DOCUMENT RESUME

ED 241 350 SE 044 283

AUTHOR Olstad, Roger G.; Haury, David L.
TITLE A Summary of Research in Science Education -- 1982.
INSTITUTION ERIC Clearinghouse for Science, Mathematics, and Environmental Education, Columbus, Ohio.; National Association for Research in Science Teaching.
SPONS AGENCY National Inst. of Education (ED), Washington, DC.
PUB DATE Dec 83
CONTRACT 400-78-0004
NOTE 161p.
AVAILABLE FROM John Wiley & Sons, Inc., 605 Third Ave., New York, NY 10016 (Contact publisher for price).
PUB TYPE Information Analyses - ERIC Information Analysis Products (071) -- Reports - Descriptive (141)

EDRS PRICE MF01 Plus Postage. PC Not Available from EDRS.
DESCRIPTORS Academic Achievement; Cognitive Development; Elementary Secondary Education; Higher Education; Instructional Materials; Research Methodology; *Science Curriculum; *Science Education; *Science Instruction; Science Programs; *Student Characteristics; *Teacher Characteristics; *Teacher Education; Teaching Methods
IDENTIFIERS *Science Education Research

ABSTRACT

The review of science education research for 1982 includes analyses of 455 studies reported in dissertation abstracts, journal articles, research papers, and papers presented at conferences. The organization of the review is topical. Topic areas include: (1) student characteristics and behavior (cognitive development, conceptual understanding, problem-solving behavior, attitudes, personal attributes, targeted audiences); (2) teacher characteristics and behavior (knowledge, beliefs, and attitudes, self-perceptions, classroom and professional behavior); (3) instructional strategies and environment (instructional systems, problem-solving instruction, experiential learning, laboratory experiences, demonstrations, organizational aids to learning, emphasis on language arts during science instruction, teaching style and techniques, classroom social environment); (4) instructional materials and technology (microcomputers, textbooks, visual media); (5) curricula and programs in elementary, middle, and high school science, postsecondary education, and marine education; (6) preservice and inservice teacher education; (7) research and evaluation practices (quantitative and qualitative methodology, testing, instrumentation, and theoretical considerations); and (8) science education policy and practice. This final section reviews program status; course content; goals, guidelines, and practices; and needs and priorities for research. (JN)

ED241350

A SUMMARY OF RESEARCH IN SCIENCE EDUCATION -- 1982

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in cooperation with the
National Association for Research in Science Teaching

SE044283

December 1983

Preface

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 Clearinghouse 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.

Readers' comments and suggestions for the series are invited.

Stanley L. Helgeson
Patricia E. Blosser
ERIC/SMEAC

This publication was prepared with funding from the National Institute of Education, U.S. Department of Education under contract no. 400-78-0004. The opinions expressed in this report do not necessarily reflect the positions or policies of NIE or U.S. Department of Education.

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Introduction

The practice of reviewing research in science education has a long tradition. It began nearly sixty years ago when Francis Curtis produced the first three volumes of research reviews now commonly known as the Curtis Digests. The practice, in one form or another, has been continued to this day. George Mallison (1977) summarized for the interested reader this ongoing synthesis in the 1975 Summary. Also of importance is the work of Alan Voelker and Charles Wall (1972, 1973, 1976) in "reviewing the reviews" and providing a bibliographic history of research in science education up through the early 1970's. More recently (the last ten years) these reviews have appeared annually in Science Education. By consulting these sources it is possible to construct a year-by-year history of research in science education, back to the first Curtis Digest which reviewed research published prior to 1925. We have a discipline with a rich tradition in research, and research reviews.

Over time, there have been many patterns of organization for these reviews. An examination of the Summaries for the past several years reveals organizational patterns based on the context of the learner (e.g., elementary, high school, etc.), the type of research (e.g., survey, experimental, etc.), the content studied (e.g., teacher education, learning, curriculum development, etc.), and others. There is no perfect pattern of organization--each has its strengths as well as its shortcomings. We have chosen to categorize the studies along the more traditional lines followed, in one form or another, by most of our predecessors. We hope this will enable the reader to locate studies of related interest based on their content, and to gain a perspective of the work in the area over the year 1982.

The studies selected for this review were all published or reported during the year 1982. Some were actually produced prior to 1982, but their abstracts appeared in the 1982 resources used to compile this review. Studies were selected primarily from information in the ERIC (SMEAC) database for that year. Working with abstracts from Current Index to Journals in Education (CIJE), Resources in Education (RIE), and Dissertation Abstracts International, we consulted original sources as available when it was deemed useful or important to do so. From these and other sources a total of 455 reports were examined, presented in this review and included in the references following the summary of research.

Problems identified by earlier reviewers continue to face us as researchers or practitioners who attempt to base practice on research findings. Chief among these are problems related to a lack of theoretical frameworks, univariate analysis of multivariate problems, unwillingness or inability to communicate clearly, lack of translation or discussion of findings for "real world" situations, and the lack of systematic study through longitudinal or cooperative efforts. The underlying problem of external validity, coupled with lack of agreement on goals and priorities, remains to be addressed by most of us. The meta-analysis work of Anderson and his colleagues [see JRST, 20(5)] to be reported in next year's Summary, along with several meta-analyses reviewed herein, which integrate findings of many studies, have the potential of addressing some of these concerns.

We hope readers find this 1982 review in the tradition now well established for science education reviews. If so, it should be useful to researchers in this and related fields, to developers and evaluators of curricula, to students of science education, to teachers and teacher educators, and to others whose interests bring them this way.

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Student Characteristics and Development

The moderating effect of individual differences on learning seems well documented in general terms, but there remain many questions regarding the relative influence of specific differences and the extent to which differences can be accommodated by instructional practice. Studies reported in 1982 which deal with some aspect of differences in student characteristics and behavior are presented in this section of the review. Reflecting the topics of greatest interest during the year, studies are grouped in clusters pertaining to cognitive development, conceptual understanding, problem solving behavior, attitudes, personal attributes, and membership in targeted groups (see Table 1). Most of the studies noted in Table 1 show relationships between student factors and learning outcomes, with the dependant variables related to achievement predominating. The student factors of greatest interest to the 1982 researchers were in the cognitive dimensions. It is noteworthy that student ethnicity received no apparent attention.

In addition to the studies presented here, Anderson (14, 15) provided results of a meta-analysis project which included an examination of previous studies which focused on the relationship between student characteristics and student performance in science.

Cognitive Development

There continues to be much interest in the Piagetian model of cognitive development, with investigators pursuing a variety of research questions. Studies presented here focus on the assessment of cognitive level, group comparisons, the influence of cognitive level on student performance, and attempts to accelerate cognitive development through instructional intervention (see Table 1). Five reviews of previous research are also presented. Critiques of previous studies focusing on student cognitive variables were also contributed by Blosser and Mayer (44).

Assessment of Cognitive Level

A new group test intended to measure formal operations in reasoning was developed by Maggio (252) who modified an existing instrument to include test items measuring correlational reasoning. A variety of procedures was used to demonstrate the reliability ($\underline{r}$ = 0.78) and validity of the instrument based on the more diverse sample, it seems, would be in order.

Table 1

Frequencies of Reports Documenting the Interaction of Student Factors With Learning Outcomes

Student Factor	Learning Outcome					
	Achievement[a]		Skills[b]		Attitudes[c]	
	R	NR	R	NR	R	NR
Level of Cognitive Development	18	3	3	1	1	0
Prior Knowledge or Achievement	4	0	1	0	0	0
Preconceptions	8	0	4	0	0	0
Cognitive Style	5	0	1	0	0	0
Locus of Control	1	1	0	0	2	0
Aptitude or Language Arts Proficiency	10	1	1	1	1	0
Personality Attributes	3	0	1	0	1	0
Personal History or Age	3	1	1	0	4	1
Gender	5	1	3	0	7	0
Attitudes	3	2	0	0	NA[d]	

Note. Reports contributing data to more than one of the above categories have been included in all appropriate frequencies. Relationships are all positive for continuous variables.

R Number of reports providing evidence for a relationship

NR Number of reports indicating no consistant evidence of a relationship.

[a]Academic performance or understanding in science.

[b]Skills of inquiry, reasoning, problem-solving, or language arts.

[c]Positive attitudes toward science or science classes.

[d]Not applicable.

Birdd (40) provided further evidence that cognitive level can be measured by a variety of means. Testing 194 students of grade 9, Birdd obtained comparable results from both a group test and a process of questioning during a class demonstration. Pearson (310), employing 192 secondary students, also reported no significant difference between group testing and individual interviews on four of eight Piagetian tasks examined.

The performance of 394 college students on four Piagetian tasks was examined using a microcomputer. DeLuca (95) developed the computer version o the tasks in order to compensate for perceived deficiencies of traditional testing, such as gender bias, misleading perceptual cues, familiarity with the tasks, and the economics of data collection. He discusses the resultant patterns of problem solutions and the relative means of using the computer format.

Group Comparisons

In a study of Saudi Arabian college students, El-Sowygh (109) found the following distribution of cognitive levels: 15.7 percent at the level of formal operations, 39.5 percent in a transitional phase, and 14.8 percent at the concrete stage of mental operations. It was noted during multiple regression analysis that from among 14 demographic and academic variables, formal reasoning was most strongly related to mathematics GPA and amount of coursework in science and engineering. Of 420 community college biology students, Dettloff (96) estimated nine percent to be at the level of formal operations, with several background characteristics, verbal ability, and ability in mathematics accounting for 42 percent of the variance in cognitive level.

Hale (157) found only four percent of 59 medical students to demonstrate formal operations, with 96 percent in the transition from concrete to formal operations. In other study of medical students, Hale and Witzke (158) found 57 to 91 percent (depending on the problem solving case) of 67 medical students able to demonstrate formal operations, with the proportion varying according to the tasks being assessed. Song (378) studied prospective secondary science teachers and found 40 percent to be at the level of formal operations. Science achievement, cognitive style, and IQ were found related to cognitive level.

In a study of 80 adolescents aged 15 through 19 years, Ehindero (106) used analysis of variance to detect significant differences in cognitive development among four Nigerian groups. A higher proportion of schooled subjects than nonschooled subjects exhibited formal operations, while nomadic subjects performed spatial tasks more successfully than did nonnomadic subjects. In another study of Nigerian children (n = 300), Ehindero (107) found the rate of cognitive development among subjects to be slower than that reported in technologically advanced cultures. Although finding no uniform progression of development, a gradual trend was observed with conservation of displacement volume acquired last. Billeh and Khalili (39) studied the level of cognitive development among students of grade 11 in Jordan, finding 17 percent to be at the level of formal operations and 52 percent at the concrete stage of mental operations, with some gender differences being reported.

Sunal (395) reported his work with hearing impaired adolescents, noting large differences between such students and their peers, with differences in cognitive development accounting for 10-15 percent of the difference in science achievement between groups as measured by standardized tests. The discrepancy in cognitive development, however, seemed greatly reduced by sustained exposure to science instruction rated high in variety, activity, and amount of feedback. Tipps (405) studied another targeted group, gifted students, and found their cognitive development to be more advanced than that of nongifted peers. Even so, among the factors examined, age was the strongest predictor of cognitive level, followed by achievement in science.

A comparison of a different nature was made by Behinaein (31) who compared performance in content-free logic tasks with performance in logic tasks associated with the specific content of three academic disciplines. Although subject expertise in a particular discipline had no significant effect on performance of content-free tasks, subjects presented with a logic task in their area of expertise outperformed subjects having expertise in other disciplines. This study and others focusing on group comparisons illustrate the variety of factors influencing cognitive development and the accurate assessment of that development. Cultural factors, organismic variables, academic experience, and aptitude all seemingly modulate the progressive nature of cognitive development. But can cognitive development be intentionally accelerated through instructional intervention?

Accelerating Cognitive Development

Selecting 25 field-dependent, undergraduate science students functioning at the level of concrete operations, Withers (439) employed manipulative and written exercises to promote formal reasoning. A significant treatment effect was observed, with students functioning at the formal level on tasks related to instruction which involved manipulation of variables and combinatorial reasoning but the effect did not transfer to other tasks--not related to instruction--involving inverse proportionality. Similar results were obtained by Lawson and Snitgen (230) who investigated the effect of instruction on 72 college biology students. The proportion of students classified as formal operational increased from 11.1 percent pretest to 75 percent on the posttest, but other evidence implies a substantial test-retest effect. Again, transfer of formal operations to tasks unrelated to instruction was not demonstrated. Huh (191) employed a highly structured instructional sequence to effect a shift in level of mental operations among 57 college students and provide evidence of a significant treatment effect which included some transfer of reasoning skills to novel situations. The efficacy of the instructional technique seems unresolved, however, since the research design involved a treatment versus no treatment comparison. A correlation was noted between degree of field independence and a shift toward formal operations. Results of the Adolescent Reasoning Project (Laetsch and Linn, 222) also provide evidence of a relationship between reasoning and cognitive style; and the problem of transfer was again shown; students do not readily generalize mutual operations to novel situations immediately after training.

In a related study, McKenzie and Padilla (271) tested the hierarchy of the Piagetian model to determine whether or not proportional and probabilistic reasoning are prerequisites for correlational reasoning. After examining the test response patterns 579 students of grades 6 through 12, they found that only 45 percent of the results fit the logical hierarchy. In another attempt with 200 students of grades 9 and 10, results were still inconclusive.

Convinced that instruction does influence cognitive development, Villavecincio and Tayko (415) have developed instructional units in biology which are intended to promote logical thinking skills. Taken into account were the cognitive demand of textbooks and the influence of the teacher's levels of cognitive development on students.

Despite the preponderance of evidence supporting the Piagetian model of cognitive development, however, there remain some ambiguities regarding the nature of the developmental sequence and the overall effect of instruction on the rate of development. The influence of cognitive development on student performance, though, seems well documented.

Correlates to Cognitive Development

There continues to be much interest in documenting the magnitude and nature of the relationship between student performance and level of cognitive development, particularly the association between cognitive development and academic achievement. Studies reported by Dettloff (96), Song (378), Payne (308), Al-Mazroe (9), Bender and Milakofsky (34), Lawson (229), Chiappetta and Russell (70), Staver and Halsted (383), and Tobin and Capie (407) provided evidence of a significant relationship between achievement and level of cognitive development among students in middle school, high school, and college. Using multiple regression analysis, Chiappetta and Russell (70) provided evidence that level of cognitive development accounted for more of the variance in tests of achievement than did modification of instructional treatment. Furthermore, Lawson (228, 229) has shown that a strong relationship remains between achievement and level of cognitive development when the effect of an intelligence factor is removed.

Using multiple regression analysis to estimate the relative contributions of academic engagement, locus of control, and level of cognitive development to inquiry process skill acquisition and retention among 156 middle school students, Tobin and Capie (407) found degrees of formal reasoning to be the strongest contributor, accounting for 32 percent of the variance in acquisition and 41 percent of the variance in retention. A central question regarding the relationship between achievement and level of cognitive development pertains to the directionality of influence. Can level of cognitive development be shown to influence achievement? Lockett (243) provided evidence that students having a greater understanding of class inclusion outperform their peers in an instructional program emphasizing classificatory reasoning, but what of the effect of general cognitive ability on performance? In a study of high school chemistry students, Howe and Durr (189) found students in the late concrete stage of mental operations unable to master any aspect of the mole concept, with performance on chemistry test items generally parallel to level of cognitive development. Among their conclusions is the notion that many concepts in chemistry are beyond the mental abilities of many high school students. Selman, Krupa, Stone, and Jaquette (362) studied the cognitive development of very young students, preschool through grade 1, and found evidence supporting the hypothesis that cognitive development generally preceeds conceptual understanding. The results were not consistent, however, since knowledge in some areas seemed to preceed shifts in logical thinking. Such inconsistencies were attributed to motivational factors. Given the mass of evidence for a link between cognitive development and achievement, it seems appropriate for more studies like these which focus on the conceptual understanding, reasoning skills, and behavior associated with specific shifts in cognitive development.

Bender and Milakofsky (34), for example, found proportional reasoning to be implicated in difficulty among college students with some chemistry concepts. Bass and Maddux (28) found that students who function at the level of formal operations constructed significantly better explanations following instruction than did peers functioning at the level of concrete operations. Since there were no significant differences between the two groups on a test of knowledge, it seemed appropriate to attribute the difference in quality of explanations to level of cognitive development. However, the link between level of cognitive development and academic behaviors is not clear. Babel (22), for instance, attempted to relate level of cognitive development to selected science process skills with mixed results. The sample was heavily biased toward pre-concrete subjects, however, so the results do not seem reliable. In an attempt to teach questioning skills to secondary chemistry students, Hartford a[illegible]od (167) realized a significant treatment effect but fo[illegible] no evidence of an effect related to level of cognitive development. Though problems of group equivalence limit the generalizability of these results, the results do illustrate that students at a variety of stages in cognitive development can learn behavioral patterns, such as questioning skills. But understanding, conceptualization, and effective use of the information gained from the questioning may be another matter.

Furthermore, Lawson (228) has provided evidence that the mitigating effects of other factors must be considered. In a comparative study of grade 7 students and college students, he found differences in the relative contributions of intelligence, cognitive style, prior knowledge, and level of cognitive development. Though level of cognitive development accounted for the largest proportion of variance (27 percent) on a test of scientific reasoning among students of grade 7, it accounted for a much smaller proportion of variance (1 percent) among college students. Cognitive style and prior knowledge were much more influential factors at the college level, accounting for 19 percent and 9 percent, respectively, of the variance on a test of scientific reasoning.

Reviews of Previous Research

In a comprehensive overview of adolescent thought, Vaidya (413) described his work and the findings of numerous studies conducted by his students. The findings include evidence that concrete operational thought dominates the adolescent years, that cognitive demand varies among school subjects, and that adolescent students are typically unable to test hypotheses or treat more than one variable at a time. In order to assess adolescent thought patterns and level of cognitive development, Vaidya has suggested that, teachers must, like Piaget, attempt to interpret the inaccurate student responses to questions.

Piagetian research has been reviewed many times in a effort to discern overall trends in findings, applications of theory, and methods of research. Lawson (226) marshalls evidence to demonstrate the validity of studying the development of general cognitive operations in the manner described by Piaget. In another synthesis from past literature, Lawson (227) assumed that student reasoning abilities should be a concern among science educators, and he argues that causal reasoning schemata should be taught during the process of testing hypothesized relationships. The efficacy of such efforts would seem a valuable focus of research given the ambiguities regarding the transfer of reasoning skills to novel situations.

Other areas needing more study are mentioned by Linn (241) who cited many previous studies in her advocacy of elucidating practical factors in reasoning, such as aptitude, environmental conditions, and effects of instruction. Nagy and Griffiths (292) warned, however, that much research suffers from methodological flaws and divergent interpretations of Piaget's model of cognitive development. They question the simplistic relationships often assumed between the outcomes of reasoning and the mental operations used, and they point out inconsistencies in efforts to accelerate cognitive development through instruction.

Conceptual Understanding

There has developed recently a strong research interest in the conceptions students hold regarding natural phenomena. Hawkins (169) has listed conceptual obstacles which inhibit understanding of scientific concepts, and Niddzielski and Walmsley (296) identified many misconceptions related to chemistry and mathematics that high school students bring to their college experience. Several investigators have provided evidence that all students adopt conceptions of phenemona which to them seem logical and coherent, and which influence the rate and extent of learning in science classrooms (Leith, 235; Gilbert, Osborne, and Fenshorn, 141; Andersson, 16; Green et. al, 148). Citing various misconceptions regarding motion, Green et. al argue that teachers must identify the serviceable misconceptions held by students and, then, adjust instruction to focus on conceptual obstacles. Andersson (16) concurred and has reported several examples of faulty student reasoning based on misconceptions. Results of interviews and test responses demonstrate the diversity of misconceptions and the need to identify and categorize misconceptions in the various disciplines of science. For example, after examining a variety of misconceptions in biology, Fisher and Lipson (123) have developed a taxonomy of errors, which includes: (1) primary encoding errors (faulty information), (2) errors of relationship, (3) errors of processing encoded information (faulty use of algorithms), and, (4) errors of management (faulty logic or models, and inappropriate use of knowledge).

Many investigators have focused on specific misconceptions, particularly in the physical sciences, and have documented the descriptive influence of misconceptions in problem solving, explaining phenemona, and applying knowledge. In the domain of physics, some aspects of an impetus theory of motion have been studied by McCloskey (263, 264), McCloskey and Kohl (265), and McCloskey and others (266); student understanding of the "at rest" condition has been studied by Minstrell (279); conceptions of gravity have been studied by Watts (424); conceptions of force have been studied by Gilbert and others (140) and Clement (73), and conceptual change related to special relativity has been studied by Hewson (175). These studies provide evidence that, although instruction can correct some gross misconceptions, naive beliefs are generally left unaltered if not addressed directly through instruction. Furthermore, McCloskey and Kohl (265) have demonstrated that such misconceptions are not merely vague notions about abstract situations. That is, results indicate that misconceptions regarding curvilinear motion are manifested in situations where people observe and interact with moving objects. Minstrell (279) has described various strategies for eliciting student misconceptions and factors influencing changes in student understanding, and he described a strategy for improving students' conceptual understanding. P. Hewson (175) has also described an instructional strategy which focuses directly on the preconception of students, and has provided evidence that the metaphysical commitments of students also play a significant role in conceptual understanding, even when a student is unable to articulate the notions in a detailed fashion. Even among students committed to causal explanation, M. Hewson (173) has shown that alternative conceptions are widespread which seem unrelated to aptitude or level of cognitive development. Student age, home language, and exposure to physical science instruction were also unrelated in this particular case. M. Hewson has elsewhere (174) proposed, however, that non-Western students experience conceptual obstacles in science as a result of cultural, environmental, linguistic, and religious factors. This is seemingly a fertile area for research. How pervasive are such factors in restraining conceptual understanding in science?

Some investigations have focused on concepts in chemistry, with Anamuah-Mensah (11) identifying eleven conceptual errors associated with volumetric analysis, Cervellati and others (64) reporting misconceptions related to the mole concept, and Shepard and Renner (365) examining misunderstanding of the physical states of matter and chemical changes. Shepard and Renner provide further evidence that concepts being presented in senior high school are not being learned.

In the life sciences, student understanding of the following were studied: the concept of life (Brumby, 54), the concept of animal (Bell and Barker, 33; Bell, 32), concepts related to the circulatory system (Catherall, 63), various concepts in genetics (Longden, 247; Costello, 83), concepts related to photosynthesis (Simpson and Arnold, 367), and concepts related to tropical diseases (Okafor, 302). Brumby interprets her results as illustrating the anthropomorphic orientation of students and their ability to incorporate principles of experimentation into explanations. She questions the current emphases in high school on a compilation of scientific facts and performance on objective examinations, while schools fail to adequately encourage students to integrate knowledge in order to develop a functional understanding of the world around them. Longden (247) has provided evidence that some misconceptions may, in fact, be promoted by the manner in which concepts are taught, citing the frequent representation of meiosis as a series of inanimate stages.

Considering the influence of student concepts on learning from a different perspective, Simpson and Arnold (367) selected a major concept in biology, photosynthesis, and examined mastery of selected prerequisite concepts among over 500 students of ages 11 to 16 years. After constructing a concept map focusing on photosynthesis and adopting a model of concept mastery, they analyzed conceptual understanding on the basis of personal interviews and performance on written tests. They found evidence of great inadequacies in prerequisite understanding and a gap between actual concept attainment among students and the level of attainment assumed by teachers. Simpson and Arnold also question the nature of curriculum content and suggest that prerequisite conceptual understanding be examined more carefully before topics are judged intrinsically too difficult for high school students because of their level of cognitive development.

Among concepts in the earth sciences, studies have focused on the concept of geologic time (Ault, 20), concepts related to mineral classification (Finley, 121), and selected concepts related to the seasons, day and night, solar energy, the changing earth, and the interdependence of humans and environment (Rollins and others, 345). Following a study of student ability to integrate knowledge from geology lectures, textbook reading, and laboratory sessions, Ulerick (412) cited prior knowledge of relevant concepts as a major contributor to learning.

Though most researchers express the opinion that misconceptions impede learning and must be confronted more directly, the relative effect of various misconceptions has received little attention. On the basis of interviews with elementary school students, Ault (20) has suggested, for instance, that the concepts of time held by young students pose no more of a barrier to understanding geologic history than do the concepts held by students of other age groups who are ignorant of geologic events. Is such generally the case? Are there no significant interactions between misconceptions and age, level of cognitive development, academic experience, or other variables of traditional interest? There seem many unanswered questions regarding the interaction of conceptual understanding, learning, and other factors identified as influencing academic performance.

Perhaps more fundamental than specific misconceptions related to the various scientific disciplines are general conceptions of physical causality from a Piagetian perspective (Acuna, 4; Fraser-Abder, 129; Hann, 161; Wolfinger, 441), and the effect of science teaching on conception of causality among young children. These studies all report significant treatment effects among students at the preoperational, transitional, and concrete operational stages of cognitive development, with students progressing through precausality forms of animism and dynamism prior to developing notions of true causality. Despite significant treatment effects, however, Wolfinger (441) has shown that students who learn to define living in terms of observable characteristics may continue to employ animistic thinking. Findings also indicate that science teaching may affect the conceptions of causality held by preoperational children and concrete operational children differentially. Given the centrality of physical causality to concepts in science, it seems imperative to explicate the development of personal beliefs regarding causality and the implications of such beliefs for instructional practice. It seems a better understanding of the interaction of cognitive development, notions regarding causality, and conceptual understanding, particularly among young children, would provide a firmer foundation for advocating particular instructional strategies in science. The need seems especially acute given Vaidya's (413) evidence that children hold to their thoughts firmly. As Hewson (173) has suggested, if nothing is done during instruction to reduce the status of irreconcilable misconceptions, science concepts will be rejected, rotely memorized, or relegated to an abstract position bearing no relationship to concrete events in the world.

Problem-Solving Behavior

A popular movement among science educators in recent years has been the effort to establish problem-solving as a major focus of instruction. Although helping students use information to solve problems seems a worthy endeavor, the appropriate content of problem-solving instruction seems somewhat unclear, and the objectives somewhat ambiguous. Among researchers there have been attempts to: (a) elucidate the strategies used by successful problem solvers, be they students or practitioners having demonstrated expertise, (b) prescribe instruction that promotes problem definition and solution, (c) identify correlates to successful problem-solving behavior, and, (d) identify specific difficulties encountered by students when attempting to solve problems. The studies reviewed here extend such efforts and pose some additional questions for investigators to consider.

Chi (68) summarized the findings of eight studies which focused on problem-solving strategies. The findings suggest differences between experts and novices in the way problems are perceived and in the manner relevant knowledge is applied to problems. Domain-specific knowledge deficiencies seemingly limit the range of inferences generated by novices in their attempts to solve problems. Stewart (389) studied the relationship between knowledge and problem-solving behavior in the domain of genetics. He distinguished meaningful problem solving performance from what is merely successful performance with routine use of algorithms, suggesting that those who construct meaningful problem solutions will be able to offer adequate explanations for each step in the process. Stewart has provided evidence that students can develop algorithmic strategies which lead to correct problem solutions even though significant misconceptions regarding underlying relationships are retained. The mental operations associated with combinatorial logic were performed, but lack of knowledge prevented a coherent conceptual understanding. Such findings do not, however, render invalid the search for domain-independent problem-solving strategies. Bapat and Kiellerup (26) examined subjects representing a broad range of expertise in chemistry, and found some evidence of generic strategies. No strong correlates were found, however, between problem-solving behavior and IQ or personality variables, leaving unresolved the relative contribution of conceptual understanding. If "scientific reasoning" can be assumed to be related to problem-solving behavior, Laetsch and Linn (222) have provided evidence of links between reasoning skills and both general ability and cognitive style. It is noteworthy, however, that their findings fail to demonstrate a tendency among secondary students to generalize skills of inquiry.

While attempting to elucidate problem-solving strategies in the specific domain of genetics, Tolman (409) isolated some common difficulties among high school students. On the basis of findings, he proposed a modified instructional sequence intended to reduce the conceptual difficulties students seem to have with the content. This, it seems, is a productive area for research in many science domains, identifying the sequence of instruction that most effectively promotes functional use of domain-specific knowledge by students. Reif and Heller (327) also prescribed an instructional model intended to facilitate problem solution, a model which begins with generation of a domain-independent description of the problem, but proceeds to a redescription of the problem in terms of a domain-specific knowledge base. Supporting results from experimental testing of tne model were presented.

Two other studies focused on difficulties encountered by students. Kramers-Pals et. al (215) considered recurring difficulties associated with problem analysis, planning a solution strategy, and performing routine operations, while Phillips (317) considered what is often considered a routine operation, measurement. The very real barriers related to measurement were clearly demonstrated by Phillips who studied the attempts of students in grades 1 through 6 to perform simple measurement operations. He found that only 62 percent of the grade 6 students tested could use three different sticks of varying lengths to compare the heights of two block towers. Such results illustrate dramatically the extent to which fundamental processes are being neglected in some educational settings.

Results of research in problem-solving demonstrate the need to help students make functional use of knowledge. Beyond elucidating misconceptions and assessing levels of cognitive development, researchers must identify domain-free and domain-specific methods of information processing, and strategies for bringing knowledge to bear on relevant problems. As Fuller (131) has suggested, the change in research emphasis from problems to problem solvers has unified research to some extent, but there must be increased efforts to integrate researcnt domains and research of cognitive development with problem-solving research.

Champagne and Klopfer (66) have provided some indication of the interplay among conceptual understanding, cognitive development, and problem solving behavior. Using factorial analysis to test the efficacy of a causal model of student achievement, they obtained some measure of the relative contributions of conceptual understanding, level of cognitive development, and mathematical aptitude among college students in a physics course. Because problem-solving efforts generally involve the use of mathematical algorithms, and because mathematical aptitude as defined in Champagne and Klopfer's study includes facility with some problem-solving skills, it is here assumed that mathematical aptitude provides at least an indirect measure of facility with a subset of problem-solving skills. In a study of 900 high school students, for example, Cox (86) obtained evidence that aptitude in mathematics is among the strongest predictors of science process skill achievement. Champagne and Klopfer (66) found physics achievement, then, to load most heavily on two factors--acceptance of Newtonian physics and aptitude in mathematics--with the three strongest components of the Newtonian physics factor being conceptual understanding of motion (.73), formal reasoning ability (.88), and mathematical skill (.40). The three strongest components of the mathematical aptitude factor were mathematical skill (.89), degree of exposure to mathematics in high school (.50), and degree of exposure to mathematics in college (.44).

Among variables related to experience and achievement in mathematics and science, then, formal reasoning, conceptual understanding, and mathematical problem-solving skills seem most strongly related to achievement on physics test emphasizing mechanics. Acknowledging the rather indirect measure of mathematical problem-solving skill and the use of an unpublished measure of cognitive development, these results of Champagne and Klopfer provide some circumstantial evidence for the relative contributions of cognitive development, conceptual understanding, and problem-solving ability in the domain of mechanics.

Attitudes

There continues to be much research interest in student attitudes toward science, with investigations reported in 1982 focusing on the link between attitudes and achievement, the effect of attitudes on course selection, and the factors influencing attitudes. Being mindful of the common practice among researchers to use self-report instruments to collect data regarding attitudes and the tendency to interpret verbal expressions and response to questionnaires as valid indicators of attitudes, there will be made here no distinction between expressed attitudes and attitudes truly held. The reviewers believe, however, that a fundamental weakness in attitude research is the measurement problem and an uncautious reliance on self-report instruments. Critiques of nine previous studies focusing on student attitudes or attitude assessment were contributed by Blosser and Mayer (42).

Attitudes and Achievement

After a review of previous research, Fraser (127) concluded that any relationship between attitudes and achievement is weak, both generally and in science. He has recommended that science teachers focus directly on achievement, rather than attempting to promote positive attitudes as a means of improving achievement. Kahle (202) also provided evidence that positive attitudes are not necessarily accompanied by increased achievement. Referring to results of the 1977 National Assessment of Educational Progress (NAEP) in Science, she has shown that even though ethnic minority group members (blacks in this case) express more positive attitudes than do whites toward science, science-related careers, and scientific research, their achievement in science as measured by the NAEP cognitive items is well below that of whites. These findings are disappointing, and the seemingly logical connection between attitudes and achievement may be questioned, but perhaps an underlying relationship is being systematically masked by moderating variables.

Hough and Piper (188) have provided some evidence for a link between attitudes and achievement. Using residualized gain scores to control individual differences among 583 students of grades 4, 5, and 6, they found a correlation of 0.45 between achievement and attitudes. Although multiple regression techniques could have been used to provide more information regarding the relative contributions of attitudes and other variables, this study does show the presence of a relationship for a moderately sized sample of students prior to years of segregation due to course selection bias. Hamilton (160) used a similar sized sample (n = 576) of Jamaican students to seek a relation between attitudes and achievement on external science examinations. A significant positive correlation of 0.29 was found between attitude and achievement, with the correlation for females (r = 0.38) being much greater than that for males (r = 0.20).

Another attempt to link attitudes and achievement in science was reported by Mitchell and Simpson (282). Working with 113 community college biology students, data were collected on measures of achievement, attitude toward biology, attitude toward the institution, and academic self-concept. While there was no evidence of a change in attitudes during the course, there was a significant positive correlation (r = 0.26) between achievement and attitude toward biology. Other findings included a significant positive correlation (r = 0.38) between achievement and academic self-concept and a significant negative correlation (r = 0.28) between achievement and attitude toward the institution. Regarding achievement and attitude toward science, then, we are left with a moderate coefficient of correlation. This general finding was corroborated by Haladyna and Shaughnessy (155) whose meta-analysis of previous studies revealed a consistent, but weak, association between achievement in science and attitudes toward science.

Effect of Attitudes on Science Course Selection

Among the subtle influences attitudes may have on achievement is included the modulation of student selection of academic coursework. That is, the relationship between attitudes and achievement in the upper grades may be restrained by a restricted range of attitudes due to self-selection bias, with students who are not attracted to science opting out of science coursework. In a study of nearly 1300 students in grades 9 through 12, Pollack (321), for example, found career goals and interest in science to be the primary reasons given by students who elect to continue in science past grade 9. More moderate contributions to the decision appear to be the influence of others, particularly parents, and a previous history of obtaining good grades in science. Students deciding not to continue on in science, however, cite poor grades in science as a very important factor and the perceived difficulty of science courses as a moderately important factor.

Louwerse (248) also provided evidence that students of grades 9 through 12 (n = 790) continue in science because of positive attitudes toward science and experiential learning, parental influence, and positive feelings for science teachers. Counselor influence, a desire to become a scientist, or the effect of science on society were not instrumental factors. Also, in a study of 889 Nigerian students in forms III through V, Daramola (92) provided evidence that attitudes toward physics, career aspirations, and aptitude in mathematics were isolated as factors influencing enrollment in physics. Of the students not enrolling in physics, 84 percent at Form IV and 79 percent at Form V cited level of subject difficulty as a reason for not taking physics.

The four studies reviewed here, all based on moderately sized samples, demonstrate the influence of attitudes on student selection of coursework. Such findings reinforce arguments for elucidating the role of attitudes toward science and for considering attitudes a prime focus for research. More powerful research is needed, especially research regarding the determinants of attitudes, the effect of instruction on attitudes, and the indirect influence of attitudes on achievement in science.

Determinants of Attitudes Toward Science as a Subject

Investigators provided evidence for a variety of factors influencing attitudes toward science, including: some aspect of previous academic experience in science (Akinmade, 6; Mazhari, 262; Levin, 239), gender (Kull, 218; Levin, 239; Steinkamp, 387; Grose and Simpson, 152; Haladyna and Shaughnessy, 155), grade level (Akinmade, 6; Levin, 239), IQ (Kull, 218), the topics or activities associated with science classes (Lazarowitz et al., 232; Dawson and Bennett, 93; Ramadas and Kulkarni, 326), motivation for learning (Haladyna, Olsen, and Shaughnessy, 156; Kull, 218), attitude toward school (Akinmade, 6), teacher characteristics or behavior (Lazarowitz et al., 232; Haladyna et al., 156), and factors related to student personality (Haladyna et al., 156). Haladyna et al. also provided evidence that student's out-of-school background experiences may have little or no systematic effect on attitudes in areas where the variance in family background experiences is not large. With few exceptions, the results demonstrating a gender effect showed males to have more positive attitudes toward science than females. Rubba and others (350) compared the effects of three different courses--a biology course, a science fiction literature course, and an English composition course--on attitudes toward science, and found no measurable treatment effect.

Regarding the relationship between attitudes and the topics associated with science coursework, the study by Grose and Simpson (152) provides some noteworthy findings; they surveyed the attitudes of 120 introductory college biology students toward the theory of evolution. Given the recent public controversy regarding the teaching of evolution in the public schools, it would be valuable to sample student notions regarding the status of the theory. A thin majority, 54 percent, expressed some sort of positive support for the theory, with a significantly greater proportion of females than males expressing support. There were not significant differences due to religious preference (Protestant vs. non-Protestant), major (biology vs. nonbiology), or influence of a high school biology teacher. Interestingly, there was an interaction effect with gender and influence of the biology teacher, with females being significantly more influenced in their support of the theory by high school teachers. As might be anticipated, subjects who perceived their church as greatly influencing their thinking did express significantly less support for the theory of evolution. Methodologically, the study seems sound, but the reviewers do have some concerns regarding the validity of the instrument, and hence, the usefulness of the findings. Though Grose and Simpson allude to weaknesses introduced by the out-of-date vernacular of the attitude scale (published in 1931), there should perhaps be more concern regarding the inaccurate portrayal of scientific epistemology and promotion of a false dichotomy of personal beliefs. Regarding epistemology, the tentativeness of empirical models is commonly acknowledged, so words such as "right" and "truth" should be used with caution in conjunction with scientific theories. Regarding the false dichotomy, many people of religious faith, including Protestants, find no inherent conflict between theories of evolution and either a belief in God or accounts of Creation such as those of the Bible. It is suggested, then, that studies such as the one described here employ an attitude scale that is more current, in terms of both language and epistemology.

The study by Haladyna et al. (156) is particularly noteworthy for several reasons: it was systematically developed from a theoretical base, it encompassed many predictor variables (39) rather than focusing on just a few, and the stratified random sample was representative of a large geographical region (Oregon) rather than a single school or district. Taking advantage of a relatively large sample size (n = 1962), they were able to go beyond calculation of correlations to multiple regression analysis. Among the array of findings, are three of particular significance: the apparently strong influence of student fatalism (likely a derivative of locus of control) on student attitudes (accounting for 24.4 percent of the variance among grade 9 males and 28.0 percent among grade 9 females), teacher influence of student attitudes (accounting for 27.2 percent of the variance in attitudes among grade 9 males and 32.5 percent of the variance among grade 9 females), and the impact of various aspects of the learning environment on the attitudes of students (accounting for 23.3 percent of the variance among grade 9 males and 32.1 percent of the variance among grade 9 females). Overall, the best regression models accounted for 39.0 percent of the variance in attitudes among grade 9 males and 45.5 percent of the variance among grade 9 females. Because regression analyses were carried out separately for males and females, and for grades 4, 7, and 9, there is, unfortunately, no estimate of the effect due to gender or grade level. A meta-analysis by Haladyna and Shaughnessy (155), however, indicated gender as a significant contributor to attitudes, accounting for an average 3.2 percent of the variance. Given Akinmade's (6) evidence that positive attitudes are negatively associated with grade level, corroboration of the trend using a large sample would be valuable, particularly in light of the evidence presented in the previous section that attitudes have an effect on student selection of science coursework. Results of the study by Haladyna et al. (156) indicate quite clearly, though, the educationally significant influence of teachers and classroom environment on the attitudes of students toward science. These results demonstrate the value of regional studies and provide support for additional efforts such as that initiated by Simpson and Troost (368). They have also developed a comprehensive and theoretically systematic study which will consider the influence of personal, home, and classroom variables on attitudes and achievement in science among students of grades 6 through 10. The large sample size of the study (approximately 4500) and the socioeconomic diversity of the subjects should provide very reliable data.

Personal Attributes

A few studies focused on factors related to personal attributes, including such variables as: cognitive style, cognitive preference, hemispheric preference, test anxiety, academic self-concept, academic engagement, and locus of control. Since there was little convergence of research interests in this category, the relevant studies are here treated individually or in small clusters. Given the magnitude of variance in student performance generally unexplained by other student characteristics or behavior, it seems unfortunate that more students do not focus systematically on personality variables or other factors related to personality.

Some aspect of cognitive style was addressed by Schenker (358), Samers (354), Anderson (12), and Poslock (323). Samers reported on the relationship between continuing education motivation and cognitive style among scientists and engineers. After studying 350 subjects associated with 19 organizations, he found scientists and engineers to be significantly more field-independent than the general populace, a preference for non-lecture classes among field-dependent subjects, an intolerance of seminars among the highly field-independent, and the importance of "advancement" and "knowledge" as motivators over "requirements" or "diversion" for all subjects. Poslock (323) also found evidence of an interaction between cognitive style and mode of instruction among 80 high school students, noting students characterized as broad categorizers (Wallach and Caron Category-Width Test) to be at a disadvantage when abstract concepts were presented inductively.

Schenker (358) and Anderson (12) both studied the effect of matching the cognitive styles of students and instructors. Working with 129 students and 6 teachers of grade 7, Schenker found no evidence for an effect of cognitive style on achievement in any of four subject areas, including science, or on self-esteem. There was some evidence, however, that certain elements of student cognitive style were associated with achievement, attitudes, and self-esteem. Anderson studied 60 community college chemistry student who were matched to their proctors with regard to cognitive style, and she, too, found no evidence of an effect due to matching. Analysis of variance did indicate, however, significantly increased achievement among those of greater field independence, and significantly more positive attitudes toward proctors and a personalized system of instruction among those of greater field dependence. No evidence was gained from either study, then, that matching the cognitive styles of students and instructors has any significant effect on learning.

Tamir, Penick, and Lunetta (400) and McNaught (272) focused on cognitive preference, with Tamir et al. measuring its effect on creativity, and McNaught measuring its effect on achievement in chemistry. In a science class for nonscience majors (n = 135), Tamir et al. found gains in creativity correlated with a high preference for questioning. This particular preference, characterized as "intellectual curiosity", was taken as evidence for a link between creativity and a distinct orientation toward information processing. It should be noted that two of the four cognitive preference subscales demonstrated unsatisfactory reliability, so cognitive preference was severely restricted to two levels, thereby constraining interpretation of the findings. Working with 304 chemistry students of grade 12, McNaught (272) obtained evidence that students having a strong preference for critical questioning and learning principles achieved significantly more on standardized examinations, particularly on test items above the knowledge level of Bloom's taxonomy.

Dunn, Cavanaugh, Eberle, and Zenhausern (101) studied hemispheric preference as an element of learning style. The learning style characteristics associated with hemispheric preference were assessed among 353 biology students of grades 9 through 12. The following were associated with a right hemispheric preference: preference for dim illumination, tolerance of extraneous sounds, need of an informal environment, lack of motivation and persistence, and a preference for tactile stimulation. Evidence for the validity and reliability of the Differential Hemispheric Activation test was not provided, nor was there any evidence provided that this cluster of apparent preferences has any significant relationship to learning.

Aspects of self-concept as they relate to achievement were studied by Hanshaw (162) and Mitchell and Simpson (282). Though primarily concerned with the relationship between attitudes and achievement, Mitchell and Simpson did find a significant positive correlation ($r = 0.38$) between academic self-concept and achievement among 113 community college biology students, stronger than the association between attitudes and achievement. Hanshaw (162), working with 46 college students in a science class for nonscience majors, failed to find any evidence for a relationship between self-concept and individual achievement, using either correlation techniques or multiple regression analysis. It should be noted that results are likely unreliable due to use of an inadequate ratio of subjects to variables (less than ten to one). In tests of the effect of anxiety on achievement, some significant associations were found, but there were no consistent patterns across groups that seem readily interpretable.

Finally, four investigations considered effects related to locus of control orientation. In a study of the potential interaction between locus of control and a personalized system of instruction, Russock (352) found no evidence of an interaction, but he did find a positive relationship between internality and positive self-concept. Tobin and Capie (407) focused on the relationship among locus of control orientation, level of cognitive development, academic engagement, and achievement with inquiry process skills. Testing 156 students of middle school science classes, locus of control was not found to be related to process skill acquisition or retention, but internality was significantly related to rates of attending (r = 0.21) and to total engagement (r = 0.20). Two components of student engagement, attending and generalizing, were significantly related to achievement (r = 0.31 and 0.36 respectively). Together with degree of formal reasoning, attending and generalizing accounted for 40 percent of the variance in achievement and 48 percent of the variance in retention. Regarding the findings related to locus of control orientation, it should be noted that the internal consistency of the measure used (Intellectual Achievement Responsibility Scale) was low (alpha = 0.66).

In another attempt to account for student achievement in science, Johnson (199) used multiple regression analysis to compare the effects of aptitude, reasoning ability, locus of control, engagement time, and attitude among 76 college biology students. He obtained evidence that engagement time is related to achievement. Findings of another study, though not including locus of control or engagement time data, seem somewhat supportive of a link between engagement time and achievement, and indirectly related to perceptions of personal control. Kane (204) studied the strategies used by academically successful (GPA > 3.5) nursing students in preparing for examinations. She found the strategies employed to be dependent upon the nature of assigned material and anticipations regarding examination content. Surely an outcome of increased engagement time may be more accurate perceptions regarding examination content, and both engagement time and the personal action resulting from perceptions regarding examination content are likely moderated by self conceptions regarding personal control.

Cohen (77) considered the relationship between locus of control orientation and performance on Piagetian-type spatial tasks following instruction (two treatment levels) among 52 students of grade 5. There was an interaction effect noted, with more external students who were exposed to instruction involving manipulatives performing significantly better on the spatial tasks than other externals not exposed to the experimental treatment. Furthermore, externals who were exposed to instruction involving manipulatives experienced a significant shift toward internality. More internal subjects were significantly affected by the treatment. The t-test was used to make group comparisons; there were no measures of reliability reported for the scales used. Assuming instrument reliability to be adequate with the described sample, Cohen's investigation provides evidence that experiential science lessons promote increased achievement on spatial tasks among less internal students, and, further, that such lessons promote shifts toward internality when continued consistently over a period of several weeks. Given the indirect evidence provided by Haladyna et al. (156, see section focusing on determinants of attitudes) that locus of control orientation accounts for a significant proportion of the variance in attitudes among students, the results reported by Cohen seem educationally as well as statistically significant.

Although the studies presented in this section of the review represent a diversity of research interests, their results demonstrate the probable influence of student attributes on academic performance and attitudes. The moderating effects of cognitive style, self-concept, and locus of control orientation seem particularly well demonstrated. The magnitude of the effects, however, and the appropriate response to such effects in science classrooms seem matters in need of increased attention. Preliminary findings should encourage us to increase exploration of personal attributes and their educational significance.

Targeted Groups

Certain student populations have been targeted for increased attention generally or in science subject areas specifically. Among those perceived as needing special attention in science are: ethnic minority group members, females, handicapped students, and gifted students. Relatively few studies reviewed here focused on these targeted groups, indicating that the special attention sought is not being given by researchers.

Most of the studies related to targeted groups considered gender differences or the correlates to successful performance in science by females. Rudy (351) studied 149 students of grade 6 for factors influencing the effectiveness of role models who appeared in a television series of science programs. Multivariate analysis techniques were used to study relationships among gender, sex-role stereotypes, interest in science, and reactions to science role models who were associated with the televised science programs. Rudy found that, despite initial preferences for same-sex role models, the attitudes of female subjects toward female role models decreased with time. Role model appeal was found related to feelings about the behavior, personality, and verbalizations of role models. Role model appearance and behavior had the greatest effect on subject attention. Overall, females who exhibited traits characterized as masculine and who perceived such traits less stereotypically were seemingly more receptive to the female role models. These findings do provide evidence for a subtle effect of personal attributes on role model effectiveness. Donovan (100) attempted to isolate teacher characteristics associated with sex-role model effectiveness, but without success. In a study of 1937 students and 30 teachers of grade 8, Donovan found that: (a) as sex-role models, science teachers have no significant effect on the science and engineering career interests of students, and (b) the interests of females in science or engineering careers were not significantly explained by teacher gender, classroom laboratory emphasis, teacher understanding of science, or teacher career interests. Though the study seems constrained by its focus on teachers and students of grade 8 only, the implications are disappointing, particularly given the evidence for subtle forces reinforcing many sex-role stereotypes operating in educational environments. Ehindero (105), for instance, offered evidence that the interaction of role stereotypes and task context can influence performance. Working with 70 high school students in Nigeria, Ehindera employed t-tests to detect significant differences in achievement on two sets of tasks, found that males performed significantly better than females on tasks having a contextual nature typically associated with males, and found that females performed significantly better than males on tasks having a contextual nature typically associated with females.

Several studies provided evidence for gender differences in attitudes, achievement, cognitive development, and personal attributes among students. Studies by Steinkamp (387) and Levin (239), reviewed in the section focusing on student attitudes, provide evidence for a gender effect on attitudes toward science. During an examination of the relationship between science achievement and several student, background, and teacher characteristics, Lo (242) used multiple regression techniques to identify gender as one of six variables contributing significantly to achievement, along with grade level, student age, IQ, mathematics and science achievement, and teacher familiarity with students. As part of a science meta-analysis project, Kahl and Fleming (201) studied the functional effect of gender differences in science achievement. Though achievement differences reported in the studies examined were generally small (about one-tenth of the standard deviation), analysis of the differences in terms of cognitive process levels revealed more educationally significant differences, favoring males by as much as one-third of the standard deviation in the physical sciences. Also, de Benedictis and others (94) may have detected a related phenomenon in their examination of NAEP results among subjects of age 17. They found use of the "I don't know" response option greater among females, particularly on items related to the physical sciences. Rojas (344) also reported evidence among adolescents of gender differences in self-concept, openmindedness, and cognitive development. In a study of 70 high school students, however, Ehindero (105) found no evidence for a gender difference in level of cognitive development.

In a study of performance among undergraduate students in a physics course, Clay (72) detected little difference between males and females, though the ratio of male students to female was ten to one. The imbalance of males to females in the physical sciences prompted development of the Girls Into Science and Technology research project which has been described by Smail and others (371). In a comparison of biological science, physical science, and nonscience majors, Baker (23) provided evidence that physical science majors, including females, tend to exhibit attributes characterized as masculine, though females in biological science and nonscience majors did not. Malik (253) surveyed 1097 female graduate students in the life sciences and humanities and compared the two groups with regard to personal characteristics and attitudes. Her results are based on a response of 67.2 percent, with 714 returning the questionnaires. The pervasive influence of sex-role stereotypes again seems evident in the observation that fewer females in the life sciences than in the humanities were certain that their discipline was a suitable choice for women. Assuming self-report instruments and personal reflection on past experiences to provide reliable data, evidence was obtained for the positive influence of early life experiences and precollegiate academic preparation in mathematics and science on decisions to pursue professions in the life sciences.

The needs of handicapped students in science received little mention among researchers during 1982. Figueroa Morales (120) tested the effects of several experiential instructional techniques on learning among eight mentally handicapped children. Using a single subject experimental design, learning curves were constructed based on instruction over 15 consecutive days. Two follow-ups were conducted, one between three and seven days after instruction and one after a period of three months. The use of manipulatives and experiential sessions seemed effective, as was the method of modelling behaviors. Coble, Mattheis, and Vizzini (75) reported the results from a survey of over 300 teachers and administrators regarding the status of science education for the handicapped in North Carolina. Although all of those responding indicated support for science as an appropriate subject to teach the handicapped, the majority indicated that science was being taught less than every other day or that they did not know for sure when it was being taught. Regarding the barriers to teaching the handicapped, the overwhelming majority cited lack of supplies, materials, equipment, facilities, time, or administrative support, and lack of personal preparation or inservice opportunities. Finally, it was learned that the predominant mode of instruction among teachers of the handicapped is a lecture-discussion method (92.4 percent). Many also use films or filmstrips (89.4 percent), manipulative activities (87.9 percent), demonstrations (85.0 percent), and workbooks (71.2 percent). A seemingly fertile area for research includes studies of instructional strategies effective among handicapped groups, the obstacles to effective instruction, and appropriate materials for teaching the handicapped would be valuable for the classroom teachers attempting to meet the special need of mainstreamed students.

Only one study, that of Mestre, Gerace, and Lochhead (275), focused on the special needs of an ethnic minority group. Working with 95 college engineering and science majors, they investigated the mathematical translation skills of monolingual (English-speaking) students and bilingual Hispanic students. Are the difficulties monolingual students have with simple ratio problems compounded for bilinguals? If so, is performance improved if the problems are presented in the first language of bilinguals? The findings of Mestre et al. do demonstrate that monolinguals have a significant English language proficiency advantage over bilingual Hispanics, but the difficulties are not mitigated by presenting problems in Spanish. Bilingual achievement as measured by both GPA and problem test performance was strongly correlated to language proficiency, but there were no significant differences among bilingual Hispanics based on the language used for testing. It was noted that bilingual students made more types of errors--errors different from the typical variable-reversal error--than did monolingual students. These results suggest, then, that difficulties in mathematical translation skills are compounded for bilingual Hispanic students, and that presenting the problems in Spanish has little mitigating effect. A study focusing on the attitudes of minority group members (Kahle, 202) was reviewed in a previous section presenting research related to student attitudes. It was noted that generally positive attitudes among minority group members toward science, science-related careers, and scientific research are not accompanied by higher levels of achievement in science.

Bogner (47) examined several correlates to artistic and scientific creativity among 63 students in grades 7 through 12. She sought evidence for an interaction of age, personality characteristics, and gender which contributes to the differential expression of creativity through artistic and scientific modes. Subjects responded to the Biographical Inventory-Creativity, the Creative Perception Inventory, and the Torrance Tests of Creative Thinking--Figural B. Significantly different response patterns were noted for artistically and scientifically gifted students, and for males and females. Age was also shown to contribute to the variance of several components of the measures. These differences in response pattern were taken as evidence for the predicted interaction.

Results generated by the search for correlates to particular modes of creativity typify the findings of many studies conducted among members of targeted groups. The paucity of studies prevents corroboration of findings, the educational significance of results remains highly speculative, and the antecedents of group characteristics and behaviors are unclear. Beyond several attempts to assess gender effects and the nature of sex-role modeling, the research attention received by female, handicapped, gifted, and ethnic minority students in science courses remained minimal during 1982. The needs of these groups are underrepresented in science education research efforts.

Teacher Characteristics and Behavior

Since it is the teacher alone in the classroom who ultimately determines the quantity and quality of science instruction to which students are exposed, it seems critically important to study the variables influencing teacher behavior. Studies reviewed here focus on various aspects of teacher characteristics and behavior with some studies measuring effects on student attitudes or achievement. Given the relatively few investigations of teacher variables, findings have been grouped into four broad categories: knowledge, beliefs, and attitudes; self-perceptions; classroom behavior; and professional behavior. Comparison of Table 1 with Table 2 demonstrates that teacher factors received considerably less attention than did student factors. Further, these teacher factors were more often assessed indirectly by their influence on student performance and attitudes, rather than by some direct measure of teacher performance. Finally, aspects of teacher behavior received greater attention than variables related to other factors. A meta-analysis of previous research focusing on the relationships between teacher characteristics and student performance was reported by Anderson (14, 15).

Horton (186) contributed a brief review of 17 studies relating to teacher characteristics and their influence on learning in individualized science programs. Citing the paucity of information about relationships between teacher characteristics and classroom effectiveness, Horton concluded that more research is needed in the area, particularly research focusing on teacher characteristics and student variables other than achievement.

Knowledge, Beliefs, and Attitudes

Two researcher efforts focused on the understanding of high school biology teachers (Ismail and Rubba, 196) and college science instructors (Wisedsook, 438) regarding the inquiry mode of science instruction. Both studies relied on self-report instruments and detected a moderate amount of perceived understanding among subjects, with Wisedsook (438) reporting increased understanding with continued graduate education. Of perhaps most importance, Wisedsook found no evidence of a relationship between understanding and the application of inquiry techniques during instruction. There was also no relationship detected between educational background and inquiry behavior. It must be acknowledged, however, that samples were small (n = 26 and 158 respectively for Ismail and Wisedsook) and represented a narrow range of educational situations. Peltzer (312) solicited the beliefs of 412 physicists and physics students regarding the intellectual factors of most importance to physics students. On the basis of 160 responses, factor analysis revealed four primary factors described as: the ability to reason visually, mathematical insight, the ability to evaluate the logic of scientific arguments, and the ability to approach problems in potentially productive ways. Responses were not found to be related to orientation--research or teaching--on the part of physicists. Given that analysis is based on only 160 responses of 412 sought, there is concern for the validity of the findings.

Table 2

Frequencies of Reports Documenting the Interaction of Teacher Factors With Selected Variables

Teacher Factor	Student Achievement[a]		Student Attitude or Behavior		Teacher Performance[b]	
	R	NR	R	NR	R	NR
Teaching Style[c]	4	0	4	1	2	0
Questioning Patterns	2	2	2	0	0	0
Concerns as Teacher	0	0	1	0	0	0
Personal Attributes[d]	0	0	0	0	1	1
Level of Cognitive Development	0	0	0	1	0	0
Understanding of Science	0	0	0	1	1	0
Educational Background	0	0	0	0	2	0
Gender	0	0	2	1	2	0

Note. Reports contributing data to more than one of the above categories have been included in all appropriate frequencies.

R Number of reports providing evidence for a relationship

NR Number of reports indicating no consistant evidence of a relationship.

[a]Academic or skill achievement.

[b]Some measure of teacher competence or effectiveness other than student achievement, attitudes, or behavior.

[c]Nature of delivery and interaction with students.

[d]Personality variables and attributional style.

Another study of understanding was conducted by Rowell (348) who examined knowledge of philosophical foundations and conceptual change in science. After examining the responses of 300 university instructors and students, Rowell described the extent to which the ideas of Popper and Kuhn have penetrated the South Australian educational system.

In a study of science teacher characteristics, Welch and Lawrenz (426) tested for a gender effect on a set of cognitive, affective, and behavioral measures. Working with a stratified random sample of 345 teachers from 14 states, they grouped teacher characteristics into four categories: interest in science, knowledge of science, receptivity to change, and teacher perceptions of themselves and their environment. Multivariate analysis of variance revealed a significant gender effect ($p < 0.0005$), with males exhibiting significantly more knowledge of science, and females showing significantly greater interest in science and receptivity to change. It was also noted that all teachers exhibited great interest in science and were relatively knowledgeable. Reliabilities of the instruments used were well established, and evidence was obtained for a lack of response bias to the questionnaires.

Four studies provided additional data on teacher attitudes, with Moore (288) seeking predictors of attitudes toward student-centered science; Barman, Harshman, and Rusch (27) assessing attitudes toward interdisciplinary instruction; Landes (223) seeking factors influencing implementation of energy education curriculum materials; and Smith (374) surveying attitudes toward career education. Though Moore (288) found evidence that concerns about self and impact as a teacher contribute to the variance in attitudes toward student-centered science, he found no relationship between such attitudes and a preference for teaching science. Concerning attitudes toward interdisciplinary instruction, Barman et al. (27) noted generally positive support for such efforts among 198 science and social studies teachers. More specifically, 77 percent supported the concept of integration, and 90 percent agreed that the emphasis should be on the interaction among science, technology, and society, but 68.6 percent were unsure of their personal level of commitment to such endeavors. There was a significant effect due to educational background on attitudes, with individuals having an M.S. (others had either a B.S. or an M.S. + credit hours beyond) being more resistant to integration. There were far fewer subjects in this category (16 of 198), however, so the result may be a statistical artifact of unequal distribution. It must also be acknowledged that only 33 percent of those surveyed responded, raising the possibility of a biased sample.

Another study (Smith, 374) provided evidence of a nonlinear relationship between teacher attitudes toward topics and teaching behavior. His results were based on a survey of 400 teachers of grades K through 12 (74.8 percent responded) regarding attitudes toward career education and its inclusion in the science classroom. Generally, teachers strongly supported career education broadly defined (being distinct from vocational education) and the appropriateness of including career education in existing courses, but teachers were only marginally positive regarding the importance of career education. Junior high school teachers were, however, significantly more positive than others regarding the importance of career education. When it comes to actual behavior, 31.6 percent of the respondents actually incorporate career education on a daily or weekly basis, even though 89.3 percent indicated a willingness to incorporate career education, and 71.9 percent indicated that it would not be very difficult to accomplish. Most (52.7 percent) cite too little time as an obstacle to incorporation, while 47.8 percent cite a lack of knowledge regarding instructional materials.

Landes (223) provided evidence that teacher attitudes also influence the curriculum. Data from a survey of participants in an energy education workshop indicate that teachers who strongly feel energy education to be important tend to indicate it in their curriculum. It was noted, however, that most considered energy education to be a part of science, even when given multidisciplinary guides. There are seemingly some interactions between attitudes and instructional behavior yet to be elucidated.

Closely related to the influence of attitudes on instructional behavior is the influence of value orientations. Carleton (60) examined the valuing behavior of two novice science teachers and developed a scheme for describing the behavior. One teacher, characterized as having a rather unidimensional values framework, perceived science teaching as a transferring of knowledge, while the other teacher, characterized as having a multidimensional framework, deemphasized conventional science in favor of a more qualitative approach. The influence of these orientations on behavior is presented by Carleton in the form of transcribed episodes of classroom experiences.

The values, attitudes, beliefs, and knowledge held by teachers undoubtedly influence instructional behavior to a significant degree. Yet, research in this area remains largely idiosyncratic and disparate. Attitudinal research has been much encouraged, but what of teacher beliefs regarding the nature of science, the essential content of science, or the relative importance of science as a subject? Is teacher knowledge or conceptual understanding a limiting factor in science classrooms? We seem to know very little about teachers as thinkers, academic mentors, and emotive agents.

Self-Perceptions

Agnew (5) questioned earth science teachers regarding personal confidence in their ability to teach toward specific objectives and the sources of their confidence. Results include a grouping of topics according to degree of confidence expressed and a ranking of the sources of personal confidence. As might be expected, the greatest source of confidence was related to previous teaching experience, but perhaps unexpected was the finding that preservice education ranked above inservice education as a source of confidence, even though 52.1 percent of the sample had completed over 45 semester hours of inservice education.

The influence of attributional style on science teaching performance was examined by Green (149, 150, 151) who solicited information from 236 elementary teachers regarding personal background, knowledge of science content, causal attributions, and choice of teaching role. She found evidence of a distinct attributional style regarding science teaching, with successful outcomes generally being ascribed to internal causes, such as ability, and unsuccessful outcomes generally being ascribed to external factors. Green also sought predictors of the time teachers allocate to science, finding two of significance: the number of science methods courses completed, and the attribution of successful teaching to ability.

In a study of implementation proneness among teachers following participation in a number of science workshops, Enochs (111) sought predictors among attitudinal and personality factors. The best predictor noted was locus of control orientation, with internality being related positively to implementation proneness. Although this study and the others grouped here under the rubric of self-conceptions each focus on theoretically distinct constructs, they are related in a functional way; they all demonstrate the subtle influence of self-perceptions on personal action. Teachers act in a manner congruent with their level of confidence, attributional style, and perceptions of control. There remain many unknowns regarding the dynamics of self-perceptions and the network of relationships among self-conceptions, other personality factors, cognitive factors, attitudes, and behavior, but findings strongly suggest this to be a potentially fruitful area of research.

Classroom Behavior

Several aspects of classroom behavior were investigated, including verbal behavior (Swift, 398; Gooding and Swift, 146; Corindia, 81; Meng, 274; Lemke, 236; Wolfe, 440; Chaiyabhat, 65), managerial behavior (Nuccio, 300; McGarity, 269), familiarity with students (Lo, 242), valuing behavior (Carleton, 60), and communicated expectations (Matthews, 259) Four studies examined generally the characteristics associated with good science teaching (Searles and Ng, 360; Byrd, Doble, and Adler, 59; Tulloch, 410; Mintzes, 280). Searles and Ng reported the results of a survey among secondary school biology teachers and principals regarding the characteristics of a good biology teacher. Of 131 subjects solicited, 63 responded (22 principals and 41 teachers) to a 100-item questionnaire. In response to 93 of the items, there were no significant differences between teachers and principals, with characteristics related to teacher, student, subject, and classroom relationships receiving the highest ratings of importance. Specific characteristics rated highly important include: ability to develop a classroom climate conducive to learning, ability to organize and present material, ability to convey great interest and enthusiasm for biology, resourcefulness, ability to demonstrate concern for student understanding of essential concepts, and ability to encourage self-motivation in students. In another study of characteristics associated with successful science teachers (Byrd et al., 59) the results were not so positive. Wanting to identify preservice students who would likely become successful teachers, Byrd et al. were unable to designate any generic differences in characteristics between successful and unsuccessful teachers.

Tulloch (410) solicited the perceptions of science teachers, supervisors, and teacher educators regarding the competencies associated with teacher effectiveness. Factor analysis was employed to reduce the perceptions to a small number (11) of underlying constructs. The factors accounting for the greatest amount of variance were: (a) attending to the mechanics of teacher centered instruction, (b) exhibiting sensitivity to expressions of student feelings and values, (c) exhibiting enthusiasm and spontaneity when working with students, and (d) planning the instructional program. Teachers tended to value growth in instructional skills while supervisors and teacher educators valued growth in factors related to scientific literacy.

Using a different strategy to elucidate teacher behaviors that influence student learning, Mintzes (260) studied the perceptions of 101 college biology students and related those perceptions to performance on a series of four tests representative of course content. Students rated the teaching performance of their instructor--relative to other university teachers--in 12 dimensions of teacher effectiveness and estimated the frequency of 20 observable teaching behaviors. The data thus obtained were subjected to factor analysis, reduced to four factors which accounted for 57 percent of the total variance, and student factor scores were correlated with achievement test score means and instructional ratings. Among the findings, a significant relationship ($r = 0.30$) was found between mean test scores and a factor characterized as information-transmitting behaviors on the part of the teacher. Such behaviors include: stressing most important points by pausing, speaking slowly, forewarning, etc.; repeating difficult ideas several times; and showing strong interest in subject matter. The author acknowledged the speculative nature of interpreting student rating forms, but this study offers a refreshingly innovative approach to the identification of effective instructional behaviors.

Identification of specific behaviors which serve as effective cues to important content for students should prove valuable to teachers and teacher educators, particularly given the evidence by Lemke (236) that much of the science content being taught is being expressed implicitly, not explicitly, in classroom communication. Wolfe, too, (440) has provided evidence that elementary teachers express recognizable cues regarding the nature of science during classroom dialogue and activities. Given the interest in improving the quality of elementary science instruction, the communication of subtle messages during instruction seems worthy of further investigation.

Swift (398), Chaiyabhat (65), Gooding and Swift (146), and Corindia (81) focused on questioning behavior and its effect on student behavior. Swift, working with 40 middle school science teachers exposed to one of four regimens of instruction, corroborated previous findings related to wait time and the cognitive level of questions. That is, as teacher wait time increased and a larger proportion of high level questions was used, the proportion of student talk increased and student answers improved in terms of length, number of relevant words, and frequency of volunteered contributions. The same results were reported by Gooding and Swift (146). In a similar study of 22 high school physics teachers, however, Chaiyabhat (65) was unable to elicit a treatment effect on student behavior through the modification of teacher wait time. In a related study of student and teacher questioning behavior in three sixth-grade classrooms, (Corindia, 81) found that students tend to model teachers in the level of questions asked. It was noted that students at the concrete level of cognitive development tended to ask what are characterized as formal-level questions after teachers had been trained to increase their proportion of higher-level questions. These two studies both demonstrate the tendency among students to model teacher behavior.

Nuccio (300) conducted an ethnographic study of eight high school science teachers for 145 hours during weeks 1, 2, 3, 13, 14, and 15 of the school year. His focus was on the managerial activities of teachers in an attempt to: identify situations requiring managerial actions, describe the managerial strategies employed by teachers, and identify the differences between effective and ineffective strategies. Nuccio grouped the variety of events requiring managerial attention into three broad categories--continuity events, intrusive events, and <u>in futurum</u> events--and described in some detail the ways effective and ineffective teachers tend to respond to the events. Among the findings are these: (a) effective teachers prevent or remedy disruptions by managing student behavior in a clear, consistent, and cohesive manner, they identify problems and act decisively to resolve them, and they integrate classroom management with their instructional style; (b) effective teachers encounter fewer continuity and intrusive events, and they spend less time with continuity events than do ineffective teachers; and (c) effective and ineffective teachers differ in their use of class time. Although these findings may not be as readily generalizable as experimental results, they aid greatly in the explication of classroom dynamics.

McGarity (269) also studied managerial behavior among science teachers (n = 30) but used a different approach, multiple regression analysis, to estimate the effects of teacher behaviors on student engagement and achievement as moderated by student aptitude. Effective managers were found to: (a) identify and help individuals not involvement, attend to routine tasks, (c) use instructional time efficiently, (d) provide feedback to students regarding their behavior, and, (e) manage disruptive behavior. The studies by McGarity (269) and Nuccio (300) allow opportunity to compare the strengths and weaknesses of two very different research strategies addressing the same issue.

Another case study similar in nature to that of Nuccio (300) but containing a statistical component is that of Matthews (259), who documented the potentially negative effects on student performance of teachers acting on preconceptions of class abilities. After demonstrating that a mixed-ability class being stigmatized as badly behaved and unintelligent was, in fact, statistically representative of grade level peers in terms of achievement on a chemistry examination, Matthews showed statistically how his original inclination to set an easier examination for the stigmatized class would have confirmed his expectations of poor achievement. Though the statistical arguments used pertain most directly to educational systems setting grade-level examinations for tracking purposes, the message is clear that low teacher expectations of student performance based on what are essentially attitudinal problems can have a debilitating effect on student performance or on teacher interpretation of student performance. Perhaps this is a counter example of Lo's (242) finding that student achievement in science is partially explained by teacher familiarity with students.

Research of classroom behavior confirms the primacy of clear communication, both verbal and nonverbal. Exemplary teachers are those who elicit and focus student attention, and who maintain student involvement. A corollary behavior involves exhibiting sensitivity to student feelings and level of understanding. The influence of teacher questioning patterns, wait-time, and managerial behaviors on student performance has also been corroborated. A weakness remaining in this area, however, is the tendency to describe behavior in terms of outcomes. For example, a successful teacher tends to exhibit sensitivity to student feelings, but by what means does a teacher exhibit sensitivity? Future efforts must elucidate effective classroom behavior in more precise, operational terms.

Professional Behavior

Two studies addressed the effect of some aspect of professional behavior or involvement on classroom performance. Pearce (309) attempted to gauge the influence of journal reading on the classroom and administrative practices of high school department heads. Overall, the influence of education journals on classroom practice seemed modest, although the effect was noted to be slightly greater on science department heads than on others. Most of the changes influenced by journals were of a practical nature, generally involving curriculum design or teaching techniques. Department heads who were most influenced by journals tended to be less experienced as leaders, highly innovative, good to excellent readers (self-assessment), and members of content-related professional organizations or educator advocacy organizations.

Zebrowski (454) attempted to assess the effect of book authorship on the educational duties of physics professors. After a historical analysis which demonstrates how economic forces have influenced the format, content, and availability of textbooks, Zebrowski presented an analysis of publication contract language and publisher expectations. On the basis of 58 responses (50 percent of those solicited) to a survey, there is evidence that access to book authorship is restricted by business priorities, but there is no evidence of undue imposition on the educational role of authors.

Kahle (203) reported the outcome of a three-year NIE project which focused on the scholarly productivity of female faculty members in science and science education positions at minority institutions. Included in her report are the results of six empirical studies conducted by project participants. Among the reported outcomes of the project was initiation of a supportive professional network among women in science education which involves peers, mentors, and individuals entering the profession.

Instructional Strategies and Environment

A large proportion of the research efforts reported for the year focused on some aspect of the instructional methods used by science teachers. Grouping the studies became a frustrating task due to their diversity, but the following categories seem to capture well the natural clustering of treatments and outcomes: systems of instruction, problem-solving instruction, experiential learning, the laboratory experience, teacher demonstrations, organizational aids to learning, infusing language arts skills into science instruction, teaching style and techniques, and the classroom environment. Table 3 shows a diversity of interests in instructional factors, although the influence of these factors is primarily measured in terms of student achievement rather than other learning outcomes. In instances where findings are related to more than one category, studies have each been classified according to the primary focus. A review of previous research related to science and mathematics instruction was contributed by Stallings (382). Critiques of more recent studies were edited by Blosser and Mayer (43, 45). The review focuses on findings reported during the 1970s. The findings of a meta-analysis project reported by Anderson (14, 15) also include a synthesis from previous research regarding instructional strategies.

Systems of Instruction

Several researchers examined aspects of individualization strategies, autotutorial systems, cooperative learning, and mastery instruction methods. Though a diversity of populations were sampled, a variety of sample sizes were employed, and several instructional systems were examined, the dependent variables in most studies included some measure of cognitive achievement. Typically, too, "traditional" or "conventional" treatments are not clearly described, but with the terms serving primarily to characterize a treatment as something other than the treatment of experimental interest.

Cotton and Savard (85) contributed a review of 44 research documents focusing on effective instructional practices among students of intermediate grades. The review comprises studies which: (a) compare instructional strategies in terms of student achievement or affective outcomes, (b) focus on effective organizational patterns, or (c) identify practices positively related to student achievement or affective outcomes. Comparisons of results demonstrate clearly the difficulty of identifying an inherently superior instructional system. Activity-based instruction was shown in 14 studies to have a positive effect on science achievement and attitudes toward subject matter. Direct instruction and mastery learning were shown in 14 of 16 studies to be more effective than were other approaches in promoting achievement and retention. Individualized instruction was shown in 10 of 11 reports, however, to foster greater achievement and retention than did conventional group instruction. Perhaps the most consistent finding is that student performance is enhanced when conventional instructional approaches are supplemented with experiential components; performance is superior to that obtained through use of either method alone.

Table 3

Frequencies of Reports Documenting the Interaction of Instructional Factors With Learning Outcomes

Instructional Factor	Learning Outcome: Achievement R	NR	Skills R	NR	Attitudes R	NR
Exposure to Science[a]	5	0	0	0	0	1
Instructional System	10	3	5	0	5	0
Experiential or Laboratory Component	8	1	2	0	2	1
Method of Presentation	6	2	1	0	2	1
Instructional Mediator[b]	4	5	0	0	1	0
Nature or Sequence of Instruction	1	2	0	1	1	1
Method of Student Grouping	2	1	0	0	0	1
Academic Skills Instruction[c]	3	0	0	0	1	0
Matching Cognitive Styles[d]	0	2	0	0	0	2

Note. Reports contributing data to more than one of the above categories have been included in all appropriate frequencies.

R Number of reports providing evidence for a relationship

NR Number of reports indicating no consistant evidence of a relationship

[a]Science versus no science, or treatment versus no treatment, with indicated relationship being positive.

[b]Mediators such as student learning objectives, advance organizers, or quizzes.

[c]Instruction in study skills or language arts skills.

[d]Matching the cognitive styles of teachers and students.

Individualization

Kapuscinski (205) carried out a naturalistic study in an attempt to identify factors influencing classroom dynamics within individualized systems of instruction. The sample included 20 teachers and 553 students in grades 3 through 8, with 10 of the teachers attending an inservice program devoted to individualization of instruction. Using a variety of data sources--investigator diaries of teacher behavior, inservice teacher diaries of strategies attempted and student reactions, teacher interviews, student summative evaluations of teacher attempts to individualize, and interviews of administrators of inservice teachers--Kapuscinski grouped factors affecting attempts to individualize instruction into six categories. Grouped together were factors related to the teacher, the student, the course of study, the facilities and materials, the administration, and the community. A primary determinant of successful implementation was found to be teacher conviction regarding the importance of individualization. The influence of other identified factors seems more ambiguous, but their effects can perhaps be clarified through empirical methods. This study illustrates well the potential usefulness of naturalistic studies in isolating variables worthy of further investigation.

Working with 712 students of grades 7, 8, and 9, Fraser and Butts (128) provided valuable evidence for the effect of individualization on science-related attitudes. They employed two new instruments to measure attitudes (seven subscales) and the degree of classroom individualization (five levels), and they used multiple regression analysis to estimate the contribution of individualization to expressions of attitude. Beyond the 30.4 percent to 38.5 percent of variance in attitude scale performance was explained by the pretest, individualization contributed another 7.4 percent to 29.1 percent, with the noted range of effects reflecting variance on seven discrete attitudinal scales. In addition to describing one of few studies examining the effect of individualization on student attitudes, the report by Fraser and Butts provides a refreshingly complete rationale for the methodology employed.

Three studies (Jackman, 197; Russock, 352; Gifford and Vicks, 139) considered the effectiveness of some version of a personalized system of instruction (PSI) or Keller plan. Jackman obtained evidence for the effectiveness of PSI in a college biochemistry laboratory setting (n = 33), Gifford and Vicks obtained similar results with college biology students (n = 80), while Russock noted favorable results with 75 low achievers of grade 8. In addition to testing the effect of PSI, Gifford and Vicks searched for evidence of a gender effect, but found none, and they used regression analysis to estimate the relative contribution of PSI to achievement as measured by test performance. They found GPA, treatment group membership, and CAT performance, in that order, to explain 42.0 percent of the variance in test performance. Motivational factors, age, gender, family income, and family size together accounted for another 6.0 percent of the variance.

Results of a related investigation were reported by Burkman, Brezin, and Griffin (56) who studied the effects on achievement of individualization in conjunction with other variables, including instructional time, student academic ability, and student assessment of treatment implementation. Soliciting student perceptions of treatment implementation provided a means of evaluating the consistancy of treatment implementation across groups, alwa difficulty in studies involving several student groups. Working with 27 teachers and 970 high school students in 89 classes, Burkman et al. used a 3 X 2 (instructional system X instructional time) factorial design to detect a relationship between achievement (Cloze-type test of comprehension) and the treatment variables and covariates. Although a complex pattern of results was obtained, the treatment variables and covariates together accounted for 48 percent of the variance in achievement. Evidence was provided that the influence of student ability tends to increase as a function of consistent implementation for all of the instructional treatments tested, though student-directed instruction seems superior when well implemented and autonomy is perceived by students. It should be noted that group-directed instruction is supported as a viable alternative by these results, with student performance following group directed instruction falling midway between average performance by the teacher-directed group and the student directed group. Although perhaps difficult to interpret, the results of this study demonstrate the complex pattern of interaction among student, instructional, and achievement variables.

Hinchliffe (177) and Al-Hashash (7) examined the relationship between achievement and programmed (self-paced) learning. Hinchliffe interpreted results obtained from college chemistry students as favorable for programmed learning, but the results obtained from a study of 363 college biology students by Al-Hashash are more ambiguous. Though no significant treatment effect was noted overall, Al-Hashash reported evidence that self-paced learning is more beneficial for students of high ability who have little previous experience in science.

Autotutorial Instruction

Two studies (Metcalf, 276; Lazarowitz and Huppert, 231) focused on the effects of autotutorial systems of instruction. Working with biology students of grade 9, Lazarowitz and Huppert compared an autotutorial system with a more conventional style involving lectures and laboratory sessions with regard to their influence on achievement and motivation. The autotutorial approach was reported as effective in increasing achievement and motivation. Metcalf (276) studied community college biology students and instructors, 26 instructors using a lecture with laboratory approach to teach 326 students, and 22 instructors using an autotutorial approach with 252 students. There were no significant treatment effects noted, though there were some significant differences between instructor intent and student perceptions of instruction. These results seem to corroborate previous findings that autotutorial approaches provide a viable alternative to more traditional approaches to science instruction involving lecture and laboratory sessions.

Cooperative Learning

As the results reported by Burkman et al. (56) indicate, there is more than one alternative to traditional science instruction, one being group directed, or cooperative, learning. Foster (125), Humphreys, Johnson, and Johnson (192), and Hanshaw (162) have focused on cooperative learning and provide some evidence for the efficacy of cooperative efforts. Foster compared the influence of a cooperative instructional system and an individualistic system on creativity and understanding among 111 students of grades 5 and 6 who were studying electrical circuits. Although the cooperative groups successfully constructed more circuits, there was no significant treatment effect on creativity or understanding. There were, however, gender and grade effects, with females exhibiting more creativity than males and students of grade 6 exhibiting more creativity than students of grade 5.

Humphreys et al. (192) compared the effects of competitive, cooperative, and individualistic systems of instruction on achievement among 44 physical science students of grade 9. Also tested were the attitudes of the students toward the instructional system experienced. Data were gathered from a pretest, three unit tests, a retention test, and two questionnaires, and were analyzed using analysis of covariance to neutralize the effect of pretest differences. A significant treatment effect in favor of cooperative learning was noted for the unit tests, retention test, and two measures of expressed attitudes. Noteworthy are the low correlations found between performance on unit tests and the retention test among students in the competitive instructional group, and evidence that the least positive attitude toward the instructional system was among students experiencing the individualistic approach. These results provide additional support for another viable instructional system, cooperative learning, and demonstrates potential value in structuring interaction among students.

Though not focusing on cooperative learning directly, Hanshaw (162) provides further evidence that endorsing cooperative efforts among students has merit. Working with 46 college nonscience majors enrolled in a biology or physical science course, Hanshaw studied the effect on test achievement of using a paired testing procedure, allowing students to work cooperatively on portions of course tests. As might be expected, the procedure resulted in significantly higher mean scores by students working cooperatively. Some effects of test anxiety and self-concept on performance were also noted, but the results were mixed across groups. It seems important to extend the findings of this study by examining individual performance on criterion measures following cooperative efforts such as the one described by Hanshaw.

Mastery Learning and Instruction

Brooks (52) and Hallada (159) examined the effect of mastery instruction on cognitive achievement and process skill achievement. Using analysis of variance to test the effect of instructional methods among 90 middle school students, Brooks found no significant differences between groups in cognitive achievement, but there were some differences in process skill achievement favoring the mastery method. Hallada (159) used a slightly novel approach in examining the effect of mastery instruction among college chemistry students. After identifying 50 of the 350 subjects as underprepared for college chemistry, the identified subjects were assigned to a system of instruction which incorporated mastery learning principles. Their performance on tests at the conclusion of the study was compared to the 300 subjects exposed to the regular chemistry instruction. A finding of no significant difference in the performance of the two groups was taken as evidence for a positive treatment effect. Although the validity of the experimental design may be questioned, the viability of the mastery instructional technique seems demonstrated.

Studies reviewed here demonstrate the validity and viability of several instructional systems. Individualization, autotutorial instruction, cooperative learning, and mastery learning have all been shown to foster positive instructional outcomes in some educational setting. It has also been demonstrated that the effectiveness of an instructional system is moderated to a significant degree by teacher convictions and consistency of implementation. Less clear are the effects of various instructional systems on variables other than student achievement or attitudes. There also remain many practical questions of how best to match instructional systems with instructional goals.

Problem-Solving Instruction

Four studies focused directly on attempts to structure instruction in a way that promotes problem-solving skills or critical thinking skills among students. Phillips (318) compared the effects of two instructional treatments on knowledge acquisition and problem-solving skill acquisition among college neuroscience students, with results indicating a significant effect in favor of the problem-solving strategy. Richardson (329, 330) also compared the effects of two treatments on the problem-solving skills and comprehension of problem-solving strategies among college physics students. The 3 X 2 factorial design used also allowed a test of differences due to an instructor effect (three instructors participated). A significant treatment effect in favor of the problem-solving treatment was noted on comprehension of problem-solving strategies. Heller and Reif (172) also examined the effect of treatment on problem-solving performance among physics students, but three treatments were compared rather than two. Results support the efficacy of providing explicit rules for constructing problem descriptions in an attempt to facilitate functional problem description and successful problem solution. Some discussion of typical student difficulties is offered.

Using a posttest only control group design with 421 high school students as subjects, Gabel (133) compared the effects of four instructional treatments on problem-solving achievement. Also examined was the interaction of instructional treatment with reasoning ability, mathematics anxiety, and verbal-visual preferences among students. Mixed results were obtained, but among the findings it was reported that students exhibiting high mathematics anxiety performed lower than other subjects, and students of high proportional reasoning ability outperformed other subjects. Finally, Moll and Allen (285) studied the effect of an instructional treatment on the cognitive achievement and critical thinking skills of college biology students, finding the treatment to promote significant gains in both domains. There were no significant moderating effects noted due to gender, major, or nature of high school background. Despite reasoning presented to discount the potential influence of increased content knowledge on critical thinking performance, no empirical means were used to neutralize such an effect.

These studies show, then, the potential to promote problem-solving behavior, skill, and comprehension through instruction. Perhaps the most obvious weakness of studies focusing on the effectiveness of problem-solving instruction has to do with the criterion measures. In every case reviewed here, treatments are tested at least in part by their influence on problem-solving behavior. The criterion measures are thus biased at the outset in favor of the instructional treatment, with no direct comparison of treatments being made on the basis of general achievement, attitudes, or some other measure of external validity.

Experiential Learning

Experiential learning is here used to indicate instructional methods that employ the use of activities, concrete manipulatives, or other forms of direct sensory experience to facilitate instruction. Investigators reported the effects of such experiences among subjects of preschool age through college age. Pursuing a rather traditional approach, Selim (361) compared the effects of expositiory versus discovery teaching methods on achievement and attitudes as moderated by IQ. Working with 276 students of grade 5 during an instructional unit of light, Selim used a factorial design with repeated measures to demonstrate a significant treatment effect favoring the discovery method. Wilson (436) sought an extended effect of discovery learning among college chemistry students by comparing the performance of students who experienced a discovery approach in high school with students having no such experience. He found no significant correlation between high school discovery index scores and performance on college chemistry examinations, but a significant correlation ($r = 0.20$) was found between the discovery index scores and laboratory scores.

Working with 51 high school chemistry students, Howe and Durr (189) compared the effect on comprehension and reasoning of two instructional treatments, one employing manipulatives and peer group interaction, and one of a more conventional nature. A posttest only control group design was used, with comparisons being tested by analysis of variance, including level of cognitive development (formal versus nonformal) as a moderator variable. A significant treatment effect was noted in favor of the experimental method among both those at the stage of formal operations and those not at this stage. The experimental design prevents differentiating the effects of manipulatives and peer group interaction, but chi-square analysis provides evidence that significantly more students exposed to the treatment are favorable toward instruction. Hyman (195) examined the effect on achievement of subject manipulation of models among college students of organic chemistry, but no significant differences were found between students exposed to teacher demonstration of models and students having direct experience with models.

Holly (183) compared the effects of two instructional treatments on the achievement and student perceptions of classroom climate during an ecology unit. One treatment included outdoor group experiences while the other involved more conventional "seat work" by individuals. Using analysis of covariance to test differences among 894 students of grade 6, Holly found a significant treatment effect on both achievement and student perceptions, with the treatment including outdoor experiences being more effective.

Three studies (Mallon and Bruce, 254; Stoneberg, 392; Smith, 373) involved nonschool settings and educational agencies. Mallon and Bruce compared the effects of a traditional planetarium program and a participatory program on the achievement and attitudes of 556 students of grades 3 through 5. Using t-tests to evaluate gain scores and analysis of variance to make group comparisons, Mallon and Bruce found both significant gains in achievement and a significant treatment effect in favor of the participatory program. Results show the effect of treatment on attitudes to be inconclusive. Stoneberg (392) studied the effects of previsit activities and postvisit activities on achievement and attitudes of 1671 students of grade 6 who visited the zoo. In this study, which involved 78 classes from 52 different schools, a randomized block design (school setting X treatment) was used to compare the effects of four treatment levels. Significant gains in cognitive achievement were noted for all treatments except the control which involved no visit to the zoo and no exposure to the previsit and postvisit activities, essentially a nontreatment. The greatest gains were noted in treatments involving classroom activities. Noteworthy in the present context is the finding that exposure to the previsit and postvisit activities alone, without a visit to the zoo, had a significantly greater effect than did a visit to the zoo without the previsit and postvisit activities. The effectiveness of such outreach efforts was corroborated by Smith (373) who examined the effects of a museum's programs on achievement among 659 students of grade 5. Using a pretest-posttest design, he found the outreach program to effect higher scores on a test of science knowledge than did on-site visits or combined programs.

Two investigations related to studies of experiential learning (Porcher, 322; Heath and Heath, 170) focused on the influence of teacher-student interaction on inquiry behavior among children of preschool and primary age. Porcher offered a descriptive analysis of what has been characterized as sciencing behavior among students in four kindergarten classes, and she attempted to identify means by which teachers influence such behavior. Among the findings are indications that teachers influence sciencing behaviors predominantly in group situations, tending to provide insufficient time for thoughtful response by students and inadequate supplies of concrete materials. In the sample studied, student sciencing behavior actually seemed to decrease following exposure to what was characterized as teacher sciencing-promoting behavior. Seemingly the notion of sciencing-promoting behavior must be more operationally defined.

Heath and Heath (170) studied the behavior of 70 children of ages 3 through 6 years, seeking differences between children allowed free manipulation of objects and those exposed to teacher intervention which tended to focus student attention. Multivariate analysis of variance with repeated measures was used to detect a significant treatment effect, with intervention promoting greater subject contact time with objects, more student-initiated activities, and a higher level of cognitive activity among subjects. Heath and Heath consider these results evidence for teacher intervention as a critical factor in developing among young people a conceptual understanding of physical attributes and interactions among objects. These findings are encouraging and exemplary of the knowledge to be gained from studies of young children. Given the abundant speculation about the importance of early experiences to achievement in science, it seems unfortunate that only two studies in this review of research focus on the preschool population.

The Laboratory Experience

Laboratory sessions are such a standard component of science instruction that the educational value of laboratory experiences is often assumed to be self-evident. Results by Louwerse (249), however, demonstrate that the influence of laboratory experiences on attitudes and learning is not necessarily clear. Working with two high school science courses (four laboratory sections), Louwerse was unable to detect any significant difference between teacher demonstrations and student inquiry in the laboratory regarding effects on cognitive achievement, process skill achievement, attitudes, or locus of control orientation. In a review of the history, goals, and research findings regarding the role of laboratory experiences in science teaching, Hofstein and Lunetta (181) pointed out some limitations of previous research efforts focusing on laboratory experiences, and they have offered some suggestions regarding potentially productive lines of research. Most studies, they pointed out, are based on small sample sizes of limited diversity, with little attention being given to the validity of instruments employed to collect data. The emphasis, too, has tended to be on methods and their effect on cognitive achievement, while teacher behavior and the elements of classroom environment receive little attention. Hofstein and Lunetta proposed that more attention be given to outcomes related to creativity, skills of problem-solving, the processes of scientific thinking, intellectual development, practical skills and abilities, attitudes and interests, and the social learning environment. Also needing clarification are effects related to teacher attitudes and behavior, instructional goals, content and the nature of activities, management techniques, and social variables associated with the learning environment. It is encouraging that some of the studies reviewed here do include data regarding student attitudes and process skill acquisition.

Oloke (303), Tofte (408), Leonard (237), Ali (8), and Schellenberg (357) each compared a relatively novel instructional method with a more conventional laboratory method, and each noted a positive significant treatment effect on achievement or attitudes. Oloke worked with 134 high school biology students, using a pretest-posttest design which included a 10-week treatment. The experimental treatment included indoor and outdoor investigations which the control treatment did not include, and results showed the treatment to significantly influence student achievement and attitudes positively. In a study involving 84 college geology students, Tofte (408) found laboratory experiences associated with a learning-center approach to have a significantly greater effect on short-term learning than did a more conventional laboratory design. Finally, Leonard (237) designed BSCS-style laboratory sessions for college students, and used t-tests to compare achievement among students of 24 laboratory sections. He found a significant treatment effect on achievement in favor of the BSCS-type sessions. In an unrelated but relevant study, among 96 students of grades 7 and 8, Newton (295) reported evidence that opportunity for student planning of activities and generalizing from the results has a positive effect on process skill acquisition. Since BSCS-style laboratory sessions would also encourage student planning in the form of experimental design, Newton's results perhaps extend findings by Leonard.

Ali (8) compared three treatment levels: lectures alone, lectures accompanied by conventional laboratory sessions, and lectures accompanied by laboratory sessions which included photomicrography activities. A significant treatment effect was noted among the 720 high school microbiology students, with the photomicrography group obtaining the highest mean score, followed by the other laboratory group. Finally, Schellenberg (357) sought a treatment effect on the cognitive achievement, attitudes, and process skill achievement of 86 college physics students. Using analysis of variance to compare laboratory sessions focusing on contemporary topics with laboratory sessions focusing on relatively standard topics, Schellenberg found no significant differences between the groups.

Two studies (Mull, 290; Singh, 369) focused on some physical conditions of science teaching laboratories. Mull sought college faculty perceptions via interviews and questionnaires regarding the status of instructional equipment. Few reported any specific policy for acquisition or replacement of equipment, 19.9 percent characterized the current level of acquisition and replacement as a serious problem, and 30.0 percent reported a very high level of inadequacy for the educational mission perceived. Singh (369) examined the potential health hazards associated with the activities and chemicals stipulated by current issues of laboratory manuals, compared the manuals to those published prior to the OSHA act of 1970, and polled all of the high school chemistry teachers of Ohio regarding their use of chemicals. After examining the ten laboratory manuals which are used by over 90 percent of Ohio high schools, Singh found significant differences among manuals regarding potential health hazards, but no significant differences were found between the current set of manuals as a group and earlier editions published prior to 1970. It was also learned that teachers continue to use highly toxic chemicals in instructional laboratories, and have not substituted nonhazardous chemicals to any great degree. It would seem important to determine whether or not such findings are broadly applicable--we suspect they are.

Teacher Demonstrations

Two research efforts (Beasley, 29; Sonntag, 379) focused on the role of teacher demonstrations in science teaching. After comparing three methods of instruction among 24 science classes of grades 8, 9, and 10, Beasley found evidence that student attention and task involvement increase when exposition is accompanied by class demonstrations. Working with college seniors in an elementary science methods course, Sonntag (379) obtained a complex set of results when comparing the effects of three instructional methods on cognitive achievement. The treatments included a planetarium lecture, a classroom lecture involving the use of a celestial globe, and a treatment comprising the two presentations. In testing for a treatment effect, student spatial ability was included as a moderator variable, and GPA, previous experience in astronomy, and class attendance were included as covariates. There was an overall treatment effect in favor of classroom lecture with use of a celestial globe, and there were some interaction effects. Students exhibiting high spatial abilities performed best in the classroom treatment, while other students performed best in the two treatments involving a planetarium experience. The results seem to support notions about the value of using visuals and concrete objects with students having limited spatial abilities. Such interaction effects may also account for findings like those of Lauwerse (249), reviewed in the previous section, which show individual inquiry during laboratory sessions to have no significantly greater effect than do teacher demonstrations. Caution must be exercised, however, in overinterpreting such results and using the same criteria to evaluate methods assumed to have different instructional roles. Garrett and Roberts (135) have contributed a critical review of research published since 190[illegible] regarding the merits of demonstrations versus small group practical work in science education.

Organizational Aids to Learning

Several studies focused on the use of various organizational aids and instructional mediators, such as: advance organizers, behavioral objectives, weekly quizzes, weekly assignments, concept clustering, use of Gowin's Vee, and concept mapping strategies. The dependent variables in all cases included some measure of cognitive achievement.

Advance Organizers

Drawing on Ausubelian assimilation theory, Tamthai (401), Skelly (370), and Giles and Bell (143) examined the effect of advance organizers on student achievement. Using a sample of 188 academically average students of grade 8, Tamthai tested the effect of employing pictorial-diagrammatic advance organizers with one of two treatment groups. Mixed results were obtained, with advance organizers having no significant effect on achievement among males. Among female students, advance organizers seemed to facilitate achievement among those characterized as field-independent, but those characterized as field-dependent seemed inhibited by the technique. A subsidiary finding was that field-independent students, overall, demonstrated significantly greater achievement than did others. Skelly (370) worked with 201 students of grade 9, using a 2 X 4 (IQ X treatment) factorial design to test the effect of four treatment levels on achievement. Analysis of covariance, using a pretest as a covariate, failed to yield a significant treatment effect. The advance organizer used was a 1500-word preview of an instructional packet on hydraulics. Giles (142) combined the use of advance organizers and concept clustering to promote cognitive achievement among 832 participants in a planetarium presentation. Results from comparing four treatments indicate that both advance organizers and concept clustering can be employed to enhance achievement. Given the inconsistency of results reviewed here, it would seem important for investigators to estimate the magnitude of treatment effects so that educational significance of results can be evaluated, and to clearly describe the instructional aid employed as an advance organizer.

Behavioral Objectives

Three studies (Forsythe, 124; Pfister, 316; Aregahegn, 17) focused on the effect of behavioral objectives on cognitive achievement. Pfister compared the effects of two instructional treatments on the achievement of 61 community college chemistry students, providing one group with behavioral objectives prior to each unit of instruction. Using a separate-sample pretest-posttest control group design, he was unable to detect any significant treatment effect. Aregahegn (17) took a rather novel approach and examined the effect of providing information to parents regarding the behavioral objectives associated with instruction. Using a control group design to study the effect among 202 students of grade 6 and t-tests to compare group means, a significant treatment effect was obtained. Multiple regression analysis also was used to demonstrate that treatment group membership contributed significantly to both achievement and attitudes. The educationally significant finding here is that ach evement was demonstrated to be affected by parental knowledge of instructional objectives. Combining organizational techniques, Forsythe (124) attempted to influence achievement among 144 community college biology students through use of both advance organizers and behavioral objectives. The results included an inconsistent array of significant and nonsignificant effects not readily interpreted.

Weekly Quizzes and Assignments; Use of Gowin's Vee; and Concept Mapping

Duty (102) compared the effects on achievement of administering weekly and biweekly quizzes to 193 college chemistry students, with results supporting the use of weekly quizzes. In a study of weekly assignments, Kremer (216) compared the effects of distributing assignments having detailed structure with assignments outlining only general guidelines. Using a pretest-posttest 2 X 3 (treatment X IQ) factorial design with a sample of 95 high school biology students of grade 10, he found a significant overall treatment effect favoring the detailed assignments. Interaction effects were not clear.

Gurley (154) compared two instructional treatments, one conventional high school biology instructional model and one incorporating concept mapping strategies and the use by students of Gowin's Vee to identify interrelationships between theory and practice. Employing a quasi-experimental case study design to accomodate the field situation, Gurley found no significant treatment effect on performance as measured by objectively-scored tests, but essay questions seemed to elicit higher quality responses from the experimental group.

Overall, there seem few valid generalizations that can be extracted from studies reviewed here regarding the use of organizational aids and instructional mediators in science classrooms. Some techniques are sometimes effective with certain groups. Given the dynamics of classroom interaction and the influence of teacher behavior on student performance, perhaps more research on how successful teachers employ instructional mediators to effect achievement is in order.

Emphasizing Language Arts Skills During Science Instruction

Based on evidence from previous studies that science experiences enhance cognitive skill development and have positive effects on language arts skill development, Mishler (281) recommended that, as much as possible, science be integrated in the classroom with language arts. Fulton (132) attempted a measure of integration, using four levels of instructional treatment with 186 science students of grade 7 to study the effects. Using a pretest-posttest design, significant differences in achievement between groups were found for three of the six comparisons, favoring integration. Butler (57) included training in reading and study skills prior to textbook reading assignments in selected biology and child development classes. Based on a sample of 115 community college students, Butler found no significant differences between groups on a measure of reading comprehension, but content achievement was significantly increased by the technique. Working with 76 Egyptian high school students, Zaher (453) used elaboration techniques to prepare students for reading English textbooks. Significant effects were noted on reading comprehension, content achievement, and attitudes. These results seem weakened by the nature of the alternative treatment in which the control group studied the same content with no text, essentially rendering a treatment versus no treatment situation. In a related study, Ackley (3) examined the effect of various Cloze procedures on content achievement among 233 science students of grade 7.

Although the results reviewed here do not seem conclusive regarding the benefits of integrating science instruction and some aspects of language arts instruction, the potential for influencing achievement in science through such integration seems evident.

Teaching Style and Techniques

There were several studies of instructional treatment that do not form a homogeneous group and do not fall easily into the previous categories of this section. They are, therefore, grouped together here as individual techniques of teacher intervention that can be used with most any instructional system or along with other instructional strategies. Roadrangka and Yeany (333) studied the effect of teaching style (direct versus indirect) on the engagement time of 147 middle school and high school students. Level of cognitive development and quality of implementation were considered as moderating variables. Results indicate that both teaching style and quality of implementation effect engaged time, as does level of cognitive development.

Wollman and Chen (442) studied the effect of a teacher intervention technique (social interaction) on student performance. The treatment required teachers to probe students for evidence, explanations, and evaluations of results as students were engaged in a task of controlling variables. A pretest-posttest design included a six-week treatment period, with two 45-minute sessions per week. Based on a sample of 83 students in grade 5, t-tests were used to make 16 comparisons between three class groups on two posttests. There was a significant treatment effect on 15 of the 16 comparisons, favoring the social interaction treatment. The results were interpreted as evidence that teacher intervention such as implemented in the social interaction treatment consolidates prior skills and knowledge. It can certainly be taken as evidence that teacher intervention can enhance the effects of experiential learning.

Beaver (30) attempted to enhance student performance and teacher intervention by structuring an ESS unit according to an inquiry-script plan. Working with 12 teachers and 293 elementary students, Beaver demonstrated that teachers could successfully employ the technique to promote achievement of unit objectives, with no negative effect on teacher behavior or student activities. Lewis (240) examined the effect of teacher intervention, questioning behavior, on concept formation among 30 students of grade 7. Using a pretest-posttest design and two treatment levels, Lewis was unable to detect any significant differences between groups, though both groups exhibited significant gains in conceptual understanding by the end of the treatment period.

In a study of 176 physics students of grade 10, Ho (178) examined the effect on achievement, motivation, and effort of using a second language (English) rather than a first language (Chinese) for instruction among bilingual students. Using analysis of covariance, with aptitude as a covariate, Ho detected no treatment effect. The treatment groups did differ significantly in aptitude, favoring the second-language group. This apparent selection bias may well have confounded the results. Altering the speaker rather than the language, Vockell and Fitzgerald (417) studied the effect of a guest presentation on student attitudes, and found no evidence of an enhanced effect.

In providing a naturalistic account of questioning patterns exhibited by an inexperienced teacher during a teaching episode, Kilbourn (209) has initiated discussion of a seemingly unexplored dimension of teacher intervention. He has demonstrated that beyond probing students through mechanical questioning strategies teachers must increase student awareness of the intellectual operations they use to analyze information Characterizing many teaching materials as epistemologically "flat", Kilbourn has suggested that teachers must promote epistemological richness during instruction by actively provoking students to be aware of the epistemological features of lessons. Although the notion of epistemological richness must be explicated more fully, Kilbourn's idea may provide a means of enhancing the quality of research into teacher questioning patterns and other forms of teacher-student interaction intended to promote conceptual understanding.

Classroom Social Environment

Some aspect of classroom social environment was studied by Nieminen (297), Serrano (363), and Lockheed and Harris (244). Nieminen reported the findings of a six-year study focusing on the achievement of students from elementary schools of different sizes. Among the findings there is evidence that, in science as well as some other basic subject areas, students from combined classrooms of small schools perform just as well as students from larger schools. Serrano (363) examined the social networks and friendship patterns among 10 high school physics students, finding no evidence of a strong social network or the anticipated friendship linkages among classroom peers. In a related study, Lockheed and Harris (244) examined the interaction among male and female peers in 29 classrooms of grades 4 and 5 in an effort to account for the unequal participation in the sciences by males and females. A classroom sociometric scale, an attitude survey, a problem-solving task, classroom observations, and posttests were used to collect data. It was determined that opportunities for peer learning, particularly cross-sex learning, were few, and it was learned that students do not seem receptive to cross-sex grouping. These findings are not encouraging since it is often assumed that appropriate cross-sex interaction would be particularly beneficial for females in promoting scientific literacy.

Instructional Materials and Technology

Of the studies having to do with instructional materials and technology, by far the majority focus on the use of textbooks or microcomputers (see Table 4). This circumstance may seem a bit imbalanced given the suggestion by Molnar (286) that educators must expand their understanding and use of information technologies to meet identified needs in what has become an age of information. He provided a compendium of recent research findings to demonstrate the uses of current technologies and their potential role in treating student misconceptions, developing problem-solving skills, enhancing motivation, and so on. Young (452) also contributed an overview of research related to the use of educational media among students of grades 6 through 9. He attempted to identify the most effective uses of media technologies, taking note of advantages and disadvantages of each medium. There is little doubt that information technologies have much potential in educational settings, but there is also little doubt that powerful technologies have been relegated to trivial applications in the rush by many educators to be current. The push to incorporate new technologies into instruction will likely force an expansion of research in this area, particularly among science educators.

Table 4

Frequencies of Reports Documenting the Interaction of Instructional Media With Learning Outcomes

Instructional Medium	Learning Outcome					
	Achievement		Skills		Attitudes	
	R	NR	R	NR	R	NR
Microcomputer Graphics or Simulations	0	1	2	1	0	1
CAI or CMI[a]	5	0	0	0	1	0
Textbook Helps	5	0	0	0	0	0
Textbook Readability	1[b]	1	0	0	0	0
Structured Laboratory Guides	1	0	1	0	1	0
Projected Media	2	0	0	0	2	0
Supplementary Printed Materials	2	0	1	0	1	0
Format of Printed Visuals	3	0	0	0	0	0

Note. Reports contributing data to more than one of the above categories have been included in all appropriate frequencies. All relationships are positive except where noted otherwise.

R Number of reports providing evidence for a relationship

NR Number of reports indicating no consistant evidence of a relationship

[a]CAI = Computer Assisted Instruction; CMI = Computer Managed Instruction.

[b]Achievement is reported as inversely related to level of readability.

Microcomputers

A variety of efforts involving the instructional use of computers were reported, including: development or evaluation of CAI modules (Spain, 380; Soldan, 377; Moore, 287; Berger, 35; Leece, 233), comparisons of CAI with other modes of instruction (Saldana-Vega, 353), the use of simulation (Sampson, 355; Ploeger, 320), the use of graphics animation (Peters and Daiker, 314), student attitudes toward CMI (Steffenson and others, 385), and barriers to instructional computing (Neufeld, 293). Berger (35) described in some detail the development of a computer program designed to develop the process skill of estimating and the evaluation of the program's influence on learning. His results include examples of classic learning curves, indicating clearly that computers can be successfully employed to achieve specific learning objectives. Gains in learning related to use of CAI modules in biological science were reported by Spain (380), Leece (233), and Soldan (377), but Soldan's findings did not indicate an enhancement of achievement when CAI supplemented traditional teaching methods.

Saldana-Vega (353) provided evidence, however, that CAI can be employed to significantly enhance test performance among physics students when used to supplement teacher instruction or when used in place of teacher instruction. Working with 74 preservice teachers, Ploeger (320) also reported a significant treatment effect favoring CAI when computer simulation was used to promote instructional laboratory safety. Caution must be exercised in interpreting the results, however, since the pretest-posttest design included a treatment-no treatment comparison. Some noteworthy results regarding the effectiveness of computer simulation were reported by Sampson (355) who examined the use of simulation to enhance acquisition of generic analysis skills. No significant effect was noted following treatments lasting eleven weeks. A significant treatment effect favoring computer simulation was detected following a condensed five-week treatment during the shortened summer session of classes. These results may indicate an instructional advantage for computer simulation when treatment periods are shortened. Peters and Daiker (314) reported no significant treatment effect with a sample of 400 organic chemistry students when animated computer graphics were employed to enhance achievement and attitudes.

Steffenson and others (385) assessed the attitudes of 64 college biology students regarding a system of computer managed instruction. Findings indicate an overall positive response, with students favoring the immediate diagnostic feedback and the opportunity to take tests at their convenience. In an attempt to identify barriers to increased use of instructional computing, Neufeld (293) solicited feedback from the chemistry departments of every college in southern California. She also visited 12 sites having exemplary programs. Barriers identified included administrative and economic factors, faculty barriers, and barriers associated with commercial suppliers. The most common characteristic of institutions having exemplary programs is the presence of one or more faculty entrepreneurs who have invested much personal effort and time in the development of programs. It is suggested that individuals having such interests in other institutions be identified and supported in their endeavors.

Textbooks

Textbooks were analyzed for level of readability (Steinberg, 386; Field, 119; Wright, 444; Fathi-Azar, 117; Zipin, 455) aspects of organization (Chastko, 67; Dansereau, 88, 89, 90, 91; Kozma, 213; Fathi-Azar, 117), and aspects of content (Stuart, 393; Fathi-Azar, 117; Fuhrman, Lunetta, and Novick, 130; Factor and Koser, 113; New Zealand Department of Education, 294). McFadden (268) described the development and evaluation of a study guide to accompany a college biology text, and Kiyimba (211) described the development and evaluation of five science readers intended to foster communication, observation, and experimentation skills. Kiyimba's efforts demonstrate that well-written, inexpensive supplementary materials can be produced for use among low-income groups, a critical need among many remote groups.

In a study of three subject areas treated by three published science textbook series across three grade levels (4, 5, and 6), Steinberg found greater differences in level of readability across science subject matter content than were found across grade levels or between publishers. Working with 111 elementary students, Field (119) provided evidence that science achievement is adversely affected by tests or textbooks having a level of readability above the level of student reading ability. It was further demonstrated by Field that gains in science achievement tend to parallel gains in reading achievement. Wright (444), however, provided evidence that simply reducing the readability of textbook material will not necessarily have a significant effect on achievement. Working with 265 high school biology students, she had content rewritten to a grade 6 level of readability after determining that 67 percent of the subjects could not satisfactorily comprehend their biology textbook. Wright offered several possible reasons, most methodological, why no significant effect was noted on achievement following a four-week treatment, but it was acknowledged that increased reading comprehension may not lead directly to increased learning. There are likely other moderating factors such as student characteristics, teacher behavior, instructional strategies, or, perhaps, the "epistemological flatness" of much instruction described by Kilbourn (205).

Dansereau (88, 89, 90, 91) reported extensive work on the influence of textbook processing aids (headings, etc.) and the effectiveness of training students in the use of such aids on reading comprehension and recall of information. He obtained a variety of evidence for the positive effect of processing aids (88, 89) and showed that students can profit from generating their own headings for textbook material (90) or from being exposed to training in the use of processing aids (89, 91). He also provided evidence that students characterized as field-independent outperform those who are more field-dependent in the processing of biology and geology content. It must be noted that these results were obtained from samples of general psychology students rather than from students in natural science courses. Chastko (67) studied the influence of embedded questions in text material on test performance among 109 high school chemistry students, and found increased test performance associated with the use of questions regarding knowledge and comprehension which were embedded.

The New Zealand Department of Education (294) examined school science textbooks and reference books for their portrayal of roles in science according to gender. The Department considered the number of roles portrayed, the inclusion of males and females in illustrations, the number of references to famous individuals, and sexist language. A general bias toward males was found, although some books did treat gender roles in a balanced manner. Females were occasionally portrayed in roles typically assumed by males, but the reverse was not noted. Despite attempts to remove sex-role stereotyping from educational materials, it seems clear that bias continues to exist in books used in schools. In a related study, Fathi-Azar (117) analyzed the biology and geology textbooks used in Iranian high schools. Among the findings reported is evidence that controversial issues, such as evolution and earth history, and the nature of scientific enterprise are not well treated. Readability levels also seem inappropriate, and chapter questions are at a low level in the cognitive domain.

Fuhrman et al. (130) assessed the extent to which five current high school chemistry laboratory guides promote inquiry and investigation in laboratory activities. They examined content organization of manuals and the tasks given for students to complete, and they reported a variety of summative analyses. Though inquiry is encouraged in a general sense, it was found that students typically are expected to follow specified procedures rather than to design experiments and that students are seldom challenged to generate hypotheses, make predictions, explain relationships, or define problems for future study.

Visual Media

Logue (245) compared the effects of a variety of media on conceptual understanding and attitudes among 242 students of grades 8 and 9. Focusing on the concept of geologic time, he obtained evidence that a slide-tape format can be more effective than filmstrip, 16 mm film, or flipcards in representing factual information. It was also found, though, that students expressed greatest interest in 16 mm films, with a lecture format being least favored. Slide-tape presentations were preferred over printed and illustrated materials. Walter (421) compared the effects of two delivery formats--lecture versus slide-tape presentations with accompanying manipulatives--on conceptual understanding among college nonscience majors. A significant treatment effect on conceptual understanding was obtained in favor of the slide-tape treatment during a unit on weather.

Johnstone and Mahmoud (200) described the use of animated film to facilitate an understanding of osmosis among 440 high school students. Cook (79) described the use of videotaped recordings of experienced individuals solving physics problems, and student response to the recording is summarized. In another attempt to facilitate understanding of osmosis and other aspects of cell biology, Mann (256) compared the use of line drawings versus visual-tactile diagrams among 84 college biology laboratory students. Effect of the two forms of illustrated materials as moderated by reading ability were compared using analysis of variance. Among the findings is some evidence that students having higher reading ability exhibit greater achievement when exposed to line drawings, while those with lower reading ability respond more positively to visual-tactile diagrams.

Winn (437) also focused on diagrammatic presentations, studying particularly the logical sequencing of diagrams and the role of drawings within diagrams. His concern is that features of diagrams be used in a way which facilitates the identification, classification, and sequence of concepts. Using analysis of variance to test comparisons in a 2 X 2 (format X order of diagrams) factorial design, Winn detected a number of significant effects among his 273 students of grade 9. Among the primary findings is evidence that diagram sequence has a significant effect on conceptual understanding and that the presence of drawings within diagrams can improve concept acquisition. In this study, diagrams illustrating the evolution of dinosaurs were used during an eight-minute treatment which was followed immediately by a multicomponent posttest. The most effective treatment included drawings of dinosaurs along with labels and which depicted dinosaurs from oldest to youngest in geologic time in sequence from left to right, top to bottom. Lehman (234) also demonstrated the effectiveness of combining diagrammatic information and other visual data to enhance learning. Working with 160 high school students, he compared the influence of a typical periodic table of the elements with two modified versions, one accompanied by additional numeric information and one accompanied by additional visual information. Among students with minimal experience in science, there was a significant treatment effect in favor of the periodic table modified with visuals. Overall, the modified tables tended to benefit students exhibiting higher levels of verbal comprehension.

Microcomputers have joined textbooks as instructional aids of popular research interest. As the minutia of textbooks and visuals are being refined to maximize effectiveness, however, research of computer usage tends to be more exploratory in nature. Computer assisted instruction and computer managed instruction have been shown to be effective in promoting student achievement, but can the power of microcomputers be exploited in other modes to meet the particular needs of science teachers? As with all instructional aids, microcomputers will likely demonstrate their full educational potential when used to enhance teacher skills rather than replace them.

Curricula and Programs

A large proportion of the studies reported in 1982 pertained to the development, evaluation, or comparisons of science curricula or programs (see Table 5). It shows

Table 5

Frequencies of Reports Documenting the Interaction of Curriculum With Learning Outcomes

Curriculum	Learning Outcome					
	Achievement		Skills		Attitudes	
	R	NR	R	NR	R	NR
Activity-Based[a]	6	1	5	1	4	1
New Curriculum or Program	2	0	1	2	1	2
Nonschool Programs	3	0	0	0	2	0
Interdisciplinary Courses	1	0	2	0	0	0
Environmental Studies	0	0	0	0	1	0
Energy Education	1	0	0	0	0	0
College Coursework for Nonscience Majors	0	0	1	0	0	0

Note. All noted relationships are positive.

R Number of reports providing evidence for a relationship

NR Number of reports indicating no consistant evidence of a relationship.

[a]Predominantly curricula developed through projects funded by NSF.

several efforts to document the effects of activity-based curricula on student achievement, skills, and attitudes. In an effort to accomodate the diversity of studies in the most straightforward manner possible, studies in this section are, with one exception, grouped according to academic level. Three studies focusing on marine education do not fall neatly into the established categories, so are treated as a separate group. Two other reports (Kyle, 220; Kyle, Shymansky, and Alport, 221) refer to a meta-analysis which cuts across categories in estimating the impact of NSF-funded curriculum projects of 1955 through 1970. Comprising 105 experimental studies which involved 45,626 subjects, the meta-analysis compared the effect on student performance of traditional science curricula and the NSF-funded curricula which emphasized inquiry, integration of theory and activity, and higher cognitive skills. Despite a great diversity of performance measures, results show the NSF-funded curricula to be more effective than traditional curricula in promoting student achievement, positive attitudes, critical thinking, and process skill proficiency. A pervasive positive effect was found even after removing the moderating effects of grade level, science discipline, student characteristics, teacher characteristics, school characteristics, and research design. The effect on achievement is even more pronounced among females, urban students, and members of high or low socioeconomic groups. These results are taken as good reason for not abandoning the aims and methods of science education initiated during the Sputnik era. Evidence of the impact of science curricular efforts on student performance was also contributed by Anderson (14, 15) in his meta-analysis project report.

Elementary School

Several studies focused on the educational outcomes of activity-based science programs, particularly those developed with NSF support. A synthesis of past research through meta-analysis (Shymansky, Kyle, and Alport, 366) provided evidence for the effectiveness of ESS, SCIS, and SAPA in promoting student performance in several dimensions. Compared to traditional textbook programs, the NSF programs are reported to produce an overall gain of 12 percentile points in cognitive achievement while enhancing process skill development, increased performance on tests of reading and arithmetic skills, and positive attitudes toward the course, the school, and self. A similar analysis is reported by Bredderman (50, 51) who pooled the results of 57 studies involving 13,000 students. He reported an average improvement of 20 percentile units on science process measures with the NSF programs, with the effect being greater for disadvantaged students. Gains were also shown with the NSF programs for creativity (16 percentile units), attitudes (11 percentile units), perceptions (10 percentile units), logic development (10 percentile units), language development (9 percentile units), science content (6 percentile units), and mathematics (5 percentile units). Effects on classroom practice indicate that NSF programs increased student activity by nearly 10 percent, decreased talk time by 9 percent, and decreased lecture time by 7 percent.

In an attempt to elucidate the effects of a recent version of the SCIS program, however, Karanovich (206) detected no significant treatment effect on reading or science achievement in a study involving 89 students of grade 1. A related study by Cornett (82) provided no evidence of a significant relationship between the number of ESS units experienced by students of grade 6 and attitudes toward science. An activity-based science program in Minneapolis which incorporated some ESS and SCIS units was shown by Clark and Premu (71) to enhance student performance in several domains when compared to other science programs taught elsewhere in Minnesota. These mixed results are consistent with those of many previous studies based on small samples and individual programs. One value of meta-analysis seems to be the potential for distilling subtle effects by pooling the efforts of limited studies.

In related studies, Walton (422) examined the effects of an elementary kit program in Anchorage, Poslock (323) described behaviors exhibited by teachers using the Science 5/13 program, Brown and Reed (53) evaluated the effects of a process oriented program developed in Nigeria, and Coble and Rice (74) presented the results of an 18-month project assessing the status of elementary science education in North Carolina. The results reported by Brown and Reed (53) corroborate findings that activity-based programs can be effective in promoting process skill development, interest in science, and understanding. Given such findings, the report by Coble and Rice (74) is somewhat discouraging. In a survey of 891 elementary school teachers, fewer than 15 percent reported using an activity-based science program, with the use of NSF-funded curricula being 1[illegible] percent. Approximately 70 percent reported using textbooks, but 42 percent teach science less than once per week. During a conference of public school supervisors, however, desire was expressed to: develop a comprehensive array of science objectives for elementary school along with appropriate instruments to measure achievement, develop model programs in which science and other subject areas are integrated, and disseminate relevant research findings to teachers.

Among the relevant research findings disseminated to teachers should surely be the evidence that activity-based programs do have positive effects on student performance. Teachers must be encouraged to consider implementation of curricula which have been shown to foster student achievement, critical thinking, positive attitudes, and process skill proficiency. Teachers should also be aware that activity-based programs seem particularly effective among students characterized as disadvantaged.

Middle S

A systematic review of literature (1965-70; 1975-80) addressing the status of science education in middle school and junior high school was contributed by Hurd, Robinson, McConnell, and Ross (194). They have pulled together a wealth of information from statements of middle school philosophy and goals, committee reports, analyses of programs, research studies, and policy statements. Much of what is known about middle school and junior high school science education, they reported, has been extrapolated from elementary and high school research data.

An abundance of data generated during field testing of the BSCS Human Sciences Program have been made available. Several codebooks for data files provide frequencies for values of: (a) 1275 field-test variables (Robinson and Tolman, 337), (b) variables and reviewer ratings of the 623 program activities (Robinson and Tolman, 338), (c) student ratings of activities associated with the Surroundings module (Robinson and Tolman, 343), (d) 310 variables related to the Knowing module (Robinson and Tolman, 342), and (e) 3,173 student-activity interactions for the Knowing module (Robinson and Tolman, 336). Robinson (335) provided the evaluation instruments along with instructions which were used to collect data for the field test. Robinson and Tolman (341) also provided a user's guide which presents background information regarding the program materials and the data collection procedures used to field test the 13 interdisciplinary modules of the Human Sciences Program. Another user's guide (340) presents a description of program activities and the conceptual design for their evaluation, including activity characteristic codes, variable names, labels, and coding format. Finally, there is a user's guide (Robinson and Tolman, 339) which documents the codebook (Robinson and Tolman, 337). In a separate but related study, Hill (176) compared the effects of a traditional science program with a module from the Human Sciences Program. Working with eight classes of students in grade 8, Hill used factor analysis in a pretest-posttest design to test the effect of treatment on attitudes toward the science course and level of logical thinking skills. There were no significant main effects noted, but there was a significant effect favoring the Human Sciences Program on attitudes toward activities. There were also significant gender by treatment interactions noted, along with a significant teacher effect.

In another evaluation of program effects, McDuffie and DeRose (267) provided descriptive data of achievement associated with distinct implementation of ISCS, Level 1. A significant increase in quantitative aspects of achievement (requirement completion rate) was noted over the five year period described, but there were minimal differences in qualitative aspects (level of mastery). Chi-square analysis yielded significant interaction effects between achievement and IQ and reading ability. The instructional strategies associated with ISCS were deemed well suited to the initial learning styles of only a small proportion of students, with program success depending on a high degree of teacher involvement, commitment, and supervision.

Several studies focused on curricula designed for specific educational contexts or populations. Sunal and Sunal (394) described and evaluated a science curriculum developed for the hearing impaired through modification of two commercial science programs. Gennaro (138) described evaluation of a course, for middle school children and their parents, in animal behavior which included excursions to the zoo. The rationale and responses to surveys related to such courses are also presented. Pretesting and posttesting indicate that attitudes toward the experience were positive and that gain scores in understanding were statistically equal for parents and children.

Blum (46) evaluated an environmental studies curriculum in terms of student perceptions of course usefulness for achieving various goals. Results were interpreted as evidence that an inquiry oriented curriculum can have a positive effect on students' perceptions of school subject usefulness. There were no significant differences noted in effect according to gender or academic ability. Two aspects of methodology were somewhat novel and give reason for caution in interpreting results. The control treatment was specifically designed for the investigation, so the evaluation did not involve a comparison of two existing curricula or the more common comparison between an experimental treatment and a "conventional" treatment. Also, participating teachers were selected to some extent on the basis of commitment to a particular instructional orientation. Rather than being assigned randomly to curricular treatment, teachers were assigned to the treatment which best accomodated their own personal style. Blum provides his rationale for the procedures. In another study related to environmental concerns, Coffey (76) evaluated the implementation of an energy education curriculum in one school district. Working with 530 students of grade 5, he provided evidence that a consistently implemented program can have a positive effect on knowledge, attitudes, and behavior related to energy use.

Two studies focused on the effect of curriculum on aspects of cognitive development. Pell (311) compared two science curricula regarding their effects on cognitive achievement and evaluation skills among 190 students of grade 8. Using factor analysis in a pretest-posttest design, Pell obtained an array of results, many in support of the Introductory Physical Science curriculum. Staylor (384) attempted to compare the effects of NSF-funded curricula versus other curricula on intellectual development. Following a six-month treatment in a pretest-posttest nonequivalent control group design, no significant differences were noted between the curricula regarding effects on intellectual development.

Among the more encouraging results presented in this section of the review are those associated with innovative new programs designed specifically for middle school students. Field-testing of the BSCS interdisciplinary program provides a new curricular resource for classroom teachers and an extensive database for interested researchers. Also noteworthy are the introduction of a new science curriculum for the hearing impaired and a science unit for parents and their children.

High School

In an effort to assess the impact on learning of nontraditional curricula developed during the 20 years following 1955 Weinstein, Boulanger, and Walberg (425) used meta-analysis to achieve a synthesis of findings from 33 studies involving 19,149 students. They obtained a significant overall effect amounting to a 12-point percentile advantage for students exposed to the innovative curricula. Analyses undertaken to detect biases related to methodology, individual differences, and instrumentation revealed no significant differences across groups.

Three other curriculum evaluations were reported by Owen (307), Koech (212), and Ridley and others (331). Owen reported results from case studies and a survey of approximately 300 schools regarding the Australian Science Education Project (ASEP). Among the findings it was shown that approximately 66 percent of the schools reviewed had adopted ASEP to some degree within two years of publication. The degree of adoption is related to: (a) teacher access to ASEP materials, (b) the nature of school science guidelines, and (c) the receptivity of science departments to innovation. Koech (212) examined implementation of the biology component of Kenya's Secondary School Science Project. Despite congruity between course objectives and national examination objectives, and generally positive attitudes by teachers toward the course, several factors were noted to be obstacles to implementation. Among the factors were the following: (a) inadequate inservice training and supervision of teachers, (b) the effect of external examinations on instructional priorities, (c) inadequate supplies of curricular materials and equipment, (d) lack of consistency among course units regarding level of difficulty, and (e) insufficient involvement of teachers in development and revision of units. Finally, Ridley and others (331) surveyed U.K. college physics departments (n = 33) regarding high school preparation in physics. Former Nuffield students seemed to perform better than others in practical work, but lacked proficiency in mathematical skills. Overall, university instructors tended to favor traditional physics for students.

Focusing on student perceptions, Tamir and Amir (399) sought student views regarding high school science experiences, while Bojczuk (48) solicited student opinions regarding the relative difficulty of chemistry concepts. Among the findings reported by Tamir and Amir from responses by college freshmen and high school seniors is evidence that high school experiences in science do have effects on college achievement in science. It was also noted that high school biology tends to be perceived by students as more inquiry-oriented and helpful than chemistry or physics in preparing for college experiences. Working with 463 motivated and academically capable students, Bojczuk (48) found topics involving ions and content associated with the mole concept to be perceived as most difficult by students. Also detected was a significant gender effect on the perceived difficulty of several topics, and an often assumed inverse relationship between interest and perceived difficulty. It is also noteworthy that the unit judged by most students as among the most difficult--organic chemistry--was considered by teachers (n = 40) to be among the easiest units to teach.

Worley (443) described the development and implementation of a set of secondary chemistry offerings, while Gaudin (136) examined the effect of chemistry course placement on achievement. Analysis of covariance was used to compare the performance of 514 students on a standardized achievement test which is used to predict academic success in college. Some of the students had taken high school chemistry before taking high school biology, while the others had taken biology first. No significant differences in performance was detected between the groups, so the sequence of instruction seemed to have no effect on student preparedness for college.

Attempts to integrate content and coordinate the efforts of departments were reported by several authors. Goodstein (147) provided the results of a pilot study of a course emphasizing applications of mathematics to science. Although the course was implemented in several forms, it was shown to be useful and well received by students and teachers. Left unsettled is the question of how best to implement the course in a traditional curriculum. Hart and others (165) surveyed the extent to which high school departments of mathematics and science cooperate. Although several styles of cooperation were noted within schools, there was no situation found where mathematics and science are formally integrated throughout the school. Case studies (Hart and others, 166) of two schools that coordinate efforts in science and mathematics were presented. Craft and others (87) surveyed teachers (n = 86) regarding their attitudes toward integration of health into the science curriculum. It was concluded that integration can be achieved without sacrificing science content. Johnson (198) attempted to identify the relevant energy conservation content for integration into industrial arts courses. A review of the literature was followed by a survey of teachers regarding the relevance of topics. Regarding the matter of energy education, Hofman and Glass (180) reported the results of three studies focusing on the Project for an Energy-Enriched Curriculum, and they provided information of a pilot study.

Roth (347) and Ting (404) reported efforts in support of new science curricula. Roth surveyed teacher perceptions (n = 235) regarding the major tenets of a unified science curriculum, finding generally positive attitudes toward the curriculum. It is perhaps noteworthy that the strongest support came from experienced teachers who have strong science backgrounds and who emphasized the social sciences in college coursework. Ting (404) reported efforts to identify a set of themes for a proposed curriculum which includes content on the philosophy of science, the history of scientific enterprise, and the interaction of science with all aspects of human experience, including nonscientific modes of explanation. From a variety of sources ten themes were identified which are said to subsume the themes of the current major curriculum. Supporting evidence for the subsuming power of the themes has been provided.

Efforts to revise the high school curriculum demonstrate a healthy concern to render the curriculum increasingly relevant and effective. Findings reviewed here indicate that curriculum projects of the two decades following 1955 have generated science programs which foster increased student performance. Though obstacles to implementation of such innovative programs remain, the evidence that high school science experiences influence college achievement impels us to pursue continual curricular refinement and opportunities to integrate subject matter. The flux of scientific knowledge and societal concerns precludes completion of the task.

Postsecondary Education

Relatively few research efforts were directed toward an aspect of postsecondary education in the sciences, but those reported represent a diverse set of research interests. Five studies focused on programs and courses for those pursuing careers in technical professions, three focused on matters related to specific science courses in the standard curriculum, and three focused on the status of specific graduate programs. Of particular interest are two reports relating the status of graduate programs in science education. Also noteworthy, Chiang and Andersen (69) surveyed chinese graduate students studying physics in Taiwan and the United States. Their results indicate that students pursuing their degrees in the U.S. feel less well prepared than their counterparts. Curricular revisions were recommended.

Programs and Courses for Technical Professions

Mowery and Wolf (289) described the rationale, goals, and curriculum development and evaluation procedures associated with the Science and Engineering for Technicians Project. A series of study guides was designed to facilitate learning of generic science and engineering skills, but reported results provide no support for use of the guides as self-study or stand-alone materials. Collins and Sarrubbo (78) provided the results from their surveys of students, graduates, and representatives of four-year technical colleges regarding the curricular needs of students enrolled in the Engineering Technologies Program and the Engineering Science Program of a community college. Through the use of interviews, observations, and examination of documents, Mullenax (291) examined an innovative program in Columbia, the Rural University, which prepares people for roles as development specialists--Engineers for Rural Well-being--over a period of six years. Student selection procedures, instructional methods, and program outcomes are described. Harrell and Gibbs (164) examined the continuing education resources used by scientists and engineers to maintain professional competence. Working with a sample comprising 480 subjects working in small, geographically dispersed companies, Harrell and Gibbs have provided results, conclusions, recommendations, supporting documentation, and a list of desired courses. Regarding courses, Twidwell (411) described the development and evaluation of four courses in extractive metallurgy which have a modular, self-paced format.

Individual Science Courses

Concerned about the attitudes of nonscience majors toward scientific enterprise and their own ability to succeed in science courses, Carrington (61) designed a chemistry course specifically for nonscience majors which was intended to promote changes in attitudes. Results indicate that there was a measurable positive change in attitudes toward science among students, with the change being significantly greater than that noted for two comparison groups. In addition to an attitude effect, Ballard (24) sought an effect on achievement and student attrition rate related to the use of interdisciplinary materials. Working with 642 students in college biology, chemistry, and mathematics courses, Ballard was unable to detect an overall treatment effect, although use of the materials did produce a significant positive effect on attitudes among male students under the age of 23 years. Interested more in the cognitive outcomes of coursework, Pizzini, Treagust, and Cody (319) investigated the use of formative evaluation over a three-year period to increase student achievement in specific subject matter. Using a one group pretest-posttest design to study three class groups (n = 26, 25, and 13) taking the same biochemistry course in succeeding years, a nonaparametric statistic indicated significant increases in student achievement each year. This study seems noteworthy for its empirical demonstration that formative evaluation can guide course modification which yields desirable learning outcomes.

Status of Graduate Programs

Evaluated were programs in microbiology (Poupard, 325) and science education (Yager, 445; Yager, Bybee, Gallagher, and Renner, 448). Poupard compared the curricula of 12 master's degree programs in clinical microbiology, a relatively new specialty, through a survey of 137 program graduates and administrators. A model curriculum based on his findings was described. The status of graduate programs in science education was reviewed among institutions offering only master's degrees (Yager, 445) as well as among others offering higher degrees (Yager et al., 448). Both studies provided a wealth of information regarding the nature of programs, faculty, and student support. Yager (445) documents the eras of rapid growth (1960-70), slight growth (1970-75), and decline (1975-80) for science education programs in terms of programs, students, and faculty. In a comprehensive report, Yager et al. (448) provided data collected from surveys of institution deans (n = 365, a 90 percent response), representatives of the 35 leading science education programs, and members of five selected groups of science educators (n = 144). Only 40.2 percent of the responding institutions reported a program in science education, and among those having programs, only 2? percent reported having a formal department or center for science education. Overall, preservice teacher education was cited as the primary focus of science education programs, with teacher education the primary interest among faculty members; relatively little interest in research was reported.

Along with the recent decline in programs and science educators at graduate institutions, there have emerged some noteworthy employment patterns for program graduates as well. Though return of doctoral graduates to K-12 educational environments was rare in 1960, it had become common by 1970 and the major arena for employment by 1980. Many doctoral graduates also find employment in industry, health fields, government agencies, and public nonschool centers having educational programs. Given the recognized deficiencies in public school science education, these findings regarding the status of graduate programs in science education, the lack of interest in research among science educators, and the developing employment patterns among recent doctoral graduates should be cause for great concern. At a time when a broad base of leadership in science education at the collegiate level is becoming most crucial, the supply is in decline. More regarding the findings of Yager et al. (448) is presented in the section of this review devoted to science education policy and practice.

As the studies presented here demonstrate, the role of science curriculum research and evaluation at the postsecondary level remains somewhat ambiguous. There are studies of individual courses, studies of technical training programs, and surveys of attitudes and practices, but systematic study of science curricula for liberal arts students, be they science or nonscience majors, is rare. As the community of science educators grows, it would seem appropriate that postsecondary science curriculum become a major focus of research attention.

Marine Education

Though only three investigators (Kastuck, 207; Thornley, 403; Lanier, 225) examined aspects of marine education, their findings cut across the age groupings employed in this section of the review. Kastuck described the development of three educational resources--a multimedia presentation, a resource document for educators, and a model aquaculture site--focusing on the study and aquaculture of the blue mussel. Based on responses to questionnaires sent to schools, individuals, and organizations, Thornley (03) provided an assessment of marine education efforts in public elementary and secondary schools of California. Lanier (225) employed a Delphi survey technique with marine science personnel and interested lay people in an attempt to identify appropriate objectives for precollegiate marine education programs. The result was a list comprising 38 knowledge objectives, 29 skill objectives, and 73 attitude objectives. Among marine science personnel, the greatest concern was for objectives related to ecological and environmental issues and to the dynamics of interacting environmental systems. Lay people indicated greatest concern for objectives related to water pollution and the environmental impact of human activities.

Teacher Education

In this section are reviewed studies related to the preservice and inservice education of science teachers (see Table 6). It is noteworthy that junior high/middle school teachers received relatively little research attention. A comprehensive review of research reported between 1965 and 1980 was offered by Sweitzer (397), while Blosser and Mayer (44) critiqued more recent studies. Using meta-analysis to consolidate the findings of 68 studies, Sweitzer found knowledge of science processes to be the most common teacher outcome measured. Such was not the case during 1982, with treatment effects on expressed attitudes and other affective outcomes being often reported.

Also of interest are findings related to the status of teacher education programs. Following a study of the academic preparation of biology teachers (n = 77), chemistry teachers (n = 101), physics teachers (n = 71), and advanced biology teachers (n = 100), Anderson (13) supplemented the results with recommendations for teacher certification requirements, teacher education programs, school practice, and future research.

Following the first phase of a more comprehensive investigation, Mechling, Stedman, and Donnellan (273) provided information regarding the preparation and certification of science teachers. A survey of deans associated with the leading teacher education institutions revealed that only 17.8 percent of the programs require preservice elementary teachers to complete coursework in each of the following areas: biological sciences, physical sciences, and earth sciences. One half of the programs require only eight semester hours of science coursework, the same amount generally required of all college students. A variety of statistics demonstrate that institutions place more emphasis on science processes and teaching methods than they do on science content. Also noteworthy is the paucity of programs and methods courses for middle or junior high school teachers. For middle schools, 28.9 percent reported preparation

Table 6

Frequencies of Reports Documenting the Outcomes of Teacher Education Experiences

Teacher Education Experience	Measure of Outcome			
	Student Performance	Teacher Performance	Teacher Sentiments[a]	Teacher Credentials
Early Childhood (Preservice)	0	1	0	0
Primary (Preservice)	0	0	1	0
Primary (Inservice)	1	0	0	0
Elementary (Preservice)	0	3	8	0
Elementary (Inservice)	1	4	2	0
Middle School (Inservice)	0	1	0	0
Junior High (Inservice)	0	1	2	0
Secondary (Preservice)	0	2	0	0
Secondary (Inservice)	0	2	0	5

[a]This category includes measures of both attitudes and level of anxiety toward science or science teaching.

programs and 4.4 percent reported methods courses specifically intended for prospective teachers, with the proportions reported for junior high schools being 33.3 percent and 4.4 percent respectively. More findings of the study by Mechling et al. (273) are presented in the section devoted to science education policy and practice.

Examining the congruity of elementary teacher education practice and professional guidelines regarding preparation for science teaching, Miner (278) contacted 505 U.S. institutions (56 percent responded) known to offer elementary education programs. Multivariate analysis techniques were used to assess relationships among institutional characteristics, personnel characteristics, and program characteristics. Results indicate that relatively few professional guidelines are consistently met by institutions. Among the findings, 66 percent of the responding institutions emphasize science processes, but only 22 percent meet guidelines in providing adequate facilities, materials, and individualized instruction.

Preservice Teacher Education

Analysis of teaching behavior as a pedagogical technique, preservice teacher characteristics, and affective outcomes of preservice experiences were studied by researchers interested in the preparation of prospective science teachers. Suggestions for the design of preservice programs were offered by Owen (306) who examined literature related to science and mathematics teacher effectiveness, and by Cash (62) who extracted principles for biology teacher education from a conceptual analysis of Teilhard de Chardin's concept of evolution. Voltmer and James (418) also provided data bearing on the relevant content of preservice experiences from their examination of laboratory teaching competencies. A list of 70 competencies was developed and subjected to the review of 82 science educators involved in certification programs, 89 percent of whom held a Ph.D. in science education. Deletion of eleven competencies deemed not appropriate by the reviewers, because of the equipment and skill requirements, reduced the list to 59 competencies that should be developed by preservice education programs. Finally, one component of the meta-analysis project reported by Anderson (14, 15) included a synthesis from previous research on science teacher education practices focusing on strategies of inquiry.

Reports by Dillashaw and Yeany (97), Yeany and Porter (450), and Yeany, Padilla, and Riley (451) focus on the use of behavior analysis to train teachers in the use of desirable teaching strategies and classroom behaviors. The report by Dillashaw and Yeany provides the rationale for the technique and describes the use of two analysis systems. The training protocol in both systems involves the analysis of model lessons through identification and coding of teaching strategies observed. Preservice teachers then teach a lesson themselves and perform a self-analysis. Yeany et al. (451) reviewed literature related to the systematic analysis of teacher behavior, with Yeany and Porter (450) performing a meta-analysis to examine the effects of training in behavior analysis on behavior exhibited by science teachers. Results of the latter investigation indicate that analysis training has a positive effect on teacher behavior. In a somewhat related study, Franklin (126) compared the relative benefit of feedback from experienced teachers and peer feedback following microteaching sessions. Though there were some significant differences noted between ratings of actual performance by three judges, there was no significant effect noted due to the status of the person providing feedback. Based on a sample of only 19 preservice teachers, however, the lack of an effect must be interpreted cautiously.

Preservice Teacher Characteristics

El-Gosbi (108) sought relationships among several variables in a study involving 85 college students. He compared science majors, early childhood education majors, and intermediate elementary education majors with regard to level of cognitive development, SAT performance, GPA, process skill achievement, and academic background in science. Among the array of relationships presented, significant differences were reported between science majors and early childhood education majors in level of cognitive development, with science majors exhibiting a higher level of development.

Ngoibi (299) examined the relationship between level of moral reasoning and environmental behavior among preservice and inservice teachers in Nigeria. Working with 110 subjects of a stratified random sample, an ex-post facto nonexperimental design was employed. Knowledge of environmental concepts was low, with moderating effects being related to academic status (graduate versus undergraduate), professional status (inservice versus preservice), gender (male versus female), and religious preference (Moslem versus Christian), with the first category listed for each pair exhibiting greater knowledge. It was also found that level of moral reasoning was positively related to knowledge of environmental concepts, commitment to the environment, and level of education. In another study based in Nigeria, Ogunniyi (301) examined the conceptions held among preservice science teachers regarding the language of science. Subjects, 53 students in a science methods course, indicated the degree of their agreement with statements related to the views of selected philosophers regarding the nature of scientific language. The responses of subjects did not consistently endorse the perspective of any one philosopher, though a preference seemed apparent for the view of Hempel and other scientific empiricists. The results demonstrate most clearly that subjects could not consistently distinguish empirical and theoretical concepts, with 75 percent identifying terms such as molecule, atom, electron, and gene as empirical concepts. Most also considered laws and theories to be true and verifiable assertions, and 79 percent thought the primary objective of working scientists to be the improvement of human welfare.

Guntawong (153) assessed the attitudes toward science and science teaching among 376 Thai preservice elementary teachers, finding a majority to express positive attitudes toward both. It was noted that attitudes were moderated by type of secondary school background (public versus private) and geographic cultural pattern. During another study of attitudes, Perkes (313) found female elementary education majors to express more apprehension toward animals than did males.

Wellington (427) presented survey results from 27 universities and 30 polytechnics and colleges in Great Britain regarding the characteristics of students in training to teach physics. Among the findings, it was learned that only 13.5 percent of the prospective physics teachers at universities were female and that a broad range of ages were represented (21 to 59 years). Only 27.1 percent had first degrees in physics, though many had engineering degrees. Results from the polytechnics and colleges were very similar.

Affective Outcomes of Preservice Experiences

Westerback (429) reported the effects of two science content courses on the attitudes toward teaching science and anxiety about teaching science among 149 preservice elementary teachers. Results provide evidence for a significant positive change in attitude and reduction in level of anxiety. No consistent relationship was detected between academic achievement and attitudes or level of anxiety, but there was evidence for an inverse relationship between positive attitudes and level of anxiety. Westerback and Gonzalez (430) sought evidence for a relationship between level of anxiety and achievement or experiences in science among 27 preservice elementary teachers. They provided evidence that anxiety related to science and science teaching may be reduced if a conscious effort is made to structure success into tasks identified as evoking anxiety. Bjorkqvist (41) attempted to reduce insecurity toward science teaching among preservice elementary teachers (n = 56) through modification of a methods course, but no significant treatment effect was noted.

Lucas and Dooley (250) and Malone (255) examined the effects of course experiences on attitudes. Using a one group pretest-posttest design with a sample of 67 students, Lucas and Dooley compared the effectiveness of a science curriculum course and a science content course in fostering positive attitudes toward science and science teaching. Their results indicate that the science content course failed to effect a change in attitudes, but the curriculum course did effect a significant change in attitudes toward science teaching. Malone (255) evaluated the effects of three different science methods course treatments on the concerns and attitudes of preservice elementary teachers. Two treatments focusing on teacher concerns effected positive shifts in attitudes and levels of concern, but no significant difference in effect was noted between the two treatments.

The effects of field-oriented science methods courses on affective orientations of 30 preservice elementary teachers were studied by Sunal (396). Two new instruments were employed along with existing instruments to measure affective attributes and teaching behaviors, with significant affective changes being noted over time. Indeed, 70 percent of the variance in teacher behavior ratings could be explained by the expressions of identified attitudes toward teaching and learning science. Similar attitudinal variables accounted for 53 percent of the variance in self-perceptions and perceptions of student behaviors. These results provide evidence for a moderating effect of affective variables on preservice instruction.

Studies by Martin (258) and Horak and Blecha (185) focused on relationships between attitudes and instructor variables. Working with 25 preservice teachers in a science methods class, Martin used a one-group time series design to examine the influence of instructor credibility on attitude change. Results indicate that instructor credibility contributes to shifts in attitudes, but seems not to be the primary effector. Horak and Blecha (185) examined the relationship between subject rating of instruction and subject attitudes toward inquiry and traditional methods of teaching elementary science. Since an emphasis of science methods instruction was on developing a personal teaching style, it was anticipated that subjects adopting a style similar to their methods instructor would tend to rate course instruction higher than would subjects adopting a different style. Results were mixed, with significant differences in overall rating being associated with adopted instructional style, but with no significant differences among groups regarding ratings of course content, degree of interest in course, or instructor performance.

Reduction of science anxiety and the promotion of positive attitudes toward science teaching have joined instructional competency as major foci of research in preservice teacher education. Though results are mixed, studies reviewed here provide evidence that positive changes in attitudes and level of anxiety among preservice teachers can be fostered by focusing on teacher concerns and by structuring success into science experiences. Similarly, effective classroom behavior can be fostered by focusing on formal analysis of teacher behavior and by structuring constructive feedback into microteaching experiences. A weakness of research in the area seems to be the paucity of research attention given to preservice teachers who are pursuing positions in middle schools or high schools.

Inservice Teacher Education

The appropriate content for inservice efforts, the most practical modes of inservice instruction, and the effects of inservice experiences on teacher behavior remain matters in need of much study. The need for data is particularly great in developing countries where adequately prepared science teachers are in short supply and opportunities for professional growth are limited. The nature of the global situation is perhaps typified by the findings of Hashem (168) who examined the perceived inservice needs of biology teachers (n = 261, 95.3 percent of those contacted) in Kuwait in an attempt to evaluate the effectiveness of inservice programs. He found the majority of respondents to have inadequate preparation in the content and teaching methods of biology and inadequate inservice opportunities. In a related study, Aun (21) reported results of a survey among teachers in 90 Malaysian schools regarding the importance placed on laboratory safety, with the results indicating a high level of concern and a desire for inservice education in classroom safety. The diversity of perceived inservice needs among U.S. science teachers is indicated by the findings of Rubba (349) who reported data from a survey of 79 physics teachers. A majority of expressed needs were interpreted as being congruent with recent efforts to render physics instruction more humanistic. Given the diversity of circumstances world-wide with which science teachers must cope, it seems imperative that increased efforts be directed to the systematic study of inservice needs among science teachers, all of whom must have continuing professional support.

There also seems a need for continual evaluation and revision of inservice programs congruent with perceived needs and desired outcomes. Horak and Blecna (184), for example, described and evaluated a one-year science inservice program for elementary teachers, a program which included content instruction, laboratory activities, and acquisition of resource information. The remainder of reports in this section focus on the outcomes of inservice experiences, the effects of inservice experiences on teacher behavior and on measures of cognitive and affective variables.

Effect of Inservice Experiences on Teacher Behavior

Kearns (208) designed and evaluated an inservice program intended to improve the quality of elementary science teaching. The design was somewhat novel in combining a building-based approach and a grade-level team approach which focused on specific instructional problems. In a case study comprising the principal, science supervisor, and teachers of grade 5 in one school, teachers were using an inquiry teaching strategy at the conclusion of the program and had formed a team to plan instructional strategies and future inservice activities. Attempts to substantiate statistically as effect on student achievement (n = 473) through group comparisons, however, were inconclusive.

Another inservice program described by MacDonald (251) was also shown to be effective in modifying the instructional style of teachers. Following an inservice training in the use of new science kits, secondary science participants were shown to allow more time for student activity, to ask a broader variety of questions, and to devote less time to teacher talk than did a comparison group.

Lombard (246) relied on questionnaires (n = 210) and interviews with selected participants (n = 20) to examine the effects of Science Teaching and Development of Reasoning workshops on the teaching style and methods of secondary science teachers. Of the participants, 89 percent reported an increased personal awareness of reasoning processes used by their students, 79 percent acknowledged that they should plan or teach some classes differently, and 73 percent reported experiencing some change in teaching style. Some common misconceptions were expressed, however, including a confusion between effective teaching methods and those which promote cognitive development. For example, many seemed to think that use of "concrete" methods of presentation can render more concrete a concept which requires thought at the level of formal operations. Lombard described several factors which limit teacher ability to implement workshop ideas, including: (a) insufficient time to assimilate the ideas, (b) inadequate knowledge of the cognitive demand of curriculum materials used, (c) insufficient time for development of revision of curricula, and (d) inadequate communication with peers having similar interests.

Enochs (111) examined the proneness among junior high school science teachers to implement innovations presented during inservice experiences. He provided evidence that implementation proneness is related to teacher locus of control orientation, assertiveness, and surgency, but the external validity of the findings are severely constrained by the use of volunteers, a small population sample, and nonparametric analyses.

Two investigators, Kushler (219) and Landes (223), examined attempts to increase the instructional time devoted to energy education through inservice education. Kushler evaluated the effects of four treatments--two consultation strategies and two workshop strategies--among teachers in 111 high schools. Compared to teachers of a control group experiencing no treatment, teachers in all four treatment groups devoted significantly more time to energy education following treatment. Though the two workshop strategies seemed to produce the most positive results, there were no statistically significant differences in effect among the four treatments. Landes (223) sought the effect of workshop attendance on degree of energy curriculum implementation among elementary teachers. Though 50 percent of those responding to a survey indicated inclusion of energy education in their curriculum, there is no evidence that the inservice experience had any effect on the degree of implementation. Insufficient time and lack of administrative support were cited by respondents as obstacles to implementation. It was also noted that teachers tend to perceive energy education primarily as a component of science even though presented as a multidisciplinary topic during the workshop and within the associated materials.

Effects of Inservice Experiences on Cognitive and Affective Measures

Spooner and others (381) and Krockover (217) provided evidence that inservice programs can have a positive effect on teacher attitudes toward science and science teaching. Spooner et al. reported the effects of a five-day workshop on the attitudes of elementary school teachers, while Krockover (217) presented the results of a 32-week program on the attitudes of middle school teachers and junior high school teachers. Bethel, Ellis, and Barufaldi (38) examined the effects of an inservice program on the philosophical orientation and the attitudes toward science and environmental science education of 102 teachers of grades 4, 5, and 6. Data were obtained from an NSF-funded teacher development program comprising 32 sessions of 2 1/2 hours each and 16 hours of field work; comparisons were made between the treatment group and a control group receiving no treatment in a pretest-posttest equivalent control group research design. An increased tendency to hold scientific knowledge as tentative and more positive attitudes toward environmental science education were evident after 16 weeks of treatment, with significant differences being noted between groups at the conclusion of the treatment. It was suggested that group comparisons may have been confounded by interaction of treatment subjects with control subjects during participation in other workshops conducted during the same calendar period. In another report related to the same investigation, Bethel and Hord (37) provided evidence that the inservice experience had a positive effect on personal knowledge and professional growth as well as attitudes.

Bondonzi Mansfield (49) attempted to document the effect of inservice education on student performance and attitudes. A randomized control group design was employed to compare the achievement and attitudes of 132 students in grade 3 who were members of two treatment groups, with the teachers of one group being retrained in Piaget's theory of cognitive development and teachers of the control group receiving no instruction. No significant treatment effect was detected.

Glass (145) examined the effects of an NSF-funded energy education inservice workshop on teacher knowledge of energy-related issues and on attitudes toward the issues. Compared were 27 elementary teachers participating in the 30 weekly sessions of the workshop and a control group of 27 elementary teachers, each being a peer of one of the experimental subjects. Though growth in knowledge was evident, there was no significant change in attitudes accompanying the growth.

A variety of workshop designs have been shown to foster positive changes in teacher attitudes, knowledge, and classroom behavior--at least for the short term, but several factors often seem to prevent full implementation of workshop ideas. Lack of time to translate ideas into action, and minimal support from peers and administrators seem to inhibit implementation. Beyond maximizing participant response to the workshop experience, there remains the challenge of nurturing implementation of workshop innovations by participants after inservice exposure.

Research and Evaluation Practices

Many studies focused on the practices and instrumentation associated with science education research and evaluation, with several authors addressing matters related to quantitative methodology, qualitative methodology, testing, instrumentation, and theoretical considerations. Table 7 shows several interesting patterns in the conceptual and analytical foci of studies reported during 1982. There was a strong interest in student factors and instructional strategies, with the predominant forms of analysis being the testing of group differences and the use of descriptive statistics without a test of differences. Particularly, there was a great interest in comparing the effects of instructional strategies and surveying matters of policy and practice. This later concern seems reflective of the perceived crisis in U.S. science education. The lack of multivariate analyses of complex problems is well documented. Regarding the priorities for research in

Table 7

Frequencies of Reports According to Conceptual Focus and Form of Analysis

Form of Analysis[a]	Conceptual Focus[b] SC	TC	IS	IM	CP	TE	RE	PP
GD	28	9	52	21	11	12	3	1
MR	14	4	5	1	2	2	2	1
SC	22	4	4	2	2	6	15	2
DS	17	8	3	11	8	6	4	32
MA	2	1	1	0	5	3	0	0
QA	13	5	3	4	6	3	2	2
R	11	3	7	3	3	2	8	6
CA	8	0	2	0	2	2	14	5

[a]GD = testing of group differences; MR = techniques based on multiple regression or correlation; SC = techniques based on coefficients of simple correlation; DS = descriptive statistics; MA = meta-analysis; QA = qualitative analysis; R = review of previous research or project findings; CA = conceptual analysis.

[b]SC = student characteristics or behavior; TC = teacher characteristics or behavior; IS = instructional strategies; IM = instructional media and environment; CP = curricula and programs; TE = teacher education; RE = research and evaluation; PP = policy and practice.

science education, results from a poll of the NARST membership (101 responded, approximately 13 percent) were presented (Abraham, Renner, Grant, and Westbrook, 2). Respondents indicated the five areas of science education they each considered most in need of research, and the responses were prioritized, classified (31 categories), and tabulated. With 12 categories accounting for 66 percent of the average priority values, the greatest perceived need was for more research on instructional strategies. Through consolidation of related categories, three clusters of greatest concern were identified: instructional strategies, learning, and attitudes. A summary of research reported during 1981 was contributed by Voss (419), and the descriptions of awards granted during 1981 for science education development and research was provided by the Directorate for Science and Engineering Education (98, 99). A review of basic research in science education was edited by Yager (447), and brief abstracts of 115 presented papers at the 1982 NARST Annual Meeting were edited by White and Blosser (433). The Society for College Science Teachers (376) also published the program and 82 brief abstracts of papers presented at the 1982 NSTA convention.

Quantitative Methodology

Glass (144) provided a comprehensive description and demonstration of meta-analysis, the application of research methodology to the findings of several previous empirical studies. As described, extraction of new information is sought by applying statistical procedures to the grouped findings of previous investigations, with the hope that inconclusive results from independent studies can be pooled to yield general effects that are comprehensible. Specific criticisms of the technique are addressed, with meta-analysis being defended as a formal way of pursuing integration of educational research. As the technique is employed with increasing frequency over the next few years, its functional contribution to empirical research will be more easily assessed. In a related yet separate matter, Miller (277) described the potential value in performing secondary analysis of existing data sets. He also provided three examples of methodology and the results obtained.

Supporting arguments with data and rationale, Leonard (238) advocated use of quantitative treatment verification as a standard component in research which compares teaching methods. In a review of investigations (all reported between 1975 and 1980) which included tests of significant differences between independent as well as dependent variables, it was noted that every case showing significant differences between independent variables also exhibited significant differences in dependent variables, without exception. Too often it is merely assumed that the various levels of treatment in an experiment differ in some significant way, with no efforts being taken to demonstrate a difference empirically.

Several studies focused on aspects of intensive time-series research designs. Willson (434) distinguished a time-series experimental design from time-series analysis, using a parametric regression technique to reanalyze data from an earlier study. The results obtained were comparable to previous findings, but were statistically more sound. In another study regarding the data collected during time-series designs, Mayer and Rojas (261) examined the effect of testing frequency on the validity of data. Investigating the effect of three frequencies of testing on measures of achievement and attitude, they found no evidence for a threat to the validity of the data. No trends in differences between groups were noted, though earlier findings regarding the presence of a learning curve over the time of the observations and a momentum effect on achievement were corroborated.

In a related study, Farnsworth (115) sought additional evidence for the validity of using the intensive time-series design to develop profiles of achievement and attitudes for students at two different levels of cognitive development. Results indicated increased achievement for both groups, with those at the level of formal operations out-performing those at the level of concrete operations. Also, those of the formal group exhibited a more positive change in attitude toward the subject matter, while those of the concrete group exhibited a more negative change in attitude toward science teachers. The latter finding seems noteworthy considering the cognitive demand of much subject matter in science and the recognized tendency of secondary students to avoid science courses. Focusing on level of cognitive development, Farnsworth and Mayer (116) attempted to determine whether or not an intensive time-series design could be employed to discriminate between concrete and formal operational children, while also generating learning curves as exhibited in previous studies. Working with 95 subjects over a period of 56 days, daily performance on single multiple-choice questions was recorded, with data from individual students being condensed to a group mean and treated as a single subject score. Results support the use of the design for discriminating levels of cognitive development and for collecting achievement data.

Qualitative Methodology

Yager (446) described techniques of qualitative synthesis and a role for such synthesis, using the example of Project Synthesis to illustrate the value of such efforts. It is argued that qualitative syntheses can be employed to generate the theories and conceptual models needed in science education through integration of research findings. Beyond integrating findings through qualitative techniques, several researchers have endorsed a form of qualitative study, or naturalistic research, as a means of generating valuable data for science education.

Easley (104) argued that educational research would be more useful to classroom teachers and, indeed, more scientific if naturalistic efforts were employed to generate conceptualizations which could direct quantitative efforts. It was further suggested that most current research efforts are overly concerned with quantification to the neglect of explanatory mechanisms. Extending the argument, Rist (332) explicated the nature of qualitative research, describing an epistemology based on experience, empathy, and involvement, and elaborating description of the key processes involved in qualitative studies. Qualitative and quantitative research was presented as mirror opposite methodologies which, if juxtaposed, could provide greater illumination of a particular research problem than what would be provided by either alone. Roberts (334) also promoted the complementarity of quantitative and qualitative research, demonstrating how the two categories of methodology, differing in nature and outcome, are similar in basing knowledge claims on recognized patterns of argumentation. It was suggested that graduate students in science education must acquire a broad conceptualization of legitimate research which comprises both quantitative and qualitative methodologies. Another advocate of naturalistic research in science education, Smith (372) emphasized the inductive nature of such investigations and a logic of discovery which begins with data. Field methods and the phases of naturalistic research were explained and illustrated using information from published case studies. It seems evident from arguments and findings presented here and elsewhere that there are legitimate roles for both qualitative and quantitative forms of research in science education, that the two forms can interact synergistically, and that many science educators must broaden their view of what constitutes legitimate research methodology.

Testing

Other than the report by Kingdon and Hartley (210) describing the first examination of advanced biology practical work notebooks to be conducted at the University of London, studies of testing focused on either matters associated with specific standardized tests or the instructional use of tests. Stephens (388) examined the relationship between performance on the Medical College Admission Test (MSAT) and the National Board of Medical Examinations-1 (NBME), finding only 10 percent of the variance on components of the NBME being explained by performance on the MCAT. Modu and Taft (283) sought evidence for the validity of the multiple-choice portion of the Advanced Placement Chemistry Examinations. The performance of advance placement candidates was compared with that of first-year chemistry students from 32 institutions, with advance placement candidates scoring significantly higher than college chemistry students.

Some have used standardized tests for purposes other than that for which they were designed, including curriculum evaluation. Nimmer (298) examined the use of standardized tests to evaluate curriculum revisions and demonstrated the insensitivity of some test components for such uses. Data from examination of five common achievement test batteries reinforces the need to use instrumentation oriented toward assessment of specific objectives when evaluating programs.

In other reports related to testing, Hoste (187), Wilson (435), and Lang (224) presented the implications of their findings for classroom testing. Wilson argued for the value of using pretests to neutralize effects due to prior knowledge or test taking "savvy," and Hoste (187) used factor analysis to examine the extent to which performance on a biology examination indicated knowledge rather than higher levels of understanding. In a study illustrating some of the problems associated with estimating degree of mastery on criterion-referenced tests, Lang (224) examined procedures for setting standards and factors influencing reliability and validity of tests.

Instrumentation

There continues to be a great deal of energy and time devoted to the construction and evaluation of new instruments, instruments to measure some aspect of achievement, instruments to measure student and teacher attributes, and instruments to quantify some aspect of the instructional process. Mayer and Richmond (260) commented on the extensive duplication of efforts among science educators with researchers tending to generate new instruments for each new study rather than refine existing instruments. They reviewed a variety of instruments which have been developed to measure student characteristics, attitudes, teacher variables, and other variables related to the assessment of science curriculum and instruction. Several new instruments were mentioned in reports cited in other sections of this review, and several, having been presented in more detail, are reviewed briefly here.

Two instruments were developed for use in a laboratory setting, one to measure student achievement (Ganiel and Hofstein, 134) and one to assess teaching methods and curriculum materials (Abraham, 1). Ganiel and Hofstein developed and evaluated an instrument used for continuous assessment of high school student performance in the physics laboratory, and they obtained evidence for gains in objectivity and precision of student performance with the new instrument. Abraham (1) introduced a Q-sort instrument for collecting descriptive information regarding teaching methods and curriculum materials used in the science laboratory, information valuable for management and evaluation of instruction. The instrument allows students to systematically describe the characteristics of the educational environment in a teaching laboratory. Results from studies of general chemistry laboratories provide evidence of three prevalent orientations: verification laboratories, guided inquiry laboratories, and open inquiry laboratories. A variety of uses for the Q-sort technique were suggested.

Tobin and Capie (406) and Berger (36) described attempts to measure process skill achievement. Tobin and Capie described the development and validation of a group test for measuring integrated process skill achievement, providing evidence of content validity, construct validity, and reliability. Reliability data indicate that the 24-item paper-and-pencil test can be used with students of middle school through college age. Berger (36) described the instrumentation, methodology, and analysis techniques developed to measure skills associated with estimating linear distance. This study is noteworthy in having used microcomputer simulation to study skill development among students.

Farmer, Farrell, Clark, and McDonald (114) attempted to determine the degree of congruity among estimates of cognitive development based on three different measures, two paper-and-pencil tests and one interview protocol. Working with 512 students of grades 9 and 10 who completed the group tests, and a subsample of 69 students who responded to three Inhelder tasks, Farmer et al. obtained evidence that paper-and-pencil instruments provide a less rigorous definition of formal operations than do interview techniques. It was acknowledged that the ease in administration and scoring of paper-and-pencil instruments, which renders them practical for many practitioners, is gained through a trade-off in terms of rigor. Pezaro (315) also commented on the use of group testing to assess level of cognitive development.

Several authors contributed findings associated with attempts to assess attitudes. Reporting on the development of specific instruments, Krajkovich and Smith (214) and Wareing (423) presented findings from attempts to assess student attitudes toward science, while Vockell (416) presented findings from attempts to measure student attitudes toward animal life. Following a pilot study among 388 students of grades 7 through 12, the scale developed by Krajkovich and Smith was revised and examined again with a sample of 251 students of grade 9, with evidence for construct validity and adequate reliability (0.86) being obtained. Wareing (423) developed a Likert scale for use among students of grades 4 through 12 and presented preliminary findings associated with test construction and a pilot study among 204 students. Reliability estimates ranging between 0.91 and 0.94 were reported. Based on data from development and field-testing among 69 elementary students, Vockell (416) offered evidence for the reliability and validity of his instrument designed to measure attitudes toward animal life.

Schibeci (359) compared the use of Likert scales and a semantic differential procedure to measure attitudes among 362 high school students. Significant correlations were found between subscales of the instruments, with coefficients ranging from 0.06 to 0.52. The data seemed to indicate that Likert scales are more sensitive to specific attitudes while semantic differentials more easily provide data regarding general attitudes.

Two reports regarding use of the State-Trait Anxiety Inventory (STAI) were offered by Westerback (428) and Westerback and Roll (431). Westerback examined the usefulness of the STAI for measuring preservice elementary teacher anxiety toward teaching science, with results indicating that the instrument can measure changes of anxiety level in specific situations and that subjects extremely anxious about teaching science can be identified. Westerback and Roll (431) reviewed studies employing the STAI.

The tendency among investigators to construct new instruments is reflected in studies presented here and elsewhere in this review. New measures of attitudes, anxiety, level of cognitive development, and process skill achievement seem most often generated. The appearance of two instruments designed to assess student performance in laboratory settings is more novel. The use of a microcomputer to assess skills (Berger, 36), however, may signal the beginning of a new and welcome trend. Microcomputers allow flexibility and sophistication of measurement that will likely have a profound effect on the quality and quantity of data gathered through instrumentation. Unfortunately, microcomputers are likely to also increase the proliferation of new instruments.

Theoretical Considerations

While Westmeyer (432) questioned the wisdom of attempts to couch all science education research questions as theories to be tested, a few authors focused on theoretical considerations directly. Stewart and others (390) offered justification for including the conceptual content of science instruction as an important variable in studies of the learning and use of science knowledge. Van den Berg, Lunetta, and Tamir (414) assessed the convergent validity of the cognitive preference construct from data collected by three measures, a conventional instrument and two measures based on learning behavior among students. Results from a sample of 71 college students in a science laboratory and a sample of 37 students of grade 10 provide strong evidence for validity of one mode (questioning), but not for others. A rationale for the results was offered.

Two reports focused on theories related to cognitive functioning. To the three most influential paradigms in science education research, those of Ausubel, Gagne, and Piaget, has been added a fourth, information processing psychology, which Stewart and Atkin (391) have characterized as encompassing the prior three and overcoming some of their weaknesses. Stewart and Atkin described a model of the human memory system, and they derived implications for research from the model.

Posner, Strike, Hewson, and Gertzog (324) presented a model for personal change in conceptual understanding which was derived from contemporary notions regarding corporate conceptual change in science. Features of the model are illustrated with accounts of student attempts to solve problems through application of the special theory of relativity. Also offered by Posner et al. are educational implications of the model, including implications regarding curriculum objectives, instructional content, teaching strategies, and teacher roles.

Science Education Policy and Practices

A heightened awareness of inadequacies in science education seems apparent among authors who provided data of local, regional, and national policy and practices. Topics most commonly addressed included: the status of science education programs; goals, guidelines, and practices; course content; and needs and priorities for research (see Table 8). Only Dyer (103) addressed directly an aspect of professional concerns with her study of promotion criteria in the science departments of two large metropolitan universities. In examining criteria related to teaching, scholarly activity, and service, she collected information regarding publication, external grants obtained, and student evaluations of instruction.

The epistemological foundations of science education also lack in-depth study, with only two authors contributing works of general interest. Emmitt (110) examined the philosophy of Jacob Bronowski as a basis for liberal arts curricula giving equal emphases to arts, sciences, and ethics. Four pragmatists who have contributed to philosophy of science--Peirce, Dewey, Kuhn, and Quine--were studied by Costello (84) for direction in developing an epistemology of education. Without a more comprehensive foundation of conceptual analysis and epistemological inquiry, the science education community will continue to be guided primarily by opinion and reaction to sources of discomfort.

Status of Programs

Despite the rhetoric of recent years, the status of science education programs at all levels seems unchanged. Audeh (18, 19) provided results from a longitudinal study of 100 public elementary schools, ten in each of ten states, with the sample comprising the principal and three

Table 8

Frequencies of Reports Documenting Matters of Policy and Practice in Science Education from a Variety of Information Sources

Matter Studied	Information Source[a] S	T	A	E	D	P
Status of Science in Elementary School	0	4	1	0	0	0
Status of Science in Middle School	0	0	0	0	1	0
Status of Science in Secondary School	1	1	1	0	0	1
Status of Science in Undergraduate College	2	0	0	2	0	1
Graduate School Science or Science Education	1	0	0	3	1	2
Status of Science Education for Handicapped	0	1	1	0	0	0
Status of Marine Education	0	1	1	1	0	0
Guidelines for Science Courses and Programs	1	2	0	1	1	1
Goals for Science Education	2	4	2	2	1	0
Teacher Education and Preparation	0	3	1	2	2	1
Teacher Certification	0	2	1	1	0	0
Criteria for Excellence in Science Teaching	0	2	2	1	0	0
Promotion Criteria	0	0	0	1	0	0
Scholarly Productivity	0	0	0	1	0	0
Research Needs	0	2	1	3	1	0
Course Difficulty	2	2	0	0	0	0
Integration of Subjects	0	3	2	0	0	0
Career Education Component in Science	0	1	0	0	0	0
Facilities and Equipment	1	1	0	3	2	1

[a]S = students; T = K-12 teachers; A = state or school administrators; E = postsecondary educators; D = documented guidelines or research findings; P = operational programs.

randomly chosen teachers from each school. An attempt was made to identify any changes in status occurring between 1970 and 1980 while also assessing teacher characteristics and attitudes. Corroborating the results of earlier studies, teachers were found to have minimal preparation for science teaching, a decline in the availability of science consultants has occurred, and a decline in science emphasis has occurred even though the majority of schools have not changed their science programs substantially between 1970 and 1980. These findings are further corroborated by Manning, Esler, and Baird (257) who surveyed 191 elementary teachers in Florida. They found 12 percent of the teachers to have no preparation of any kind to teach science, with only 40 percent having taken three or more college science courses. Perhaps more critical, only 4 percent of the teachers ranked science as their favorite subject to teach over reading, language arts, social studies, and mathematics. Indeed, over 50 percent ranked science fourth or last in terms of preference.

In a related study, Burke (55) investigated the extent and nature of science education in four parochial schools of an Australian city. It was found that science receives low priority in the four schools and is often neglected. The amount of instruction appeared to depend on the interests of individual teachers, few of whom implement activity-based lessons. A modest role for science education in elementary schools, then, does not seem confined to the United States. Orpwood (305) presented the conceptual basis for similar research to be conducted in Canada as well, with the rationale, aims, nature, and phases of the study being provided. As such studies are conducted in a variety of nations, a broader database will become available for examining the relationships between the status of precollegiate science education and indices of policy, funding, teacher preparation, and educational structure.

It has become clear that the status of precollegiate science education is influenced primarily by teacher preparation. If that is so, some findings of Mechling et al. (273) regarding teacher certification seem particularly relevant. From the responses of certification officers in 46 states, it was found that only 19 states are known to require science coursework for certification as an early childhood teacher, and only 12 require a science methods course of elementary teachers. There is great diversity regarding certification practices for middle/junior high school teachers, with 30 states making no distinction between junior and senior high school certification. For secondary school science teachers, 22 states reported a policy that permits a certified teacher to teach all of the sciences. Though only 13 states require a specific secondary science methods class for certification, 30 states require a minimum of 24 semester hours of science coursework in a single discipline. From a 12-state sampling of practicing elementary school teachers, Mechling et al. found 50.5 percent of the teachers to feel that their undergraduate courses did not adequately prepare them to teach science. Furthermore, 65.7 percent of the teachers have completed no graduate work in science education, 70.7 percent have no access to elementary science inservice opportunities, and 63.6 percent have no science consultant services available.

At the tertiary level, Hodes and Morsch (179) contributed an executive summary of the status of science education in two-year colleges (n = 183) based on a survey of administrators, faculty members, and students. Focusing on a specific discipline, Shapiro and James (364) examined the status of biochemistry courses at 120 colleges in the mid-atlantic region of the United States. They presented data regarding library holdings, textbooks and laboratory manuals, laboratory equipment, and course durations. Snyder (375), focusing more directly on the relationship between status and policy, studied the influence of funding by the federal government on doctoral education in the natural sciences. He offered several recommendations related to federal policy.

The status of science education programs at graduate institutions was comprehensively reviewed by Yager, Bybee, Gallagher, and Renner (448). During phase one of their study, 365 institutions were contacted (90 percent response) in search of graduate programs in science education, with phase two of the study being a more detailed examination of the 35 largest programs (90 percent response). Also reported are the perceptions of science educators among five selected groups. Though relatively few institutions reported having formal departments or centers of science education, approximately 40 percent reported having some sort of graduate program in science education. Institutions having the leading programs reported a decline in science education faculty members between 1975 and 1980, with a concomitant decline in graduates during the period and funding for graduate scholarship or service. The current instability in science education, then, seems not restricted to elementary education or even precollegiate education, but pervades the entire science education community.

Goals, Guidelines, and Practices

Renner (328) explicated the relationship between power and purpose in curriculum development, teaching, and research. Science education was presented as a discipline with well defined purposes at the precollegiate level but less well defined purposes at the collegiate level. Though the purposes of precollegiate science education may seem clear, Enz (112) presented evidence of considerable diversity of opinion regarding curricular goals. From a survey of relevant literature, she compiled a list of 17 science education goals, and sent the list to 100 science educators for ranking. The educators were selected randomly from the NARST membership, and those responding to the survey (60 percent) contributed an additional 41 goals to those identified by Enz, with many of the contributed goals being in direct opposition to the original 17. Most agreed that science education must emphasize the processes, concepts, principles, and generalizations of science; but beyond that there exists considerable diversity of opinion. Following another survey of science educators, Yager et al. (448) reported that 60 percent of the respondents cited confusion and uncertainty about goals as a major problem in science education.

Challenging a long-standing goal of science education, Gauld (137) marshalled evidence in support of his contention that educators should not include development of the scientific attitude (in the form generally conceived) as a primary goal of science education. From a variety of data sources he demonstrated the empiricist conception of scientific attitudes to be untenable and a false image to which students are molded. At the least, it seems, a clarification of attributes and reformulation of the concept are in order. Regarding the manner by which curricular policy is established and curricula are adopted, Orpwood (304) offered some clarification. From his study of the processes by which a particular curriculum is selected for adoption, a conceptual framework was developed for analyzing the discourse of policy deliberations.

Related to the status of science in elementary schools as presented in the previous section is the amount of instructional time actually devoted to science by teachers. In a study of the influence of instructional time, materials, and activities on science learning among 1393 students of grade 5, Romance (346) found the time devoted to science to be highly variable (15 to 180 minutes per week). In an effort to increase the amount of instructional time typically alloted to science, Sanders and Sanders (356) offered an instructional model involving teachers on special assignment which has been successfully employed to increase science teaching time.

Mohamed (284) examined the perceptions of middle school teachers and their students regarding the goals of science education and the classroom behavior of students and teachers. Correlational analyses were used to test the relationships among observed, perceived, and ideal classroom behavior. The results indicate that both teachers and students tend to behave in ways inconsistent with the goals and desires of both groups. Considering the diversity of opinion regarding goals which has been documented, inconsistency of behavior with acknowledged goals confounds even more an understanding of the status of science education in schools.

At the secondary level, Al-Saif (10) used data from measures of cognitive development, science teacher qualifications, and program comparisons to develop guidelines for science education programs in Saudi Arabia. Balzer (25) described scientific and technical education in the Soviet Union, emphasizing secondary preparation, and Taylor (402) presented a historical review of changes in biological education among Ontario high schools from 1871 to 1978. The changes he noted included: a considerable change in the topics considered, a change in the nature of textbook authors, and a great increase in biology courses for general students. The relationship between biology programs and curriculum ideologies was also discussed.

At the college level, Cooper (80) examined the transfer process from junior to senior colleges for students in physical sciences and mathematics. Data collected from 32 institutions in Arkansas through questionnaires and interviews indicated considerable agreement between published guidelines and practices. The findings should aid policy decisions related to articulation programs. A more national survey was conducted by Miner (278) who examined the congruity between elementary teacher education program practice and professional guidelines regarding preparation for science teaching. Seemingly, relatively few of the guidelines are consistently met by the institutions, with only 22 percent meeting guidelines related to facilities, materials, and individualized instruction. It was noted that a majority, 66 percent, do emphasize science processes as recommended.

At all levels, it seems, the most general finding regarding the goals, guidelines, and practices of science education is that diversity reigns. Variability in the status of science education at all levels is reflected in the diversity of opinion regarding the relative merits of curricular goals. The amount of instructional time devoted to science, particularly in the elementary school, remains highly variable among schools, and classroom behavior seems often inconsistent with perceived goals. A degree of variability in goals and practices should be admitted as a healthy and natural condition, but behavior inconsistent with perceived goals and professional guidelines is a matter worthy of attention. Perhaps the behavioral implications of goals need clarification, and perhaps many educators are unaware of published guidelines. There seems little hope of coordinating science education efforts until goals and guidelines are widely supported and the behavioral implications clear. Efforts such as Project Synthesis (Harms, 163) should help rectify the current situation if heeded.

Course Content

Despite dissatisfaction with the status of precollegiate science education and a diversity of opinions regarding program goals, it might seem probable that practitioners would agree on the subject matter to be taught. Walker (420) provided evidence, however, that such is not always the case. Results indicate that high school chemistry teachers do not agree on what topics to include in courses, and college chemistry instructors are often incorrect in their assumptions regarding the subject matter taught in high school. In another study of teacher opinions, Finley, Stewart, and Yarroch (122) conducted a survey among teachers of earth science, chemistry, physics, and biology in an attempt to determine what content is considered most important by teachers and what content is considered most difficult for students to master. After constructing a 50-item questionnaire for each of the four disciplines, they solicited responses from 100 secondary teachers in each discipline. It was felt that since classroom teachers select course content and facilitate student learning, they are in the best position to identify practical problems for which solutions would improve instruction. Subject matter identified as both important to teach and difficult to learn included content related to: photosynthesis, cellular respiration, cell division, atomic structure, expressions of chemical reactions, forces and motion, plate tectonics, and mineral classification. The identification of these content areas as important but difficult to learn can serve to direct research in content domains and the search for debilitating misconceptions.

The role of field work in biology instruction was the focus of studies by McKelvey (270) and Fido and Gayford (118). McKelvey examined the role of biological field stations, accumulating data from visits to field stations, interviews with station personnel and students, and surveys of the literature. Of primary interest was the organizational structure, facilities, programs, and funding of field stations. Focusing more on course content, Fido and Gayford (118) solicited opinions from a random sample of biology teachers in England regarding the nature and extent of field experiences included in coursework.

Needs and Priorities for Research

Hurd (193) offered his perceptions of the critical issues in science education, noting a need for continuous and focused (theory-based) study and research. The objective would be to produce a normative framework and associated goals for science teaching from appropriate data and conceptual analyses. Contributing to the framework and identifying some areas greatly in need of study, Harms (163) presented the rationale, methodology, findings, and recommendations of Project Synthesis, a research study of science education based on information from six selected databases. Discrepancies between desired and actual status of five identified areas of science education were described, and recommendations for practice were offered.

Several related studies (Yager and Kahle, 449; Bybee and Yager, 58; Yager et al., 448) have also provided much data useful for identifying matters in need of immediate action, setting priorities for research, and establishing policies for science education. Yager and Kahle reported the opinions of science educators at 28 leading graduate centers for research in science education, and they compared the opinions to those collected during two previous major studies. The following are six areas of need identified from responses to all three efforts which could serve as the foci for research: scientific/technological literacy; teaching behavior; goals for science education; student attitudes; the interplay of classrooms, theories of learning, and cognitive development; and social imperatives. The strongest recommendation, however, was for the identification of new directions in science education which are derived from a reassessment of past goals, assumptions, definitions, practices, and activities.

A synthesis of six studies reported by Bybee and Yager (58) supports the recommendation for new directions. Bybee and Yager consolidated information from six previous studies of the major problems confronting science educators and some potential solutions proposed by groups participating in the studies. The major problems identified by the groups include: public distrust of science, lack of professional leadership, and an inadequate theoretical foundation for science education. Reformulating the major goals and statements of purpose for science education was, however, of highest priority for all the groups. In a related report, Yager et al. (448) categorized the six major problem areas as conceptual, organizational, teacher-related, student-related, university-centered, and societal; and they characterized proposed solutions as relating to administration, research, science content, theory and learning, and teacher education.

The priorities for research suggested by studies presented here reflect the need to consolidate ideas regarding the goals of science education efforts. These studies also demonstrate the difficulties associated with setting new directions from a pooling of opinions. Now that some general priorities for research have been identified, the challenge is to move beyond opinion to the formulation of goals through scholarly endeavor.

Conclusion

It seems clear that a great many people perceive the community of science educators to be in need of clarified goals and statements of purpose. We agree, and suggest that any reformulation of goals and purposes must be derived from conceptual analyses, research findings, and a reassessment of past goals and practices.

Science educators have become quite sophisticated at generating findings from empirical research. In the findings reported in this review is confirmation of the great diversity among us in matters related to priorities, attitudes, instructional styles, and research interests. There is, however, a common respect for logical reasoning, conceptual analysis, inductive inquiry, and argumentation grounded in data.

Considering the present state of science education and our awareness of the need for priorities and solid research, all science educators must commit themselves to a renewed sense of leadership. It will be not only through political means or by increasing the volume of our scholarly efforts, but by addressing identified needs, basing our research on epistemological foundations, and paying heed to quality and direction, that we can find that common purpose and those shared goals for science education. The time is now!

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