollment in science. The reports by Bridgham (30, 31) and the study by Dial (52) considered enrollment in physics classes. Bridgham tested a model in which he proposed that ease (or difficulty) of grading would be the principal determinant of science enrollments. In his model, Bridgham compared science grade averages with non-science grade averages for students to arrive at an "ease of grading index" for a science teacher. He postulated that relatively more students would elect a science course if grading is "easy" and more would enroll in subsequent courses. This relationship should hold particularly well for students not committed to science careers. Using data gathered from 27 schools, Bridgham found that except for males who had taken chemistry, ease of grading did correlate positively with election of science courses, but results for election of subsequent science courses were "mixed."

Dial (52), working independently, studied factors influencing Alabama students election of high school physics. She found peer influence to be the most significant factor, much of this operating through the peer's advice regarding the difficulty of grading or demands of classwork in physics. Her results lend support to Bridgham's "model." However, a more basic issue is how grading practices influence students' motivations and self-image. Non-election of science (or mathematics) is probably only secondarily related to grading practices, with the primary factor being the degree of achievement (or cognitive drive) motivation resulting from successful or unsuccessful study (c.f. Ausubel, p. 367).

## ENVIRONMENTAL EDUCATION

We have witnessed in recent years a growing public concern for the maintenance of environmental quality. It is not surprising, therefore, to find several research reports in 1972 dealing with issues of environmental education. Three studies are cited here, each dealing with cognitive and affective factors in environmental education.

Brady (27) used eight field trips with one group of high school biology students and media supported presentations with another group. Both groups received the same list of behavioral course objectives and the same pretests and posttests. He found no significant differences between the two groups on tests of achievement of course objectives for units I and III, but test results for unit II favored the field trip group. No difference in attitudes was found. Berger (14) developed laboratory exercises for environmental science, a college introductory science course. Cognitive achievement tests favored students taught with the lab activities over those not given the experimental exercises. However, no differences in "attitudes toward environment" were found between the groups. Luce and Volksdorf (115) evaluated an experimental college course in environmental education and found a decrease in scores on an environmental awareness test administered prior to and after instruction.

The results of these studies can be summarized in much the same way as studies reviewed under Instruction--when course objectives are carefully specified and appropriate instructional materials are used, cognitive learning can be appreciable. Affective education continues to be elusive both in curriculum planning and in evaluation.

## SCIENCE CONSULTANTS

During the "golden" 1950's and 1960's, science enrollments expanded rapidly and most large school systems employed some kind of science consultant. With tightening school budgets, we are witnessing a reversal of this trend, but perhaps the pendulum will begin to swing back by 1980. In any case, it may be worth examining the role of science consultants and how their efforts can be improved.

Mahn (117) used teacher questions and concerns to analyze the role of science consultants in conjunction with the installation of Science - A Process Approach in twenty-one schools. He identified a number of teacher queries and admonished that a science consultant needs to be familiar with the curriculum and appropriate instructional techniques. Harty (74) studied consultant activities in the same installation program and found similarly that consultants did not always know the curriculum goals and methods and that personality factors were important.

Too often teachers become science consultants by administrative appointment, sometimes with "political" influences, and not as a result of their special talents or competencies. Both Mahn and Harty observed this problem and we have seen the unhappy consequence in several personal experiences.

## RESEARCH METHODOLOGY

Although many studies cited in this review dealt with significant research methodological issues, three reports in 1972 dealt primarily with this subject. Anderson's (3) paper presents some of his work developed more extensively in his two books (232, 233). In his 1972 report he describes his method of kinetic structure analysis using data from two lessons. Penick and Brewer (142) discuss the power of statistical tests and the probability that a true null hypothesis could be rejected in published research reports. They point out that small sample size, poor experimental design and other difficulties frequently make it impossible to reject a null hypothesis when it should be rejected. Lawlor and Lawlor (105) discuss some problems encountered in selecting material to be included in research review series published by Columbia Teacher's College Press (241, 242, 243, 248, 253) and criticize particularly the "jury" approach to selection of research for inclusion.

## HISTORY AND PHILOSOPHY

Three dissertations dealt with historical material. A special topic in history of science was analyzed in the paper by Salvatore (160); literature searches on the topic of science education history were summarized by Ogden (137) and McKenna (124).

Salvatore (160) discussed historical cases which exemplified the use of interdisciplinary tactics to construct scientific explanations: the uses of models from math and physics to elucidate biological phenomena. The foci of the reports were on the works of Alfred J. Lotka and Vito Volterra, with emphasis on the developmental aspect of their conceptual models of population dynamics and evolution, beginning from "his [Lotka's] initial attempt to view populations as chemical aggregates, to his formulation of the law of evolution in terms analogous to the concept of irreversibility in thermodynamics, and finally to his development of the fundamental system of kinetics." The author's analysis of Volterra's contributions included the development and application of a mathematical model to species fluctuation and "some of the implications of [his] applications of the principles and laws of mechanics to the dynamics of biological associations."

An historical analysis such as this, which focuses on the development of explanatory models, speaks directly to the philosophical question, "What is science?" and the question held in the first, "How does scientific knowledge grow?" Answers to these questions should in turn provide the framework for science education. The historically interdisciplinary nature of science, as discussed in this study, ought also to be a focal point for a re-ordering of science education thinking. In terms of Thomas Kuhn's (252) paradigmatic view of science, revolutionary shifts in the structure and focus of scientific problem solving are the means by which science appears to progress. One source of these revolutionary shifts in science appears to come from interdisciplinary inspiration, as pointed out in Salvatore's thesis. In light of Kuhn's view of science, as well as others holding similar views, it would seem that an integrating of traditionally isolated school curricula is in order. A restructuring of science education along interdisciplinary lines would seem also to correlate with a learning theory which stresses the relational aspect of new knowledge with old. Cognitive stability of new knowledge is achieved when it is associated directly with already stable knowledge [Ausubel (235)]. A learner's scientific cognitive structure would appear to be more stable when old and new knowledge becomes associated across traditional disciplinary limits.

Two dissertations dealt with historical views of science education, both focusing on high school science.

Ogden (137) looked at changing objectives in high school chemistry during the period 1918-1967. Statements of objectives from numerous periodicals were categorized under the following headings: knowledge, process, attitudes and interest, or cultural awareness. The following statements were among the major trends he saw:

1. A shift in emphasis from knowledge category (subperiod 1918-1946) through attitude and interest (subperiod 1945-1967) to an almost equal concern for all categories in the latest period (subperiod 1963-1967).

2. In an ordering of objectives from most to least important, objectives relating to "scientific methods of thinking and "major facts, principles, concepts, or fundamentals" were rated most important and "sociological implications" and "the nature of science and scientists" appeared as least important of the nine objectives during one or more of the six subperiods studied.

3. "The objectives most frequently published in conjunction with research activity were 'major facts, principles, concepts or fundamentals' during subperiod 1 (1918-1933). 'Scientific habits or attitudes' during subperiods 2 and 3 (1932-1946), and 'scientific methods of thinking' during subperiods 4-6 (1945-1967)."

In a comprehensive study of science education in secondary schools in the years 1950-1972, McKenna (124) found little change in the objectives--only changes in procedures to achieve the objectives. He cited the increasing use of multi-media, methodologies such as team teaching, independent study and computer assisted instruction, and the trend toward laboratory use in classroom teaching. However, the teacher-centered lecture method continued to be predominant over student initiated classroom activity. With regard to laboratory work, McKenna noted "a decline in the 'exercise' type of laboratory and demonstration procedures in favor of the problem-solving approach." Also, he noted that with the advent of increased laboratory activities came a decline in content-oriented teaching.

The trends in changing objectives in chemistry education, as reported by Ogden, reflect the trends seen by McKenna in his broader report of science education as a whole: a shift in emphasis on content to emphasis on science method or process, or at least to an equal concern for each (Ogden). There are two questions which might be worth considering with regard to the conclusions stated here.

1. Is there, in practice, an actual decline in emphasis on content despite the stated objectives of the newer curricula? Is this decline consistent with a learning theory such as Ausubel's?

2. Is "the scientific method" as a set of classic rules for conducting research correct, both philosophically and practically? How does teaching about method tie in with a learning theory?

Three doctoral studies came under the category of Philosophy. Two of these focused on a philosophical view of the scientific enterprise as a means of shedding light on science education. Revak (155) suggested that the development of "fluid intelligence" be the focus of an educational philosophy. He takes the term "fluid intelligence" from R. Cattells' dichotomy of "fluid" and "crystallized" intelligence. Revak reasoned that an educational philosophy based on the development of fluid intelligence and the parallel concept of science (as he uses the term) together with the act of communicating will provide ground for an educational program responsive to changing societal situations and hence prepare individuals to cope with an increasing number of novel situations. He chose to define science as a loose process in which untenable conjectures are rejected, some conjectures emerge as non-rejected explanations of phenomena, and finally a crystallization of conjectures resulting in a theory. The term "science" is equated with "fluid intelligence."

Bowen (26) presented a wholistic theoretical framework which can be used as a basis for decision-making in curriculum-instruction development as described by M. Johnson (250). She contended that for science education, curriculum decisions are based on some implicit or explicit philosophical view of the discipline of science; instruction decisions on the other hand proceed from some psychological theory of learning. In order for decision-making in curriculum and instruction to be consistent, it must have basis in an area of intersection between a learning theory and the philosophy of the discipline in question. The author analyzed areas of intersection between David Ausubel's theory of meaningful individual learning and Thomas Kuhn's description of the scientific enterprise as a process of collective learning. Scientific progress and individual learning derive from the same process of progressive differentiation and integration of knowledge structures ("paradigms" in Kuhn's terms, "subsumers" in Ausubel's terms) and not from application of methodology, rules or heuristics. The author cites data which support an Ausubelian model of meaningful learning: achievement in a subject matter area is related to the adequacy of relevant specific cognitive structure (subsumers) which a student possesses.

The apparent de-emphasis on specific content in Revak's view of the fluidity of intelligence seems to be an unviable recommendation to make in light of Ausubel's contribution to learning theory. The individual adaptability in novel situations that Revak proposes as an outcome of an education program can be seen in Ausubelian terms as the availability of large numbers of well-developed science concepts in the individual's cognitive structure.

Prusso (148) shows that science learning activities can be classified according to a hierarchical and multidimensional system of epistemological categories. The purpose of the thesis was to show that a consistently applied analysis could be used to identify "science lessons which present epistemological information inconsistent with the appropriate science model of knowledge" and thus to point out how a lesson could be modified to correct the "epistemological misrepresentation." A "Profile and Epistemological Analysis Scheme" was developed by the author as a diagnostic instrument. A Popperian view of science seems to be the closest philosophically to the thesis of Prusso.

If we are to overcome the type of research limitations noted by Hurd earlier in this report, we must examine the historical and philosophical bases for science education research. It is our view that the sciences have much to offer the field of education and especially science education if we explore carefully historical roots of contemporary ideas in science and examine philosophical structures that have been formulated to explain the nature and methods of science. While we welcome fresh thinking by doctoral candidates, as reported here, we need more serious inquiry by established scholars. Except perhaps for Joseph Schwab at the University of Chicago, we have at this time no serious scholars in science education committed to historical and philosophical analysis.

## FOREIGN STUDIES

Nine studies dealing with science education in foreign countries were reported in 1972. Some additional studies conducted in other countries deal specifically with issues under other headings and are summarized elsewhere in this review. Most of the studies reported here have limited generalizability but are cited to aid researchers interested in international science education.

Mata Guevara (122) analyzed objectives in Venezuelan elementary schools and found teachers poorly prepared and largely unaware of national elementary science curriculum goals. Novick (135) developed a chemistry course for non-science majors in Israeli high schools. He found results of a field trial suggested the course was teachable and students displayed a high interest in the topics studied. Mhlanga (126) developed an ecology unit for use in biology syllabus of Rhodesian schools. Khabele (95) studied attitudes and opinions of Zambian secondary school students toward biology. He found a generally favorable attitude toward biology but a need for greater teacher awareness of the relationship between classroom teaching practices and attitude development. Best (15) studied teacher and students' response to a checklist of what should and what does go on in biology classrooms. Black (18) investigated the levels of questioning found in West African School Certificate Science Examinations and Nigerian Science Teacher's Examinations. Using Bloom's Taxonomy (238) as a framework, he found that 1970 examinations required higher levels of thinking than 1971 exams and that physics and chemistry teachers required higher levels of thinking than biology teachers. Carss and Clarke (41) analyzed the content of the "pushes and pulls" unit of the Australian Science Education Project. They found the first portion of the unit highly structured and the second portion entirely devoid of structure. Overby (140) surveyed educational research in Sweden for 1971-72 and gave data on 108 projects. Varghese (196) studied the problem of biology instruction for meeting the needs of people in Keralu State, India. Syllabus topics, methods of teaching, evaluation, inflexible central education organization and poor teacher preparation were identified as problems.

## UNPUBLISHED STUDIES

In this section we have reviewed briefly unpublished studies identified through ERIC. Our purpose in citing these studies is to bring them to the attention of researchers as soon as possible, even though more accessible, published reports may be available in the future. We recommend that published reports of these studies be included in future reviews of research. The studies are categorized in the same order as published research presented in this report.

### Learning Theory

Moser (222) has developed an information theoretic model for human processing of cognitive tasks. Drawing on the early work of Shannon and others, Moser's theory accounts for memory processes and problem-solving processes. Fazio and Moser (213) tested some elements of this model involving information processing of memoryful and memoryless channel levels in problem-solving recall tasks. Working with graduate students, they found too much new information interfered with problem-solving, as predicted by Moser's model.

Felen (214), using the memory model of Moser (222) studied cognitive processing patterns of second and eighth grade Negro and Caucasian students solving a problem in electricity (parallel circuits). She found no differences for sex or race, and patterns for successful solutions followed that predicted by Moser's model.

Howe (218) studied the relationship of the geometry of containers and children's ability to conserve liquid volume. Contrary to suggestions by Robert Gagné, she found that knowledge of area and volume relationships were not prerequisite for conservation of liquid by third-grade children. The results support Ausubel's theory in that experience and concepts associated with liquid volume are the primary determinants of children's success.

### Studies of Achievement

Olsen and Lockard (225) compared achievement of ninth-grade physical science students who (a) received behavioral objectives prior to study and (b) did not receive objectives prior to study. Significantly higher achievement and retention was found for group (a).

Johnson (219), using a model for categorizing perceptual structure of scientific knowledge found that procedures developed could successfully index knowledge mastery, although further research is needed to determine the role of knowledge structures in problem-solving.

Thorsland and Novak (230), using an interview technique, found that students could be rated on intuitive and analytic ability scales. It was found that high intuitive and high analytic ability students were very efficient (achievement divided by study time) in learning college physics, but high analytic, low intuitive students were inefficient.

Voelker (231) studied concept attainment of elementary school students and found that children responded well on tasks dealing with gross perceptions rather than fine distinctions among examples and non-examples of a concept. He found the attainment of a concept was a function of its association with the concrete world.

Egelston and Egelston (211) studied the accuracy of self-evaluation on test performance of 210 junior high school science students. Students were asked to predict their scores before and after taking unit tests. Differences were found between the two predictions and also differences by achievement level.

## Instruction

Tauber and Fowler (229) used four different methods of providing feedback on test results in biology, chemistry and physics classes. They found no significant differences in student performance using (1) number or letter grade, (2) grade plus teacher's brief comment, (3) a grade plus one-half page or more written comment, and (4) grade plus three to eight minutes of teacher comment on audio-tape.

Agin (206) developed a socio-historical approach to teach science and found students gained significantly in their knowledge and expressed an interest in the course.

Holliday (216) used (1) audio, (2) printed, and (3) audio and printed study materials with tenth-grade biology students. The results were inconclusive and did not support a "stimulus generalization model" for science instruction.

Donaldson (210) supplemented secondary school science instruction with computer aided problem-solving and simulation activities. He found students used the computer activities in different ways.

## Teacher Education

Rowe (226) reported on studies of the length of time elementary school teachers wait after asking a question or before commenting after a student's response. Her studies of "wait time" over the past five years have shown that teachers wait an average of one second for a response and comment within nine-tenths of a second following a student's response. Teachers can be trained to increase wait time

and when this is extended to three to five seconds, there is an increase in student confidence, speculative responses, evidence-inference statements, child-child data comparisons, frequency of student questions and responses from "slow" students. Positive teacher behavior characteristics also increase.

Teacher-led discussion activity too often encourages rapid-fire answers which are best generated by rote learning patterns on the part of students. According to Ausubel's theory, meaningfully learned materials are incorporated into cognitive structure (subsumption processes) in a somewhat altered form and retrieved also in an altered form. Rapid responses are most easily generated where an identity exists between information presented to students and information requested in questions, or in other words, when rotely learned material is recalled verbatim. The common practice of rapid-fire question and answer discussion, admirably achieved by some teachers, unfortunately, rewards rote learning patterns and penalizes meaningful learning patterns. Students, unfortunately, practice increasing those behaviors that have payoff.

Novak and Moser (224) asked students of fifteen biology teachers to rate segments of lessons as (1) too fast - too slow, (2) interested - bored, and (3) understand - don't understand. Data obtained were inconclusive, but they felt students could give effective feedback of the type requested.

Blosser (208) studied questioning skills of twenty-seven secondary school science education junior students under various training regimes. Although she found differential effects on wait-time, the overall results were inconclusive.

Gardner and Butts (215) studied the relationship between teaching experience, teacher concern level and achievement of new teaching skills with thirty-four experienced elementary school teachers and twenty-seven undergraduate elementary school majors. Using two specially devised scales, they found no significant relationship between the level of "teacher concerns" and achievement after training in identifying and using behavioral objectives; a significant positive correlation was found between teaching experience and teacher's "concern level."

## Other Studies

Macbeth (220) studied the value of student manipulation of science materials in the attainment of science "process skills." He found direct manipulation increased attainment for kindergarten children but did not increase attainment for third-grade children.

Research of a survey type was reported by Berendzen (207), Bybee (209), Elliott (212), Horn (217), Mason and Craven (221), Nelson (223), Smithson (227), and Stronck (228). The subject of these studies is indicated by their titles which are presented in the bibliography.

## SUMMARY AND CONCLUSIONS

Over four hundred studies in science education were reported in 1972. All of these were reviewed and two hundred thirty-one were summarized for this paper. These studies were grouped into eighteen categories as shown in Table I. In addition to research identified by the ERIC Center at The Ohio State University, journals were searched and additional studies were identified. Studies reported in earlier research reviews prepared by ERIC were not reviewed and do not appear in the bibliography of this report. The bibliography contains references in four groups: (1) 205 titles for studies abstracted, (2) 26 titles for unpublished reports, (3) 31 titles for other references cited, and (4) 178 titles for studies not abstracted in this report.

The introductory section of this report presents the methods and criteria used in the review. Although every effort was made to review each study objectively, a significant professional bias was introduced in the selection of studies for review and in conclusions drawn from the studies. This bias was in the direction of the contribution the studies made to our understanding of teaching and learning processes and/or research methodology in science education. A brief statement of Ausubel's (1968) learning theory is included in the first section of this report and subsequent commentaries show how the findings of the study might be related to Ausubel's theory. Traditional research "issues" in science education are discussed and these are also related to Ausubel's learning theory.

Although only three studies were found that related directly to Ausubel's learning theory, a few other studies made reference to his work and his theoretical views were the most commonly cited, unless we were to consider Piaget's writings as a kind of "learning theory." The sad fact is that too much of the research in science education continues to proceed without <u>any</u> theoretical framework.

The second section of this review discusses studies dealing with student achievement. Except for the work of Anderson's students using his theoretical framework for analysis of structure in teaching, the research reports were not related to a theoretical framework and the findings generally do not add to our previous knowledge that achievement tends to correlate with indicators of previous achievement and that "guided" learning in some form results in greater achievement than "unguided" learning. We would expect these results on the basis of Ausubel's theory, but had a theoretical framework been used, it would have been possible to measure critical elements in instructional programs or in students' cognitive structure at the time study commenced. We need to know more about how <u>specific</u> concepts in cognitive structure influence subsequent learning in

contrast to how broader, more generic concepts influence achievement. We need to study alternative instructional programs in terms of their influence on the development of subordinate and higher order concepts; i.e., the effect of the instruction on qualitative differentiation of cognitive structure as well as quantitative changes. We also need more studies where learning time is a central variable analyzed in terms of the quantity and quality of relevant concepts students bring to the classroom.

In our review of studies dealing with instructional issues, we found a substantial focus on individualized instructional modes. In general, these studies support the effectiveness of individualized instructional methods over traditional group instruction modes; it should be noted that the primary values of individualized modes, especially in computer assisted instruction was in decreased time needed to attain mastery of learning objectives. According to Ausubel's theory, well-planned instructional sequences should lead to greater achievement, or more rapid learning to some criterion level, or both. Once again we wish to stress the importance of analyzing the extent to which students possess necessary "subsuming" concepts prior to a segment of instruction and to study comparative study time needed for learning. These are crucial variables for the assessment of the effectiveness of any instructional alternative.

Twenty-four studies were directly related to the work of Jean Piaget and a number of other studies made some mention of his work. Although this reviewer regards the work of Piaget as too narrow to constitute a general theoretical framework for learning, his developmental stages and clinical interview techniques do provide a basis for cross-comparisons and correlation of findings from studies based on his work. The studies tend to support the findings of Piaget and where there are discrepancies, these could be explained in terms of Ausubel's theory. Piaget's developmental stages could be considered to be a special classification of Ausubel's stress on the importance of prior cognitive structure differentiation as the principal determinant of subsequent learning and problem solving performance. The fact that Buell and Bradley (36) found that chemistry students could not separate variables and Lang (103) found that physics students could not perform some types of formal operations shows that Ausubel's theory is more generally applicable and more parsimonious than Piagetian interpretations--these students lacked the necessary subsuming concepts needed in chemistry or physics.

Evaluation in science education continues to suffer from inadequacies in available tests. This is particularly true with respect to measurement of affective variables. Some of the widely used tests are of doubtful validity, probably explaining in part some of the conflicting results reported in the literature. The research that focused on evaluation problems tends to show the futility of evaluation practices not based on a learning theoretical framework. We do not know what learning parameters are being

measured, nor do we know their relation to instructional variables. In this reviewer's opinion, the field of evaluation is desperately in need of support from learning theory.

Various forms of curriculum studies have been among the most common in the past half-century of science education research. These studies tend to show that almost any reasonable curriculum alternative will have success as measured by student achievement and attitudes toward the program; however, they do not tell us how to proceed to design radically more effective programs. None of the national curriculum projects in recent years has been built on a foundation of tenable learning theory and it is not surprising to this reviewer that "seat of the pants" approaches we have used tend to track the same ground with the same limited success.

Several studies were reported using Flanders' (245) method of interaction analysis or other forms of analysis of interaction between teacher and pupils or pupil and pupil. Some studies suggest that pupil achievement and pupil attitudes are better when teachers employ "indirect" questioning approaches rather than "direct" approaches (e.g., asking students for answers to specific teacher-initiated questions). Other studies report success in training teachers to be more aware of their questioning strategies in the classroom and to achieve more indirect strategies. In this reviewer's opinion, the occasionally favorable results of "indirect" methods probably derive from better accommodation to the learner's existing cognitive structure and subsequent sequential development of concepts, with attendant positive affective results. Our research results would be more valuable if studies were framed in terms of learning variables rather than in terms of patterns of interaction.

Studies related to problem solving ability or inquiry abilities continue to be popular for some researchers. These studies almost inevitably suffer from the difficulties associated with measuring problem solving or inquiry skills. The striking gains in these abilities shown by some investigators after a few hours of instruction could not possibly reflect a total reorganization of the individual's cognitive and affective structure needed for permanent achievement with regard to these abilities, and hence the gains must be regarded as evaluation artifacts. The subject of developing problem solving or inquiry abilities is one that has intrigued this reviewer for two decades. A theoretical framework for interpreting the nature and scope of this educational problem is now in preparation.

More than twenty studies dealt with various forms of teacher training programs and their effect on teachers. These studies tend to offer some hope for modifying teacher behavior, if we could agree on the kind of teacher behaviors needed for various learning situations. Most of the studies have an implied bias in favor of one type of teaching behavior and show an inherent assumption that this kind of behavior is the best for all kinds of learning. On theoretical grounds, there is reason to believe that motor skills,

methodological skills and attitude development can require significantly different kinds of experience than that useful for cognitive learning. The bandwagon effort to encourage "inquiry teaching" methods during the 1960's and early 1970's is reflected in the research studies reported in 1972.

Several other categories of research were reviewed and summarized in this report. Mahn (118) and Harty (75) found some disturbing inadequacies in the methods of selection and competencies of science consultants. Philosophical and historical issues important to science education were analyzed in five of the reports. Many science educators have little or no training in the history or philosophy of science, and this may account in part for the atheoretical nature of much of the research in science education.

One of the reasons this reviewer believes the field of science education can be the leading edge in educational research is that a large reservoir of training and methodological skill in research resides in our group as a product of our scientific training. We must avoid narrow conceptions of "scientific method" popular at the turn of the century in sciences and psychology, but current views that stress the human and social nature of science are highly complementary to requirements for better educational research.

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