DOCUMENT RESUME

ED 335 237 SE 052 229

AUTHOR	Baker, Dale R.
TITLE	A Summary of Research in Science Education--1989.
INSTITUTION	ERIC Clearinghouse for Science, Mathematics, and Environmental Education, Columbus, Ohio.; National Association for Research in Science Teaching.
SPONS AGENCY	Office of Educational Research and Improvement (ED), Washington, DC.
PUB DATE	Dec 90
NOTE	154p.
AVAILABLE FROM	ERIC Clearinghouse for Science, Mathematics and Environmental Education, The Ohio State University, 1200 Chambers Rd., Room 310, Columbus, OH 43212.
PUB TYPE	Information Analyses (070)
EDRS PRICE	MF01/PC07 Plus Postage.
DESCRIPTORS	*Academic Achievement; Classroom Environment; Cognitive Processes; *College Science; Computer Uses in Education; *Elementary School Science; Elementary Secondary Education; Evaluation; Females; Higher Education; Minority Groups; Misconceptions; Science Curriculum; *Science Education; *Science Instruction; Science Teachers; Scientific Literacy; *Secondary School Science; Student Attitudes; Tests; Textbooks

ABSTRACT

This summary of research in science education for 1989 is organized around 15 major themes. These themes are: (1) criteria and ethics; (2) achievement in science; (3) affect; (4) classroom interactions; (5) cognitive processes; (6) computers; (7) curriculum; (8) instruction; (9) legislation and policy; (10) misconceptions; (11) scientific literacy; (12) teachers; (13) tests and assessments; (14) textbooks and text comprehension; and (15) women and minorities in science. Each of these sections contains a summary of the research and comments. A critical analysis of the quality of the research has not been done because most of the material presented in the summary has gone through at least one level of peer review as a publication or paper. Dissertations were reported from the abstracts. A 338-item bibliography is included. (KR)

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December 1990

OERI This document was funded by the Office of Educational Research and Improvement, U.S. Department of Education under contract no. RI-88062006. Opinions expressed in this document do not necessarily reflect the positions or policies of OERI or the Department of Education.

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in cooperation with the

National Association for Research in Science Teaching

TABLE OF CONTENTS

PREFACE

The Summary of Research in Science Education series has been produced to analyze and synthesize research related to the teaching and learning of science completed during a one-year period of time. These summaries are developed in cooperation with the National Association for Research in Science Teaching. Individuals identified by the NARST Research Committee work with staff of the ERIC Clearinghouse for Science, Mathematics, and Environmental Education and the SMEAC Information Reference Center to review, evaluate, analyze, and report research results. The purpose of the summaries is to provide research information for practitioners and developmental personnel, ideas for future research, as well as an indication of trends in science education research.

Readers comments and suggestions for the series are invited.

Stanley L. Helgeson
Patricia E. Blosser
ERIC Clearinghouse for Science,
Mathematics, and Environmental Education

ACKNOWLEDGEMENTS

This summary of research could not have been accomplished without the help of many people. I would like to thank Dorothy Krcmar, my secretary, who filed and refiled articles, journals and index cards covered with notes and scribbles, innumerable times. She also kept track of which studies were in or out of the summary while constantly updating the references. Larry Sidlik, my graduate student, also deserves my heartfelt thanks. He spent most of his summer in the air conditioned splendor of the library hunting up articles and papers. Considering the summer temperature in Arizona, it was not a completely onerous task. Finally, I would like to thank my husband, Michael Piburn, for his patience and understanding. Much of the reading and writing that went into this summary took place on the weekends and in the wee hours of the morning which put a substantial dent in our free time together.

A Summary of Research in Science Education - 1989

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INTRODUCTION

This summary of research in science education for 1989 is organized around 14 major themes. These themes are: achievement in science, affect, classroom interactions, cognitive processes, computers, curriculum, instruction, legislation and policy, misconceptions, scientific literacy, teachers, tests and assessments, textbooks and text comprehension, and women and minorities in science. Each of these sections contains a summary of the research and comments. I have not attempted to do a critical analysis of the quality of the research or research designs because most of the material presented in the summary has gone through at least one level of peer review as a publication or paper. Dissertations were reported from the abstracts because of the difficulty of reading a substantial number of these lengthy documents and the cost of obtaining them.

I was quite impressed with the sophistication of much of the research. Many of the studies were well grounded in theory and the designs and data analyses were quite complex. The brief synopses of the research presented in this paper do not do justice to the richness of the findings and the significance of the conclusions. I apologize to my colleagues for this and encourage interested readers to seek out the original sources of the research.

CRITERIA AND ETHICS

What are the issues surrounding the criteria and ethics of science education research?

Lawson, Reichert, Costenson, Feddock and Litz discussed the five criteria that should be applied when conducting educational research. The first criterion addressed the issue of significance. When evaluating the quality of research, we should ask ourselves whether the research raises causal questions or ones that have the potential to be educationally significant. The second and third criteria dealt with the quality of the hypotheses. Again, we must ask ourselves if the research is based on reasonable working hypotheses that have the potential to answer the research question. We must then ask if reasonable alternative hypotheses are posed and shown to be false. Fourth, we should ask if the hypotheses and experimental procedures lead to clearly stated predictions. Finally, we must carefully examine the conclusions of the research to determine if they are correctly drawn in relation to the stated hypotheses. The authors concluded that science education research would have greater impact on education and teaching if it became more scientific.

The increase in field based research led **Brickhouse** to become concerned about the ethical issues inherent in applying the commonly accepted meanings of informed consent and confidentiality. She contended that the guidelines provided by the American Psychological Association do little to help the researcher deal with the problems that arise during fieldwork. She argued that the traditional search for ethics based on universal principles is less appropriate for field based research then ethics based on a concern for human relations within a particular context. Just as case study methodology is based on developing understandings which are bound by the context of the study, so too should ethical decisions be context bound. She stated that nurturing human relations and developing trust among the participants of the study and the researcher is a better guarantee that the subjects rights will be protected than the application of a universal principle.

Summary

Science education research is at a turning point. The field has matured and we now have a solid research base to build upon. Continued progress depends upon the quality of research. Arguments have been made for a set of standards for quality that is based in the tradition of science in which hypotheses are developed and rigorously tested. Such an approach when linked with a significant question will go a long way toward solving educational problems. Researchers in the ethnographic paradigm take the alternative point of view that questions the application of universal procedures for contextual research. These differences raise important questions for science educators as they begin to use new research methodologies. In particular, we should be concerned about grafting traditional standards onto a new research paradigm. However, arguing about the merits of qualitative or quantitative methodologies begs the question and will not move the field forward. What these two articles illustrate is that the issue is not so much the methodology, but the application of standards within a paradigm that will lead to fruitful insights in science education.

ACHIEVEMENT IN SCIENCE

What are the national trends in science achievement and how do we compare to other countries?

Chang examined the changes in science achievement that have taken place between the 1970s and 1980s. Students in the fifth, ninth, and twelfth grade scored higher in 1983 on life and physical science items, items assessing process skills and those using illustrations. However, by 1986 fifth grade students scored about the same as students in 1970 and twelfth grade students did less well than students in 1970. Overall improvement from the fifth to the ninth grade was lower in the 1980s than in 1970 while growth in achievement from the ninth to the twelfth grade proceeded at the same rate for the seventies and eighties. Gender differences emerged in 1983 with females in the twelfth grade taking less science than males. Although students in the eighties enjoyed school more than their 1970 counterparts, they did less homework, watched more television and expressed lower aspirations for college.

Applebee, Langer and Mullis summarized the findings of the National Assessment of Educational Progress. They found that the latest assessment indicated that mathematics and science achievement has improved, but the improvement is confined to lower level skills. Students understand the basic elements of science such as the structure and function of plants and animals but increases in the innovative application of knowledge and the analysis of scientific procedures and data have not occurred. The gap in achievement between white and minority students, while still larger than desirable, is closing. Particularly disturbing is the fact that black and Hispanic students score lower than whites as early as age nine and continue to play catch-up throughout their academic careers. A possible consequence of this late start is the fact that minority students at age 17 score comparably to white 13-year-olds.

LaPoint, Mead and Williams reported on the data from the International Assessment of Educational Progress (IAEP) that compared mathematics and science achievement among students from Ireland, Korea, Spain, the United Kingdom, the United States and four Canadian provinces (British Columbia, New Brunswick, Ontario and Quebec). Only the performance of students in British Columbia, Canada, and Korea could be considered outstanding. Performance in biology mirrored overall performance on the assessment except for Quebec, Canada, where the biology scores were better than the overall test performance. Likewise, performance in physics mirrored overall test performance except in New Brunswick and British Columbia, Canada, where scores were less than overall performance. In earth and space science, students in Quebec and French speaking students in New Brunswick performed less well than their overall performance on the assessment. The range in performance across countries was greatest for chemistry. Despite their high performance overall, Korean students had the least understanding of the nature of science. Gender differences (males performed better than females) were significantly large in all countries except the United States and the United Kingdom. The greatest differences were found in Korea. The IAEP also collected background variables that provided some insight into the performance data. For example, home involvement correlated with achievement. Thirty to 60% of the students reported some home involvement compared to 70% of Korean students who reported home involvement. There was also a correlation between liking science and doing well on the assessment.

Ferko examined the performance of advanced students in the United States and the participating countries in the Second International

Science Study (SISS). Students in the United States scored below the international mean in biology, chemistry, and physics. However, advanced students who had studied at least three years of science and mathematics had mean scores that did not differ significantly from the international mean. The best predictors for science achievement were the scores on the SISS mathematics and word knowledge tests.

Within Canada, **Raphael** examined the IAEP results for English and French speaking students. The results of the 1988 assessment confirmed the results of the earlier Second International Mathematics Study. Ontario French-speaking students performed less well than students in other Canadian provinces. Other performance differences in mathematics and science occurred between the French and English speaking populations in Ontario, favoring English speakers and between Ontario and Quebec French language speakers, favoring Quebec. Since care was taken to deal with problems of generalizability and translation, the sources of these differences must be sought elsewhere.

Esquival-Alfaro and Diaz-Solis also examined within-country differences in Costa Rica. They first developed a criterion-referenced instrument to assess the science knowledge of students who had completed sixth grade. This instrument was then administered to the entire third and sixth grade population of Costa Rica. Regional data indicated that the same seven objectives were mastered by 50% or more of the students in 14 out of 17 regions. Students in private schools performed better than students in public schools, students in larger schools performed better than students in smaller schools, and students in urban schools performed better than students in rural schools. Looking across the curriculum, Esquival-Alfaro and Diaz-Solis found that student performance in science was better than performance in mathematics, Spanish, and social studies.

What are the cognitive and social factors that are related to achievement in science?

Marsh and Anderson were concerned about the relationship of mathematics to achievement in an introductory college biology course. To examine this relationship they developed a mathematical test design to assess mathematical competencies needed for success in biology. The test was given to 205 students in two biology classes: Biology 100 and 105. In Biology 100, half of the students exhibited mathematical competencies at the 70% level. In Biology 105, only two-fifths of the students met this level of mastery. Students did not reach mastery level for problems requiring probabilities, permutations, combinations, the metric system, or area and volume. White students had higher levels of achievement than black students. Gender differences appeared in Biology 100 with males performing better than females, but there was no difference in the performance of males and females in Biology 105. This test correlated with SAT mathematics scores and was successful in predicting GPA. However, it did not correlate with the advance placement biology test or the biology CLEP test.

Linder and Hudson were also concerned about the relationship of mathematics to achievement in science. They compared the mathematical background of American and South African physics students in their first year of university. Mathematical background was assessed by an algebra and trigonometry test that focused on the mathematical skills most often used in physics. Three hundred and seven American and 193 South African students who had completed the beginning physics course at their respective universities were given the mathematics test. The data analysis indicated that, despite differences in populations, the students in both countries had similar mathematical deficiencies and chose the same incorrect responses to test items. Students in South Africa performed better overall on the mathematics test than American students by a full standard deviation but there were no differences in their physics grades. The correlation of mathematics performance with physics grades was low for both countries. Only 16% of the variance in grades was explained by mathematics test scores.

Yager and Krajcik investigated whether a high school physics course was a necessary prerequisite for success in college physics. Two groups of high ability students participated in a summer college physics course. One group of students had not had high school physics before participation in the summer course and one group had high school physics. The summer course was a standard introductory physics course without any modification. All students had access to tutors and dormitory counselors but were not required to use them. After eight weeks of instruction there was no difference between the groups for the mean of the final exam, course grades, or attitude toward science. The group that did not have high school physics prior to taking the college physics course studied more and used the tutors more often than the group with prior physics course experience. The authors concluded that high school physics is not a prerequisite for success in college physics for high ability students if tutoring is available.

Young examined factors that were associated with success in the first-year examinations of science students in a Nigerian university. He performed a discriminant analysis on: (1) the matriculation examination which contained an English language section and a specialist section that corresponds to the students' proposed major, (2) the number of years it took students to complete their degree or withdrawal from the university, (3) age, (4) gender, (5) results of the first university examination, (6) time of entry to the university - the first two weeks of lecture or after six weeks of lecture, (7) O level examination performance and (8) academic program. The variable with the most power to discriminate between successful and unsuccessful students was the specialist portion of the matriculation exam. Good performance on the English portion of the matriculation examination, although important for success in the university in general, was not related to success in science majors. The author recommends that cutoff scores for performance on only the specialist section of the matriculation examination be used in selecting students, with the proviso that students must also pass English.

The relationship of integrated process skills and logical thinking to academic achievement was investigated by Hsuing. She gave a sample of 635 tenth grade Taiwanese students the Test of Integrated Process Skills II (TIPS II) and the Group Assessment of Logical Thinking (GALT) as well as a test of science achievement in biology, earth science and chemistry. She found significant but moderate correlations between integrated science process skills and logical thinking abilities. Gender differences favoring males appeared in science process skills achievement, academic science achievement, and logical thinking ability. Neither the TIPS II nor the GALT were effective predictors of academic science achievement.

Baird, Perry and Simon were also interested in process skills as predictors of performance. They administered the first version of the Test of Integrated Process Skills (TIPS) to 667 students in grades 9 through 12 who were to participate in a regional science Olympiad. They found significant Spearman rank order correlations between the TIPS scores and 8 of the 22 events at the Olympiad. The TIPS correlated with performance in the Bio-Process Lab, Designer Genes, Measurement Lab, Periodic Table Quiz, Science Bowl, A is for Anatomy, Topographic Map Reading and the Pentathlon. Other predictors of success in the Olympiad were type of school, number of previous Olympiads attended, and the number of science courses completed. There were no correlations between success in Olympiad events and age, race, grade level, or being enrolled in a school that had previously placed well in an Olympiad.

Elias examined cognitive development and IQ as predictors of achievement in freshman high school biology. Selected variables were examined to determine their value in successfully placing freshman biology students. He used scores from the Shortened Longeot Test to assess cognitive level; IQ scores; the Metropolitan Achievement Test scores for reading, mathematics, and total test score; and final grades in biology. The Longeot Test was not a useful instrument in predicting student success or for identifying levels of student cognitive development. Significant correlations occurred among IQ, cognitive development and achievement. The most significant correlation was between IQ and achievement.

In Israel, **Tamir** looked at the effects of home and school variables on the science achievement of high school students. He examined student background, content knowledge, instructional strategies, and attitude toward science. In addition, he sent a questionnaire to teachers and principals. Three factors emerged as predictors of achievement. The first factor was student background. Students with higher socio-economic status performed better than students with lower socio-economic status and students with parents born in Israel performed better than students with parents born in Arab or African countries. The second factor was opportunity to learn as reflected in quantity and quality of instruction. The quantity of instruction had an effect on achievement with more instruction resulting in higher levels of achievement. The quality of instruction was not important. The third factor, interest and motivation, was seen as arising out of a combination of home and school variables. The greater the interest and motivation of students, the greater their achievement.

Using a younger population in Israel, **Zuzovsky and Tamir** looked at home and school variables that contributed to achievement in science in elementary schools. They examined home variables, the implementation of science curriculum in the schools and science instruction. They found that, in general, the home variables of parental education, number of siblings, and the number of books in the home accounted for more of the variance in science achievement than the school variables of implementation and instruction. In low socio-economic schools, home variables accounted for 75% of the variance seen in achievement. The relative importance of school variables increased when the science achievement measured was closely related to the school curriculum. Differences in the relative importance of school/home variables in explaining achievement varied according to the subject under study. Achievement in inquiry skills was more dependent upon ability than either school or home variables. Achievement in biology had a large school component because it was dependent upon knowledge of facts and concepts. Physics achievement was dependent upon both school and ability factors.

Al-Shahrani examined the relationship of student, teacher, and school characteristics to success in twelfth grade biology in the southwest region of Saudi Arabia. He found that the cognitive variables of mathematics and Arabic language competence were significantly correlated with success in biology. Mathematical ability was the best predictor of biology achievement, accounting for 32% of the variance. Parental education of both the mother and father, and father's occupation was also significantly correlated with achievement. Student interest in science accounted for an additional 13% of the variance in achievement. Teacher characteristics of interest in biology, lower teaching load, and sufficient planning time were also positively correlated with biology achievement. Only one school variable was related to achievement. Schools in which there were a large number of science classes also had students with higher achievement. Caution must be exercised in generalizing these findings because the population under study were males attending single-sex schools.

Fidler was interested in comparing school programs of high and low achieving students as measured by the Michigan Educational Assessment Program (MEAP) science test. He was also interested in determining the relative importance of home and science program variables as contributors to achievement. One hundred and three middle school principals were asked to respond to a survey that asked them to describe the school community and school science program. Again, socioeconomic status was found to be a strong predictor of achievement as measured by either district wealth or the principal's assessment of the community. With socioeconomic status eliminated from the analysis, years of science required and the appropriateness of the curriculum (programs for college and non-college bound students) explained 26% of the variance in achievement. Individual t-tests between high and low scoring schools indicated that schools that required more science, had a balanced and appropriate curriculum and used inquiry techniques had students who scored higher on the MEAP than students in schools without these characteristics. In addition, students who scored well on the MEAP attended schools that had greater amounts of science equipment and spent more money per pupil than students who scored less well. Discriminant analysis identified the combination of variables that provided the best discrimination between low and high scoring schools. These variables were years of science required, academic preparation of teachers, and curriculum balance.

Motivation toward science as it is related to attitude and achievement was investigated by **Clyne** using a population of third and sixth grade students in process oriented science programs. He was particularly interested in these relationships across race and gender. The relationship of motivation to science achievement was low and, although statistically significant, was not educationally relevant. The relationship of attitude and achievement was stronger for males and white students than for females and minorities.

Curiosity and verbal fluency would appear to be logical predictors of success in science. To determine whether these factors are important for success in science and whether there is an interaction with instructional methods, **Koran, Koran, Foster and Fire** studied students with high and low verbal fluency and curiosity scores in two instructional treatments. Treatment 1 was the more structured of the two approaches and consisted of deductive biology instruction in which concepts were defined and followed by examples and non examples of the concept. Treatment 2, with less structure, consisted of inductive biology instruction in which examples and non examples of the concept were presented first, followed by the definition of the concept. They found that eighth grade students did better in both treatments conditions than seventh grade students. In the eighth grade there was no difference in achievement between treatments. In the seventh grade, students in the deductive treatment had higher biology achievement scores than students in the inductive treatment. There was no interaction of curiosity with treatment. Students with high verbal fluency did well in both treatments.

Avellar-Fleming examined the psychological model of educational productivity proposed by Walberg with a middle class population of 332 twelve-year-olds in an urban setting in Brazil. The investigation was conducted in two phases, the aggregate model and disaggregate model. The dependent variables were first and second semester achievement scores. Results from the aggregate model indicated that significant predictors ($p < .05$ or less) of science achievement for the first semester were GPA, self-concept, quantity of instruction and peers' desire to attend college. For second semester, achievement predictors were GPA and self-concept. The disaggregate model included GPA, being a good student, and hard work in science as predictors of first semester achievement. Predictors of second semester achievement were GPA, being a good student, and redoing projects. In the reduced models, physical appearance, reading science magazines, and peers' enjoyment of science projects were predictors of achievement.

Punch and Rennie attempted to clarify the direction of the affect-achievement relationship in science. They developed a conceptual model that proposed that students' enjoyment of science and their enthusiasm for science are determined by: (1) how they perceive their past performance in science, (2) their expectations of future performance in science, and (3) the perceived usefulness of school science. To test this model, they collected data from 342 eighth grade students in two urban middle class schools in Australia. Data were analyzed using multiple regression. They found that affect was related more strongly to previous science performance than to anticipated science performance. Enjoyment of science and enthusiasm contributed little unique variance to the affect—achievement relationship.

Nordstrom investigated the problem of predicting chemistry performance for average achieving students. Existing models have been successful in predicting which students will be the most and least successful in chemistry. However, these models are less successful in predicting performance in the middle range. Discriminant analysis was used to determine the best predictors. Average ability was defined as a "C" or better grade and unsatisfactory performance was a grade of less than a "C". The best predictors of performance were: (1) scores on the SAT/ACT mathematics test, (2) high school GPA, (3) grades in high school chemistry, (4) grades in high school mathematics, and (5) grades in high school English. The discriminant model was able to successfully predict performance in 73.7% of the cases. The author concluded that given the predictors in the model, the best way to help unsuccessful chemistry students was an individualized remediation program rather than mandating a chemistry preparatory course or additional mathematics courses for everyone.

Do gender differences in achievement exist?

Klainin, Fensham and West followed males' and females' chemistry and physics achievement over a three year period in grades 10, 11, and 12 in Thailand. The students were enrolled in both coeducational and single-sex schools. The authors examined laboratory skills including problem solving, theoretical knowledge and scientific attitudes. Female performance was found to exceed male performance in laboratory skills and problem solving, theoretical chemistry knowledge, and a scientific attitude in chemistry. At the end of the three year period, females also exceeded males in a scientific attitude toward physics. However, this relationship was not consistent throughout the three year period. In the area of theoretical physics knowledge, there was no difference between males and females. The authors speculate that they did not find gender differences because all university bound students in Thailand must take chemistry, biology, and physics and that the physical sciences in Thailand are not male dominated in terms of students, teachers, or curriculum developers.

Kanis analyzed the United States data from the Science Process practical examination of 6,000 fifth and ninth grade students. He found that there were no significant differences between fifth grade males and females for either version A or B of the test. At the ninth grade, there was a difference of 3 percentage points in favor of males on the A version of the test. On the B version of the test, there was no difference in ninth grade male and female performance. There were also no gender differences in the patterns of success and failure. All students in fifth and ninth grade were successful in manipulation and following directions. Difficulties arose in items requiring inferential reasoning, drawing conclusions, and stating explanations.

Becker, performing a secondary analysis, examined 30 studies and found that, overall, males performed better in biology, general science, and physics. There were no gender differences in achievement in mixed science content studies, geology, earth science, or in the one study that examined chemistry. Neither grade level nor test length accounted for significant amounts of the variance. She found what may be a researcher effect, namely that studies that focused on gender differences had larger effect sizes than those that did not.

Linn and Hyde, in another secondary analysis study, examined gender differences more broadly. They concluded that gender differences are not general but specific to the context or the culture in which studies take place. They also concluded that when gender differences appeared, they reflected differences in course enrollment patterns and training rather than cognitive differences. Gender differences in cognitive and psychological tasks were smaller and less stable than differences in height, strength, career access, and earning power. **Linn and Hyde** recommended that the educational community emphasize research on learning and earning environments designed to promote equity and de-emphasize research on cognitive and psychological differences.

How effective have remediation programs been in improving student achievement?

Bierman and Sarinsky examined the effectiveness of a community college biology preparation course to provide students with the skills and knowledge to be successful in higher level biology courses such as anatomy, physiology, and general biology. Data were collected on mathematics and reading ability, grades in the biology preparation course, and the type of high school diploma held (regular or GED). Diploma type was considered important because the GED students were older than the students holding a regular diploma. The researchers felt that attaining a GED diploma represented a high degree of motivation to learn. **Bierman and Sarinsky** found that competency in mathematics and reading and holding a GED diploma were correlated with passing the biology preparation course. Of the three variables, mathematics competency was the most important. The GED students also did better in the follow up biology courses. Final grade in the biology preparation course was the best predictor of grades in subsequent biology courses. No differences were found in the success and failure rate in general biology, anatomy, and physiology of students who did not have the preparatory biology course as compared to those who did. The authors concluded that the biology preparatory course was not preparing students to be successful in subsequent biology courses and that success was due to maturity, motivation, and academic skills.

Remediation courses at Borough of Manhattan Community College have not been successful in preparing students to cope with content courses. To address this problem an integrated learning skills course in biology was developed on the premise that writing, reading comprehension, listening, and oral communication skills are not acquired in the abstract but are acquired as a result of learning and relating new knowledge to old. **Mazur** described the course and student outcomes. Each student received an Integrated Skills Learning Guide which outlined the course requirements, assignments, and evaluation criteria. Student progress was monitored through exams, written assignments, interviews, and audiotape recordings. Students provided instructors with feedback and instructors maintained a teaching log. The instructors employed a variety of approaches to teach the same content depending upon student needs and learning styles. Communication and interaction with peers was emphasized. **Mazur** concluded that the course was effective in improving written and oral communication. Students were able to verbalize and write about biological concepts in an organized fashion and employ the appropriate content vocabulary. The speaking activities had a positive effect on student self-confidence and self-image.

At another community college, **Mangini** assessed the effectiveness of a two week summer course to increase success in subsequent science courses. Sixteen students entering an associate degree nursing program participated in the remediation course based upon their previous science grades, SAT's and NLN pre-nursing test scores. The course was based upon Ausubel's principle of meaningful learning and focused on strengthening students' conceptual framework in science and increasing scientific problem solving. The course was evaluated using pre and post tests in science content, abstract thinking and affect. Students in need of remediation enrolled in the summer course were compared to students in need of remediation who did not enroll in the course. **Mangini** found that the remediation course was effective in improving students' knowledge of basic concepts and to a lesser extent in improving abstract thinking. However, even though the students thought the remediation course was helpful, there was no significant difference in rate of success in subsequent science courses between students who had participated in the remediation and those who had not.

Fowler investigated the developmental/remedial chemistry courses offered in 127 two-year colleges. He asked faculty to respond to questions concerning the nature of the courses, the background of the course instructors, student characteristics and advising and support activities associated with the courses. He found that the instructors were well prepared in chemistry but lacked background knowledge about remedial students. Student were placed in the remedial courses on the basis of their own feelings of preparedness without any assessment of ability. The instructors felt that lack of success in chemistry was due to inadequate mathematics background, poor study habits, poor reading ability, lack of confidence, fear of chemistry, and lack of motivation. Few instructors cited a poor chemistry background as the reason for students' lack of success. Advising was the responsibility of faculty or non-faculty counselors. Although he did not look at student success rates, **Fowler** concluded that the content, instructional materials, and teaching methods should provide students with adequate preparation for general chemistry.

House and Wohlt investigated the effectiveness of peer tutoring to improve achievement of academically underprepared students in mathematics and science. Three hundred and thirty-three college students participated in the study. Sixty percent were black. The students were randomly assigned to male and female tutors who worked with the students for one session per week of at least one hour in length. The sessions continued for an entire semester. The tutors were majors in mathematics, biology, and physics with a GPA of 3.0 or better. Tutors received 11 hours of training on topics such as communication, study skills, learning styles, math and test anxiety, and test taking skills. Semester grades in math and science were used as a measure of success. Data analysis took into consideration the effects of the sex of the student and sex of the tutor on achievement. The results indicated that the sex of the student did not affect course grade. However, sex of the tutor did have an effect on course achievement. Students who had a same sex tutor had higher grades than students who had an opposite sex tutor.

Summary

National and international data on achievement in science are not encouraging. In the United States there has been modest improvement during the decade of the eighties. However, this improvement has been confined to lower level skills. This is disturbing in light of the greater emphasis on thinking and problem solving that we can expect to see in the next NAEP assessment. Students in the United States scored below their counterparts in other nations in all areas of science. Again, this is disturbing when international performance was so poor. There are, however, two encouraging findings. First, the gap between minorities and white students has lessened, even though minority students still start school far behind the majority population and have to engage in a strenuous effort to catch up. Second, gender differences have decreased in the United States. Over all, it appears that the rhetoric of teaching inquiry skills and problem solving has not materialized into teaching strategies that enabled students to perform well in these areas. Even Korea, the nation with the best science scores falls short in the area of understanding science. Unfortunately, gender differences still remain large worldwide.

The research is quite clear on the directionality of the achievement-affect question. Attitude is not a good explanatory mechanism for science achievement, but prior academic performance is. Students who do well in college science have done well in previous college science courses and other academic areas in high school. This is especially true for mathematics, although there are differences depending upon the content area and level of the course. Logical ability did not appear to be related to achievement and the role of process skills has not been proven. Indirect measures of academic performance included hard work and being a good student. Background knowledge represented by prior science courses appeared to be important but not necessarily imperative for all students. Instructional variables included the quantity of instruction, teacher planning, and the number of classes a teacher must teach. Curricular factors included an appropriate curriculum, an inquiry orientation, and equipment. Self-confidence and motivation also played a small role in achievement. However, home variables such SES, prior academic achievement, and an academic orientation were the best predictors for success in science. These findings suggest that we must provide students with early and continued academic success in science and other subjects, through appropriate instruction and curriculum, if we expect to overcome the handicaps that the increasing number of at risk students bring with them to school.

Gender differences are not a general phenomenon and are appearing less and less in the science education research. When differences did appear, they were the result of specific contextual or cultural characteristics. I take the diminution of gender differences as a hopeful sign that reflects better instruction and a sensitivity to issues of gender equity. I hope this move toward better instruction and sensitivity can broaden in focus and include other underrepresented groups in science such as minorities and the physically challenged. Research in science education should concentrate on studies that promote learning for everyone.

The traditional format of a course did not appear to be an effective mechanism to prepare remedial students for subsequent success in science. However, courses that emphasized peer interaction or one to one tutoring do have an effect on achievement. This approach may work with remedial students because of the personal attention and affective bonds that are formed during the learning process. In addition, remedial students may have a history of academic failure because of differences in learning styles that are not addressed by traditional modes of instruction. Consequently, remedial courses that do not take a different approach to instruction can not be expected to affect student achievement.

AFFECT

What are the interests and values of students in relation to science and the environment?

Anderson, Pruitt and Courtney assessed the science interests of urban seventh grade students. They investigated: (1) whether students were interested in exploring science issues, (2) how much input students had in determining what they studied or did in science, (3) the most interesting science activities, and (4) what generally interested students most in science. They found that most students expressed an interest in studying science and exploring science issues. Topics such as the human body, astronomy, animals, heredity, and electricity were the most popular. Two-thirds of the students in the study reported they seldom or never had any input into the selection of class projects or topics. Students liked field trips, experiments, doing group projects, making observations, engaging in discussions, and drawing. The least popular activity was reading books about science and scientists.

The science interests of sixth grade students was explored by **Abdi**. He explored favorite topics, the effect of teachers on student interests, teachers' perceptions of student interests, gender differences, and the relationship of interest to achievement. He found that students were generally interested in the sixth grade science programs, but that the level of interest was low. Students responded to a Likert scale and indicated that they had some interest rather than a definite interest. This was in sharp contrast to the teachers' perception of the students. Teachers thought that all of the science topics in the curriculum were of definite or greater interest to students. Teachers had an effect on student interest in five broad categories of topics found in the curriculum: classifying animals with backbones, classifying animals without backbones, elements and compounds, sources of energy, atmosphere and climates of the world, and natural cycles. Gender differences occurred in two topics, but these small differences had no educational significance. Interest was correlated to achievement on some topics but not others.

In Australia, **Dekkers, DeLaeter and Malone** examined science enrollment trends in grade 12 from 1970 to 1987. They found that the number of students interested in science doubled from 1970. The largest increases were in the number of female students, from 26.1% of the total population enrolled to 57.1%. However, this increase in enrollment in science was not an increase in the number of students taking discipline oriented subjects such as chemistry or physics. In geology, enrollment actually declined by 37%. The increase in enrollment was in alternative science subjects such as environmental science or agriculture.

Yager, Simmons and Penick examined students' perception of the usefulness of science in three age groups: 9, 13 and 17 year olds. One group of students was selected from schools that the NSTA had identified as excellent and implementing a science, technology, and society curriculum. The other group of students was selected from ordinary schools using the standard curriculum. Student perceptions varied by age and program. Nine-year-olds perceived science as more useful than did 13-year-olds, who in turn perceived science as more useful than did 17-year-olds regardless of the type of school they were enrolled in. When the two types of schools were compared, the authors found that the students enrolled in the excellent schools with the STS curriculum perceived science as less useful than did students in schools with the standard curriculum. The authors concluded that even in exemplary STS programs the focus was on science as a preparation for further study and less on science as preparation for careers, meeting personal needs and solving societal problems.

In Finland, **Aho, Permikanga and Lyyra** examined students' attitudes toward nature and their choices for solving environmental problems. Students were presented with a text about nature and environmental problems and asked to devise a solution. They were also asked to select one of five alternatives from a list of solutions and rank order the remainder. The alternatives represented different orientations to nature. All students believed that they must treat nature well in order to survive and that there must be compromise between self-interest and the use of the environment. Students also believed that technology was the solution to environmental problems. Economic values were not an important part of the students' decisions. Males and females held different views of nature. Females looked at nature from an ecological, social, and ethical point of view. Males, on the other hand, looked at nature from a socio-economic point of view.

What are the cognitive, social and personality factors that are related to affective responses to science?

Stuessy and Rowland were interested in the relationship between locus of control and attitude toward science. They administered the Internal-External Scale and the Test of Science Related Attitudes to tenth grade biology, eleventh and twelfth grade chemistry students, and college elementary education majors. Correlations indicated that students with an internal locus of control had more positive attitudes toward science than students with an external locus of control. The strongest negative attitudes were expressed for inquiry and wanting to take part in science activities. The relationship of locus of control and attitude strengthened with age.

Science anxiety was studied by **Meissner**. He used the State-Trait Anxiety Inventory or the State-Trait Anxiety Inventory for Children and a semantic differential instrument designed to measure perceptions of science, scientists, and science teachers. Three hundred and eight fourth, sixth, eighth, tenth, and twelfth grade students responded to both instruments. One hundred and sixty-two parents responded to the semantic differential. **Meissner's** analysis indicated that there was no statistically significant relationship between grade level and anxiety. Science anxiety was related to students' perception of science, scientists, and science teachers and parental perceptions of science. Females had higher science anxiety than males. As students progressed through grades 4 through 10, their negative perceptions of science increased. This increase was most dramatic as students moved from grade 6 to 8.

Gardner and Tamir conducted a two part study about interests in biology. In part I, they performed a factor analyses on the responses of 878 Israeli students about their interests in biology The instruments used to determine interests focused on content, learning modes, cognitive processes, motivation, career patterns, interest in biology, and general interest in biology. For content, the authors found that the factor structure varied from sample to sample due to differences in responses to biochemical processes. Biology was not a unidimentional construct and interest varied according to the aspect of biology under consideration. Learning mode was also multidimensional. Whether or not students liked biology depended upon how it was taught. No distinct patterns emerged for interest in engaging in cognitive processes such as observing or calculating. Motivation yielded two factors dealing with the social aspects of science. The first factor was concern for environmental issues and the second, moral issues. Career patterns yielded four factors. Students were interested in either research, high status health careers, low status health careers, or what the authors called woodsy-birdsy careers. The highest factor loading for interest in biology was concern about success on the Bagrut (grade 12) exam. General interest in biology yielded three factors: boredom, enjoying biology, and the difficulty of biology.

In part II of the study, **Gardner and Tamir** identified the variables that distinguished between students who intended to enroll in high level biology in tenth grade and students who intended to enroll in no biology course. However, the variables were not good predictors of intention to enroll in low level biology or physical science. Students who intended to enroll in high level biology enjoyed biology, had research and high status career interest, were interested in a broad range of biology topics, and had a greater tendency to regard the Bagrut examination as interesting. Students who did not intend to take any biology in tenth grade had less interest in biology topics, were less motivated to solve biology problems, had poor grades in biology, did not perceive biology as useful, were less likely to be interested in social modes of learning, and were less likely to regard the Bagrut examination as fair.

Smith was interested in student attitude toward junior high science as a function of school and non-school factors. He assessed school and non-school factors with an instrument based on items found in earlier studies of attitude. Attitude toward science was assessed with the modified Science Attitude Scale of Semantic Differential. His analysis indicated that both school and non-school factors affected students' attitude toward science. The most important school factors were grade level, teacher characteristics, class activities, and curriculum. The teacher was the most frequently identified school factor. The most important non-school factors were race, gender, and parents' level of education.

The influence of school and non-school factors on attitude toward science of science and nonscience college majors was also investigated by **Gogolin**. She used the Attitude Toward Science Inventory to assess perception of the science teacher, science anxiety, the value of science in society, science self-concept, enjoyment of science and motivation in science. The responses of 83 science and 1,032 nonscience students were compared. The differences between the groups were statistically significant for all six aspects of attitude in favor of science majors. To explore this difference in attitude further, 25 nonscience students were interviewed. The interviews suggested that attitudes toward science result from the interaction of both school and non-school variables. Classroom environment was an important school variable. Family environment and peer relations were important non-school variables.

Schibeci also looked at home and school variables as they influenced attitude and achievement. He observed 17 high school classrooms for one school year. The classrooms were characterized by little homework, teacher demonstrations, and short answer multiple choice assessments of student progress. At the beginning of the school year the students' inquiry skills were measured. At the beginning and end of the year attitude toward science was measured. Science achievement data were collected at the end of the first semester and the end of the school year. Data about the home were collected through a questionnaire and data about peers were collected by asking students to name their three best friends and to fill out a questionnaire. He found a strong relationship between inquiry skills and initial and final attitude toward science and inquiry skills and between achievement. There were also strong causal links between initial attitude, general attitude, and final attitude.

Edwin attempted to identify the factors that distinguish students who persist in their study of science and technology from those who quit. She selected social, economic, academic, and demographic variables as possible predictors and also administered the Strong-Campbell Interest Inventory and the Pascarella and Terenzini scale. Persisters were more satisfied with their interactions with faculty and with faculty's concern for student development and their teaching than students who quit. Persisters were also more confident in their ability to persist and in their GPA. Those who quit found the subject matter too difficult, the experience too competitive, and were concerned that their grades were poor. Persisters were supported by prospects of career and job opportunities, family, and faculty.

Omerod, Rutherford and Wood examined the influence of a strong social factor, namely television, on the formation of attitudes toward science among British students. In the first study they gave 330 elementary students three attitude assessments. They found that females were more interested in nature and males were more interested in space. After one year in secondary school the differences in interest disappeared. In study II, males and females watched the same television programs and their responses were assessed. Science fiction, space, and fantasy programs were the most popular followed by less academic programs and programs about animals. The more specialized and academic programs were the least liked. The correlation of frequency of watching a type of program and liking science was different for males and females, but the overall pattern indicates that students watch the kinds of programs that reflect their interests in science. Males watch space programs and females watch nature programs. The authors suggested that television programs can be used to shape attitudes toward science.

Fishbein and Ajzen's Theory of Reasoned Action was used to examine students' intentions to engage in laboratory and non-laboratory behaviors. **Ray**, using a sample of 377 third and eighth grade students determined that the students' attitudes toward the behavior, i.e., engaging in laboratory activities, had a greater influence on their behavior than did the subjective norm. Subjective norm is the perception of pressures by significant others to perform a behavior. In other words, teachers and parents had less influence on students' intention to engage in laboratory activities than did their own beliefs and motivation.

Crawley examined the power of the Theory of Planned Behavior to predict the intentions of teachers to use investigative teaching methods. He was particularly interested in three aspects of the theory: attitude toward the behavior, subjective norm and perceived behavioral control. The subjects in the study were teachers of grades 5,6, 9, and 10 who were enrolled in an institute to learn new science activities and investigations. The data indicated that attitude, subjective norm, and perceived behavioral control were all significant predictors of the intention to teach at least half of the activities and investigations learned at the institute. Attitude toward the behavior was the single most important predictor of behavioral intention. The author concluded that teaching new science activities and investigations is totally under the control of the teachers. They needed little social support to use investigative teaching methods and they had sufficient resources and opportunities to do so.

How effective have interventions been in improving affective responses to science and science related subjects?

Pesthy studied the effect of taking mathematically non-threatening science courses on subsequent attitudes, career choice, and continued science course taking behavior. She was especially concerned about the effect of the courses on the attitudes and plans of female and Hispanic students. To assess the effect of the mathematically non-threatening science course as an intervention, she administered a pre course and post course survey. She found that students' career choices remained stable from the pre to post course survey. In addition, she found that students were less inclined to enroll in additional science or mathematics courses after enrollment in the mathematically non-threatening science course. **Pesthy** concluded that the course was not a success as an intervention.

An intervention to alter young women's self perceptions of ability was more successful. **Wilson** found that an instructional procedure that focused on positive reinforcement of abilities brought about significant changes in science self-concept and diminished perceptions that science is a male domain.

Duckworth and Lind examined the curricular goals that guide effective teachers of non-college bound students. They found that intrinsic motivation was facilitated by increasing students' feelings of efficacy in the classroom. Efficacy was increased by deemphasizing subject matter and emphasizing functional skills. Motivation was also increased by developing student interest in science. Curriculum goals were reoriented to maximize the relevance of the content to the students' world. Teachers also focused on building trust and mutual respect.

Science, technology, and society essays were found to have an effect on students' attitudes toward science. Although **Fillman** did not conceive of his study as an intervention on attitude, but rather a study to determine students' perceptions of scientific literacy, it none the less had an effect on attitude. **Fillman** found that ninth grade students who read biology essays written with a scientific literacy focus emphasizing STS issues had more positive attitudes towards science than students who read essays with a scientific literacy focus emphasizing content. The STS essay readers felt that: (1) the information was meaningful to their lives, (2) the information was useful, and (3) they would like to visit a scientist. The increase in affect was achieved without any difference in the amount of text information remembered.

Zoller and Maymon studied the effects of an antismoking intervention in health education to change attitudes and behaviors. The intervention lasted four to six weeks and was embedded in ninth and tenth grade biology classes. The intervention was successful in changing attitudes of males so that they were less in favor of smoking after the intervention than before the intervention. Females, however, were more in favor of smoking after the intervention then they were before the intervention. The intervention did not significantly decrease the number of students who smoked. The authors concluded that the intervention was effective as a prevention for males, and was successful in changing attitudes but did not have an effect on established smoking behaviors.

Two studies examined the effectiveness of the workshop/inservice format to change attitudes and behaviors a of practicing teachers. **Roadruck** evaluated the effectiveness of a workshop to improve teachers' attitudes toward the use of chemistry demonstrations as a first step in increasing the number of demonstrations used. Twenty-five chemistry teachers were involved in the workshop over a two year period. The workshop experience resulted in more positive attitudes towards chemistry demonstrations and an increased use of demonstrations. Workshop participants reported increased positive reactions to their teaching from colleagues and administrators. Workshop participants also became more active in professional activities. Teacher attitude toward demonstration was correlated with increased use of demonstrations. The number of demonstrations was not related to teacher knowledge of chemistry, years of teaching experience, or gender. Barriers to the selection of demonstrations were familiarity with demonstrations and their relevance to the curriculum.

Luke conducted research on the effectiveness of inservice to change attitudes and behavior toward the use of science process and mathematics problem solving teaching strategies. One hundred and three elementary school teachers participated in two eight-hour sessions one month apart. As in the Zoller and Maymon study, the intervention was successful in changing attitude but was not successful in changing behavior. **Luke** attributed the lack of impact on practice to four factors: insufficient time to change behavior, accuracy of self reports of teaching behaviors, lapsing into old teaching behaviors due to feelings of inadequacy, and fear of trying something new alone.

Summary

In general, students' interest in science is low but teachers do not seem to be aware of this. Topics of interest vary but are narrowly confined to the previous educational experiences of the students. Students would like to have more input into what they learn which leads me to conclude that the lack of choice in what they study may be affecting student interest. In Australia, interest in science has been growing in non-traditional areas such as environmental science but this phenomenon was not seen in the United States. Science, technology, and society curricula, designed to be more relevant and interesting for students did not result in students perceiving science as useful for their lives. Some gender differences occurred in the area of values and beliefs in that males and females don't necessarily hold the same views about science, especially when the issues are environmental.

Affective responses to science were affected by a variety of factors. The more external a locus of control a person had, the more likely it was they had a positive attitude toward science. Anxiety toward science, scientists, and science teachers also affected attitude with females expressing greater anxiety than males.

The formation of interests, positive values, and positive attitudes toward science was the result of many factors. Some of these factors, such as socio-economic status, are beyond the control of educators. However, there does seem to be a clear set of interrelated instructional and curricular variables over which we do have control. Educators must consider student interests, gender differences, and individual differences if they expect to reach all students. Educators must also be cognizant of the fact that although they may be successful in changing attitudes toward science, it is more difficult to change behaviors.

CLASSROOM INTERACTIONS

What kinds of teacher-student and student-student interactions take place in the classroom?

Jones investigated the seating patterns of target students in classrooms to determine whether a T-zone (target zone) was present. She observed 56 physical science and chemistry classes using the Brophy-Good Teacher-Child Dyadic Observation System. Target students were identified and their interactions with the teacher were compared with non-target students. To determine whether the teacher or the student determined target student status, teacher direct questions and student initiated interactions were analyzed. The analysis indicated that there was no T-zone in any of the classes observed. Target students, in this study as in others, dominated classroom interactions. They were asked more direct questions by the teacher, engaged in more conversations with the teacher, and received more sustaining feedback. Target students were self-selected by initiating interactions with the teacher. Nearly one third of the students in the study did not speak to or interact with either the teacher or other students.

To further investigate classroom interactions, **Pugh and Lock** developed a framework for analyzing pupil to pupil talk. The instrument, which had an interrater reliability of 72.1 to 90.0, was used to score transcripts of student-student conversations while observing students working in small groups on a biology task. The authors found that student conversations were characterized by many more initiating utterances than responding utterances. Students asked many questions of each other, gave orders, and made statements but few students responded to the questions, orders, and statements. Most utterances that sought or required an answer were framed as commands rather than questions. Group dynamics varied from democratic interactions to those dominated by one person. Most of the conversations focused on procedural issues and there was little talk about underlying concepts.

What gender differences exist in classrooms and classroom interactions?

Jones, in her analysis of target students, also found gender differences. Like other researchers, she found that males had more interactions with the teacher than females. More males than females were target students, but female target students had more interactions with the teacher than male target students.

In another study, **Jones and Wheatley** looked at classroom displays, students' lab behavior and teachers' verbal behavior in 60 physical science and chemistry classrooms. Classroom displays featured significantly more male than female images and many of the images were stereotypes. Due to a poster series on black scientists acquired by most teachers, there were more images of black female scientists than white female scientists. Student behavior in lab settings was sharply delimited by sex. Males dominated the groups, males volunteered to do tasks and females were observers. The teacher contributed to these differences by asking more males than females to help with demonstrations. This pattern was consistent regardless of the teacher's sex. The teachers used a variety of non-sex stereotyped examples in their lectures but remarks about student appearance were directed to female students.

Baker examined gender differences in response to curriculum and instructional strategies. She interviewed 182 students from kindergarten through twelfth grade at the end of the school year about the topics they remembered studying and the instructional strategies their teachers used. She found that although males and females may be in the same classroom together, what they remember is very different. In the elementary grades, the topics recalled are stereotypical. Males remember studying rocks, space, and weather and females remember studying plants, animals, and sea life. These early preferences, expressed through selective memory, mirrored high school course-taking patterns. Females, regardless of grade level, remembered passive instructional strategies such as worksheets while males remembered active instructional strategies such as group projects. She concluded that students arrive at school well socialized into stereotypical behaviors and preferences which act as a filter for their school experiences.

Do teachers and students view curriculum and instruction in the same way?

Boonyaraksa examined the perceptions of physics teaching among physics instructors, physics majors, and non-physics majors in eight Thai universities. He found that all three groups perceived actual teaching performance to be less than the ideal of effective teaching. Overall, instructors perceived instruction to be better than did students.

Piburn was interested in the degree of congruence between students' and teachers' views of the science curriculum. He interviewed 13 teachers, one each for grades kindergarten through twelfth grade, and 150 of their students about activities, instructional strategies, and goals. He found that elementary teachers believed that they had a hands-on approach to investigating natural phenomena in their students' world. Elementary students thought science was art. They did not remember investigative activities. Instead, the students reported singing songs and doing cut and paste art projects. Secondary teachers relied on textbooks and worksheets as the most efficient way to teach. They did not use many labs because they were not efficient. Students saw this approach as a way for the teacher to avoid work. They thought that the way to improve student learning was to focus on hands-on activities and to make class more fun. Secondary teachers attributed low student enrollment in science to laziness. Students disagreed, saying that they no longer understood the content and that it was no longer fun.

Summary

The research indicated that classroom interactions are inequitable whether the class is organized for whole group or small group interactions. Teachers must monitor their own behaviors and those of their students to insure that everyone is engaged in quality educational experiences. In particular, teachers must help students learn to work in groups and conduct meaningful conversations.

Gender differences existed in classrooms in several areas. Again we found that males dominate classroom interactions. Science classroom displays also featured more males engaged in science activities. These patterns persist despite the attention that has focused on these phenomena over the last ten years. Gender differences also existed in how students reacted to the curriculum. Being in the same classroom did not guarantee that males and females remembered the same things. Aspects of the curriculum had different saliency for males and females, so--despite coeducation--students came away from the learning experience with very different impressions of science.

Teachers should be aware of student perceptions of the classroom. Just as males and females did not appear to inhabit the same classrooms, so too teachers and students may have very different perceptions of what is occurring.

COGNITIVE PROCESSES

What role does cognitive style play in learning science?

Garrett reviewed 15 studies about IQ, cognitive style, and problem solving in science. These studies addressed problem context (warm and encouraging or neutral), problem type (single correct answer or multiple correct answers), and the cognitive styles of category width, field dependence/independence, and impulsivity/reflectivity. He concluded that the relationship between problem solving and cognitive style is exaggerated. Correlations among cognitive style, IQ, problem context and problem type were weak. Impulsives were not, as some researchers have hypothesized, more original thinkers than reflectives.

Bostic investigated whether the cognitive style dimensions of field dependence/independence, category width, impulsivity/reflectivity, tolerance for ambiguity, cognitive complexity/simplicity, and automatization/restructuring could be consolidated into a smaller number of factors. He was also concerned about the relative importance of cognitive style to understanding science once developmental level and critical thinking ability were taken into consideration. Consequently, **Bostic** administered a battery of cognitive style, critical thinking, and developmental assessments to 99 eleventh grade students. The data were subjected to factor analysis and regression analysis. From the analyses, he concluded that the six cognitive styles fell into three factors: (1) deliberation; composed of reflectivity measures; (2) assimilation composed of field independence, broad category width and automatization; and (3) flexibility composed of tolerance for ambiguity, field independence, and cognitive complexity. Cognitive style accounted for only 3% of the variance in understanding process skills once developmental level and critical thinking ability were taken into account. Critical thinking accounted for 60% of the variance in understanding science process skills and developmental level accounted for an additional 3%.

Cognitive style, M-space, and short-term storage space were studied by **Roth and Milkent**. Their study was designed to test how well these factors predicted the amount of practice needed to induce successful problem solving strategies, the ability to transfer problem solving strategies to new contexts, and readiness to abandon unsuccessful problem solving strategies. Twenty-three students who had not attained formal reasoning on proportional problems were selected to participate in training sessions designed to help them attain proportional reasoning. Training consisted of balance beam and probability problems. As a result of the training, most of the students were able to develop some strategies that allowed them to solve problems requiring formal reasoning. Neither M-space nor cognitive style alone or in combination predicted the amount of practice a student needed to be successful in solving proportional problems. Cognitive style did not correlate with the ability to transfer problem solving strategies to new situations nor to a readiness to abandon unsuccessful behaviors. However, short term storage space was a good predictor of transfer and the readiness to abandon unsuccessful problem solving strategies.

Stuessy created a model for the development of reasoning abilities in adolescents. One hundred and ninety seventh through twelfth grade students were given a battery of assessments for locus of control, field dependence/independence, IQ, rigidity/flexibility, and reasoning. She also included age, gender, and experience with science related activities. The model was tested and revised using path analysis. Significant path coefficients were found for age (.54), experience (.11), IQ (.49), and field dependence/independence (.15), directly to scientific reasoning. A path from locus of control (.29) through field dependence /independence to reasoning was also significant. These five variables accounted for 61% of the variance in scientific reasoning.

Niaz looked at field dependence/independence as a possible factor in performance on proportional reasoning problems. He used a sample of 318 college science majors who were either field dependent or independent and either good or poor at proportional reasoning. He found that students capable of proportional reasoning and who were field dependent were misled by field factors in proportional reasoning problems.

Fate control among black science and non-science oriented high school students was the subject of a study by **Clay**. In addition to locus of control, she collected data on SES, parents' educational aspirations for their children, students' educational aspirations, academic performance, perception of academic climate, and prior learning experiences in science. She concluded that science oriented students had higher fate control dominance than non science students, i.e., they felt in control over the events in their lives. Students' educational aspirations, the amount of science taken in elementary and middle school, and teachers' attitudes toward science learning had the greatest influence on fate control dominance. Socioeconomic status had little influence on fate control or a science orientation.

Diffenbach examined the relationship of laterality to information processing in problem solving, task recall, cognitive style, perception and Piagetian verbal and figural operations. He concluded that information processing, task recall, verbal and figural Piagetian operations were the best predictors of laterality.

The relationship of orientation to learning and conceptions of scientific knowledge was studied by **Edmondson**. She used interviews, small group discussions and administered questionnaires to introductory level biology students. From these data, she was able to identify three learning strategies (rote, meaningful, and compartmentalized learning) and three conceptions of science (logical positivist, constructionist, and a blend of the two views). Students who favored rote learning were male, grade oriented, and logical positivists. Students who favored meaningful learning strategies were female, oriented to material, and constructivists. Students who compartmentalized their learning with little integration had essentially developed parallel ways of knowing and were most likely to hold a blend of the positivist and constructionist view of science. **Edmonson** concluded that the dual conception of science prevented students from integrating their knowledge, thus leading to frustration and lack of meaning. She was also concerned that the constructivist view held by females would be at variance with the emphasis on logical positivism found in most science courses. She speculated that the differences would result in fewer women in science.

What is the role of logical reasoning to success in science?

Wavering studied the relationship between logical reasoning and the ability to correctly graph data resulting in a positive slope, negative slope and exponential curve. The population under study were students in the sixth through twelfth grade. Analysis of the graphs indicated that students' ability to graph increases with grade level and that the pattern of errors and abilities parallel Piagetian categories of reasoning from preoperational to formal operational. For example, some students in grades 6 through 8 gave responses to the graphing task that ranged from no attempt to draw a graph to graphs in which there was no scaling. In ninth through tenth grade, the graphs were more accurate but still contained errors such as correctly scaling the graph without indicating the relationship between variables. It was not until the eleventh and twelfth grade that students were able to correctly graph data that resulted in an exponential curve.

Students often have difficulty translating sentences into algebraic equations and algebraic equations back into sentences. **Niaz** examined this phenomenon using a sample of college students in an introductory level chemistry course. He hypothesized that formal reasoning and proportional reasoning would be related to translation ability and that reasoning and translation ability would be related to success in chemistry. He found that as formal reasoning and proportional reasoning increased so did achievement in chemistry and the ability to translate sentences into equations and equations into sentences. The ability to translate an equation into a sentence also correlated with achievement in chemistry but there was no correlation with achievement in chemistry with the ability to translate a sentence into an equation. Reversals were the most common error made. Students translated a sentence such as "There are six times as many professors as students" into 6P=S instead of P=6S.

Lavoie investigated the effects of prior knowledge and reasoning ability on students' ability to make predictions. Fourteen high school biology students were identified who were either concrete or formal thinkers and had either high or low levels of prior knowledge about water pollution. Students were observed making predictions using a computer simulation on three water pollution problems. Successful predictors were generally formal reasoners and had high prior knowledge. Unsuccessful predictors were generally concrete reasoners and had low prior knowledge. Of the two variables, prior knowledge was more important than level of reasoning.

Students often encounter difficulties in genetics. Consequently, **Gipson, Abraham and Renner** investigated the role of formal reasoning skills in facilitating success in genetics problem solving. Seventy-one biology students enrolled in a traditional general biology course were taught a unit on genetics in which the Punnett-square model for genetics problem solving was used. Eight weeks after the genetics unit the students were tested for retention of problem solving skills that required proportional, probabilistic, and combinatorial reasoning. Clinical Piagetian interviews (balance beam, colored squares and diamonds, and switch box tasks) were also used to assess reasoning. The data were analyzed using correlations, analysis of variance, and factor analysis. Direct relationships between the formal reasoning skills assessed through clinical interviews and the written tasks were low. Formal students were more successful on the written genetics assessment than transitional students, and transitional students were more successful than concrete students.

How does context and culture effect reasoning?

Khalil conducted two cross cultural studies of 891 Egyptian and British children. The first investigated 5- to 11-year-olds' understanding of the concepts of life and death (animism). He found that animism was not a universal spontaneous tendency of preoperational children. Although there were small statistically significant differences in the Egyptian and British populations practically, the differences were non-significant. The second study of 11- to 15-year-olds investigated differences in the attainment of concrete and formal operations. There were no educationally significant differences in the attainment of formal operations for the two populations. Differences, when they occurred, were attributed to differences in the two educational systems.

William compared performance on the Group Assessment of Logical Thinking (GALT) of West German students to the performance of American, Philippine, and Japanese students. In addition, he collected data on the number of hours spent studying mathematics and science. Data analysis indicated that logical thinking developed progressively from ages 12 through 15. Males performed significantly better than females in each sample. There was a statistically significant relationship between the number of hours of science instruction and logical thinking scores but there was no relationship between the number of hours of mathematics instruction and logical thinking scores. German students' scores on the GALT were below those of Japanese students, but above those of American students of the same age.

Context variables were the focus of a study by **Heller, Ahlgren, Andrews, Post, Behr and Lesh**. They examined the effects of ratio type, problem setting, and format on proportional reasoning. Two hundred and fifty-four seventh grade students were given proportional reasoning problems that varied on each of these dimensions, an assessment of qualitative/ quantitative reasoning and a rational numbers test. Data analysis indicated that qualitative reasoning is a necessary but not sufficient condition for success on proportional reasoning problems. Some success with proportional reasoning can be attributed to memorization of procedures and skill with rational numbers even in the absence of qualitative reasoning skills. Some students were also successful on proportional reasoning problems even though they lacked skill in rational numbers, but skill with rational numbers insured success in proportional reasoning. There was a hierarchy of difficulty for problem settings with the least familiar being the most difficult and the most familiar being the least difficult. Differences in ratio type were larger when the problems were in non familiar contexts.

Another study dealing with context variables focused on proportional, combinatorial and correlational reasoning. **Piburn and Baker** examined the effect of task content(familiar and unfamiliar), interviewer (male or female) and format (clinical or written) on differences in the performance of males and females. They found that gender differences were limited to proportional reasoning tasks, clinical rather than written formats, and only when the material was unfamiliar. In each case males performed better than females. A strong interviewer effect was found. Female interviewers obtained better performance from both male and female subjects than male interviewers. The authors concluded that bias in assessment was responsible for gender differences rather than an inherent male superiority in reasoning.

Bitner-Corvin examined the developmental patterns in reasoning of 84 students in grades 6 though 10. The Group Assessment of Logical Thinking (GALT) was administered three times over a 20 month period to assess changes in reasoning over time. The data were analyzed using t-tests and analyses of variance. Correlational reasoning was the most difficult for the students over each of the three administrations of the GALT. Grade level differences also appeared for each of the administrations of the GALT. The author concluded that the majority of the sample were not formal reasoners. Movement from concrete to transitional operational reasoning occurred at the end of seventh grade. Between eighth and ninth grade a plateau effect was observed and changes in reasoning were not observed after that time.

Should decision making be an integral part of science education curricula?

In a philosophical piece, **Good** explored the role of decision making in science curricula. He reviewed the research on decision making from a variety of disciplines including philosophy of science, cognitive psychology and artificial intelligence. He concluded that prediction must be part of instruction in science learning theory, especially if it focuses on prior conceptions.

Moving toward this goal, **Aikenhead** tested two theories of decision making to determine whether they could be useful in interpreting student decision making behavior during a scientific inquiry simulation. The first theory was the Social Decision Making Scheme in which decisions are believed to arise from the interaction of prior knowledge and the normative rules of the decision making group. The second theory was Valence Distribution in which decisions are believed to emerge from group interactions, especially positive comments regarding a choice. The setting was the observation of a pendulum. Observation and analysis of group interactions indicated that students based decisions on the authority of the data, the authority of the person making sense of the data, the authority of the teacher, the classroom social environment, and their own psychological states. Neither theory was successful in predicting how groups arrived at decisions. The author concluded that even a simple classroom situation is too complex to be captured by the theories.

What role does spatial visualization play in learning science?

Howe and Vasu explored the role of verbalization on the formation and retention of mental images in a sample of kindergarten, first, and fifth grade students. The imaging focused on familiar fruit. The treatment consisted of observing the fruit or listening to a description of the fruit. Immediately after observations and listening activities, students were asked to draw a picture of it and describe their mental image. The drawings were scored for accuracy. Two weeks later the students were asked to recall their images and draw them again. There was no effect on mental imagery for either treatment. The authors concluded that familiarity with the fruit may have affected their outcome of the study. Consequently, the study was repeated using unfamiliar fruits. Students who observed the fruit created more accurate mental images and retained them longer than students who had heard descriptions of the fruit. First grade students who had observed the fruit were as accurate in their drawings as fifth grade students who had listened to descriptions for both short and long term recall. Descriptions generated by students who had observed the fruit were as complete as the descriptions of students who had listened. There were no gender differences. The authors concluded that instruction that focuses on seeing real objects is better than hearing about the world.

In a similar study **Vasu and Howe** examined the effects of a visual and visual-verbal intervention on 22 first and fourth grade students. The visual group observed a fruit and the visual verbal group observed the fruit while simultaneously listening to a description. Students were again assessed using verbal descriptions and drawings. Students in the visual-verbal format had better immediate and long term recall and better descriptions of the fruit than students in the visual only format. Students in the visual-verbal format drew more accurate pictures than students in the verbal only format for immediate recall but not long term recall. In all cases, fourth grade students performed better than first grade students. Overall, more information was coded and represented in pictorial form than in verbal form. The authors concluded that, although seeing is better than hearing, a combination of approaches is better than seeing alone. Verbal approaches provided students with the necessary vocabulary for them to make sense of their observations.

Some researchers have attributed the low number of women in science to poorer spatial visualization skills on the part of women. **Howe and Doody** challenged this assertion in their study of gender differences in partial visualization. Twenty-eight males and 28 females in tenth grade biology were given a battery of spatial tests to measure field dependence/independence, perceptual fidelity, simple and complex imagery, line conservation, and cognitive regulation tasks requiring seriation and reversibility. Students were administered the tasks in small groups. Regression analysis was performed to determine the amount of variance in field dependence/independence accounted for by the spatial visualization tasks. Complex imagery and cognitive regulation accounted for 22% of the variance. No gender differences in performance were found. The results led the authors to conclude that the basic underlying processes in field dependence/independence are cognitive rather than spatial. Deficits in spatial visualization did not exist and the deficit theory does not constitute an adequate explanation for the low number of women in science.

Townsend and Clarihew investigated the effects of verbal and pictorial advance organizers on science text comprehension under conditions of high and low prior knowledge. One hundred and ten students ages 7 through 10 were presented with verbal, pictorial, or combined verbal and pictorial advance organizers prior to reading a science text passage. After reading the text they were assessed on text comprehension and their ability to answer questions based on textual information that was either implicit or explicit. Students who received verbal and pictorial advance organizers had higher levels of comprehension than students who received verbal organizers alone regardless of the degree of prior knowledge. Students in the verbal only condition were no better at answering explicit than implicit questions. Students with strong prior knowledge were helped the most by verbal advance organizers. The addition of verbal advance organizers increased the comprehension of students with weak prior knowledge.The results held regardless of reading level.

What do information processing models contribute to our understanding of problem solving?

Stewart and Dale investigated the kinds of conceptual models students created to explain the relationship of chromosomes and genes and the facility with which students could manipulate their models to explain solutions to genetics problems. The subjects were 50 ninth and tenth grade high school biology students. The authors used think aloud protocols to determine student thought processes as they solved problems, interviews with open ended questions, and activities that required students to show how their models related to their solutions. The authors found that students used mathematics models rather than genetics models. Students had either little genetics knowledge and relied on generating all possible combinations to solve dihybred cross problems or they worked backward from their mathematical model to a genetic model. Students were able to arrive at the correct answers to problems by applying algorithms or using sophisticated combinatorial reasoning without any underlying conceptual understanding.

The first step in the information processing model for problem solving is the correct representation of prior and current knowledge related to the problem. **Pribyl** investigated the influence of high and low spatial ability on students' ability to accurately represent knowledge as part of their problem solving strategies. Twelve high spatial ability and nine low spatial ability students were interviewed using the think aloud method while solving stoichiometry problems. The data were analyzed for the correct number of responses, the strategies used to answer the problem, and the representations of the problems that were formed. The two groups did not differ in the number of correct answers, accuracy, or completeness of the problem representations formed. Low spatial ability students made more structural errors than high spatial ability students. Low spatial ability students were less likely to balance equations, evaluate for a limiting reagent, or use information generated in a previous step. The groups did not differ in their ability to organize information. The author concluded that, in terms of the information processing model for problem solving, there were no differences in the performance of low and high spatial ability students.

How do students solve problems?

Ingebretsen used protocol analysis to explore how students in an introductory college physics course designed a laboratory experiment. He concluded that all students used a means-end analysis to designing their experiments. Students with more physics knowledge and experimental skills and students who had at least one calculus course were better at designing an experiment than students without this background.

Experts and novices differ in the way they solve problems. **Camacho and Good** observed 13 novices and 10 experts engaged in solving 7 chemical equilibrium problems. They examined specific problem solving knowledge, the number of problems that were correct or partially correct, and general problem solving characteristics. They concluded that problem solving is a continuum. There are not sharp differences between success and failure; some novices exhibit expert-like behavior some time. Experts and novices differ in their perception of the problem. Experts see problems as requiring careful analysis and reasoning. Novices see problems as tasks which can be solved in one or two steps. Experts used more and better heuristics, exhibited greater flexibility, had more accurate chemical knowledge, and were able to develop a qualitative representation of the problem. Novices relied on poorly remembered formulae, lacked basic chemistry knowledge such as the translation of chemical symbols from English, and had a superficial level of problem representation. Novices were more careless and did not cross check their solutions.

What kinds of interventions have been successful in enhancing students' problem solving abilities?

Crespo compared the relative effectiveness of two approaches of problem solving in a first year college biology course. He analyzed interview protocols of eight students using cognitive and heuristic approaches to solving four genetics problems. Protocol analysis indicated that the heuristic approach induced more recognizable patterns of thinking than the cognitive approach. The most frequently used patterns were developing concepts, formulating questions, affective responses, and identifying and using criteria. Developing concepts was the most frequently used pattern for both the cognitive and the heuristics approach. Some thinking patterns were exclusive to a particular approach. For example, grasping whole-part/part-whole connections, and working with consistency and contradiction were used only in the cognitive approach. Considering all phases of the problem and looking for informal fallacies appeared only when the heuristics approach was used. Neither approach was successful in ind.icing drawing inferences from hypothetical syllogisms or recognizing differences of perspective. The number of errors did not differ significantly between approaches.

Another approach to problem solving was explored by **Dumas and Caillot**. They developed cognitive aids to guide students through the process of problem elaboration by using intermediate representations. The four cognitive aids were: (1) goal analysis, which requires students to transform the problem into a physics descriptor; (2) motion analysis, which requires the study of the motion of all bodies involved in the problem to create a kinetic representation; (3) event strip, which is a temporal analysis similar to a series of snapshots; and (4) body interaction diagram, which represents the interactions of all bodies involved in the problem. The cognitive aids were taught to students in two formats. The first format presented the aids in specific training sessions separate from the students' physics class. The second format integrated the aids into the daily physics class. In the first format, students learned the cognitive aids but their ability to solve physics problems was not affected. In the second format, the students learned the cognitive aids and were more successful in solving physics problems. Their problem representations moved from qualitative representations to formalized physics conceptions. The authors take this as evidence that the aids had become part of the students' metacognitive structures.

An intervention in analytical problem solving was the focus of a study by **McMurray**. Forty-seven biology students participated in the study. The intervention consisted of 23 problems to be solved as homework. Students were required to solve at least 12 of the problems over a 12 week period. The Watson-Glaser Critical Thinking Appraisal, Form A, was given as a pre and post test as a measure of critical thinking. A test of Critical Thinking in Biology was created and also given as a post test. In addition, cognitive style was determined by the Group Embedded Figures Test. The assigned problems did not effect the critical thinking of students. The author concluded that effective interventions must be extensive, intensive and integrated into a content course.

Lawrenz and Orton explored the critical thinking instructional strategies used by science and mathematics teachers. Their survey data led them to conclude that because of differences in instructional strategies different thinking skills were encouraged. Science teachers were more likely to encourage diversity in student thinking through the relevancy of content and the use of manipulatives. Math teachers were more likely to encourage the application of problem solving skills in complex situations because of their focus on the nature of problem solving.

Yore and Russo, in a philosophical piece, explored what we should do to teach thinking in a meaningful way. They reviewed research in a variety of scholarly areas including skills research, metacognition, constructivism, and scientific inquiry. They concluded that we must start to teach thinking in the earliest grades. However, it can not be taught as something separate from content. Rather it must be taught in the context of a variety of content. This implies that teachers must have total mastery of their subject so that they can be free to concentrate on teaching thinking. They recommended a holistic approach that integrates all of the processes and teaches them simultaneously. They concluded that convergent programs have been more successful than divergent programs.

Summary

On the whole, cognitive style has not been a very powerful mechanism for explaining differences in science achievement. Field dependence/independence and locus of control have been shown to correlate with achievement but the phenomena are not robust. This is good news for educators because it indicates that students with many different cognitive styles can be successful in science. However, by ruling out cognitive style we are forced to look elsewhere for factors that influence learning.

Logical reasoning seemed to play a large role in the learning of science. It was a correlate of successful graph creation and problem solving in a number of contexts. The pervasiveness of logical reasoning to success in science may indicate that it is the essence of science or to put it another way, scientific activities are logical reasoning activities.

Culture did not affect reasoning, but context did. All people are capable of logical reasoning. However, factors such as familiarity with the task, the number of hours studying science, or interviewer effects may result in differences among groups. Researchers should be especially sensitive to context effects because they can lead to incorrect conclusions about the intrinsic abilities of groups, conclusions which are really the result of poorly designed studies.

Although decision making as part of the curriculum makes good sense on a philosophical level, the actual implementation was problematic. Before we can include decision making in the curriculum we need a better understanding of the mechanisms of the process in actual classroom situations. So far this has eluded us and remains an important area for further research.

Poor spatial ability has often been cited as a reason for the low number of women in science, however, this deficit theory was not borne out by the research. In addition, other studies showed that instruction that included visual learning has been successful in enhancing performance for males and females in elementary school populations.

Information processing models are providing a framework in which science education research can be embedded. In some cases they provide models to be tested and in others provide explanatory mechanisms for student performance. More work needs to be done in this area before we can make generalizations or come to any reasonable conclusions about which models are more appropriate for science education in terms of their fruitfulness and explanatory power.

As our research base in problem solving increases, we continue to affirm the importance of prior knowledge for success. However, we now also know that the differences between experts and novices is not so much a laundry list of what experts can do and novices can not do. Rather, we now see that problem solving is a continuum of skills and that some novices can exhibit skills that are characteristic of experts. This suggests that further research should focus on shared characteristics of experts and novices as well as distinct characteristics.

Interventions that enhanced problem solving have a common characteristic. That is, the problem solving skills were taught within the context of content. Approaches that divorced content from skills were less successful in bring about changes. In addition, successful interventions took place over a long period of time so that students had opportunities to test and practice their skills. Differences in interventions such as heuristic or cognitive instruction may result in the students' acquiring different skills.

COMPUTERS

How do teachers use computers as an instructional tool?

ENLIST Micros is a program developed by BSCS to increase the number of teachers using computers in their classrooms. **Baird, Ellis and Kuerbis** evaluated the effectiveness of an ENLIST Micros workshop for 47 K-12 teachers to effect this change. A post workshop survey indicated that 85% of the participants believed that the workshop had met the objectives of software evaluation, computer literacy, applications, and attitude development. The materials were neither too simple nor too hard and teachers would recommend the workshop to others. Changes in pre to post workshop assessments indicated that the participants had increased their knowledge and skills and felt more positive about computers. Although 88% of the teachers had computers available to them, only 33% used computers one year after the workshop and only 42% said that they used the skills gained at the workshop to train others. The main barriers to using computers were lack of money for software and supplies and lack of time to prepare. The authors concluded that it was easier to change attitudes toward computers than behavior.

Wigmore used the research on innovation to examine the way computers are used by secondary science teachers. He focused on teacher characteristics (age, sex, years teaching, education, sense of efficacy), training in computer use, administrative and district support and incentives, teacher participation in planning for the instructional use of computers, and interactions with colleagues. The 18 teachers in the study were selected because they had excellent reputations for using the computer in their science classrooms. **Wigmore** concluded that the teacher who used the computer as an instructional tool is male, over 40 years old, and has his own microcomputer. He is self taught and has acquired instructional strategies for using the computer through university courses and inservice workshops. He has a Master's degree, 16 years of teaching experience, and uses the computer to teach chemistry and physics. He has a positive sense of efficacy, one of the characteristics of people willing to try innovations. He also concluded that computer use can be increased by decreasing class size, increasing the number of computers in the classroom, and providing more release time for teachers to learn about computers and to plan instruction.

Prelle and Hiatt also examined computer use among high school teachers. They sent surveys to physics teachers who were members of the American Physics Teacher Association. Three hundred and nineteen teachers returned the surveys (79.8%). Conclusions about instruction drawn from the survey were: (1) that, although the teachers had on average seven years of computer experience, the quality of the experience was questionable, (2) the number of computers available was not sufficient to support instructional needs; (3) the number and type of computers restricted the selection of applications; and (4) teachers wanted to use the computers more often. Teachers were constrained in their use of computers by the lack of funds available to purchase software and additional computers and the availability of computers. Two thirds of the teachers were aware of the role of computers in physics instruction, but less than one third were concerned about issues related to the impact of computers upon students.

Other nations have also begun to use computers as an instructional tool. **Stogryn** examined this phenomenon by comparing the use of computers in universities in the United States and Japan. He concluded that computers are used more often and more frequently as an instructional tool in the United States than in Japan. Software was abundant and inexpensive in Japan but lacked the variety found in the United States. Neither country took advantage of computer graphics in instruction. Although the sample was small, only one university in the United States and nine in Japan, the conclusions reflect known differences in the two educational systems.

At the university level, **Zain** examined the current use of computers in introductory physics courses and the factors that encouraged or inhibited computer use. Data were collected at four universities through formal and informal interviews, classroom observations, and documents analysis. From the data **Zain** concluded that computers were used as a tool to gather and analyze data in laboratory work. However, even in this setting their use was limited.

How does instruction that employs computers affect attitude toward science and learning?

Leonard compared the reactions of students who had received biology instruction by traditional methods and by a videodisc delivery system. Student responses to a questionnaire indicated that students were more positive about the videodisc instruction than the traditional method. Videodisc students reported that their time was spent more efficiently, they paid more attention to the instruction, they understood the results of experiments better, and they were more confident following instruction than students in the traditional biology course. Videodisc students were also more satisfied with what they had learned than students in the traditional course. There were no significant differences in the two instructional formats in boredom, confusion, general interest in the lesson, or a change in attitude toward science. Neither format was superior in affecting students' confidence in conducting experiments, helping to understand difficult material, or making exams easier. Students in the videodisc format also had some concerns about the use of videodisc which they expressed in response to open ended questions. They felt that the videodiscs images were not real. This was an advantage when making mistakes but the videodisc approach did not help students gain skills in handling materials and equipment.

In another study of biology, **Hounshell and Stanford** compared the effect of microcomputers on attitude and achievement. One group of 76 high school students were enrolled in a biology course that used the computer to expand and supplement a traditional biology course. Computer simulations were used 60% of class time and 70 - 80 % of laboratory time. The control group, 126 students, received the same biology instruction without computer enrichment. Attitude and achievement were assessed using a comprehensive test of basic skills, a researcher developed instrument of attitude toward the science course, and the Science Attitude Inventory. The authors concluded that the students in the computer enhanced biology class did significantly better on the test of basic skills and had more positive attitudes toward the science course than students in the traditional biology course. On the other hand, the students in the traditional biology course had a more positive attitude toward science than the students in the computer enhanced biology course.

Huthaifi also compared attitudes toward computers in two instructional conditions. He compared the attitudes of 27 male preservice science teachers in Saudi Arabia who had received instruction on computer literacy in either a hands-on format or through a lecture presentation. A third group served as a control. Attitude was assessed by The Computer Anxiety Index. Using analysis of variance, the author concluded that the hands-on approach was more effective for improving attitudes toward computers than either the lecture or no intervention.

Computer aided instruction is infinitely patient, allowing students repeated trials with explanatory feedback. Myers examined this aspect of CAI on the achievement, retention, and attitudes of less successful secondary science students. One hundred and eighty-four students were randomly assigned to one of four treatment groups for the intervention. All CAI programs were tutorial and the content was from the life sciences. All treatments received positive feedback for correct results. Treatments varied in feedback for incorrect responses. Group 1 received no additional feedback. Group 2 received feedback that allowed them to try again if their original answer was incorrect. Group 3 received feedback that explained why the answer was correct or incorrect. Group 4 received both feedback that allowed them to try again and explanations concerning their answers. Students were given an attitude and content pretest, a content posttest and a delayed post test for content to measure retention. Multiple analysis of variance was performed for achievement, retention and attitude by group, sex and ability level. The author concluded that trial repetition and explanatory feedback did not have a significant effect in facilitating achievement, retention, or positive attitudes toward science and computers among this sample of less able students.

Savenye evaluated the effectiveness of interactive videodiscs in a year long pilot program on attitude and achievement. The videodiscs were used in 12 school districts with 26 science teachers and 2,560 students. The videodiscs were embedded in a curriculum that also included traditional labs, paper and pencil activities, teacher demonstrations, computer games, and teacher and student guides. A variety of grouping strategies was used with the videodiscs. Analysis of the data for attitude and achievement indicates that a curriculum that uses videodiscs as an instructional tool along with more traditional strategies can improve achievement scores, especially for low ability students, and can improve attitudes toward science. Students enrolled in the classrooms in which the videodiscs were used intended to take more elective science courses than students enrolled in traditional science courses.In addition, teachers liked using the curriculum and found it easier to teach.

Software graphics vary in levels of visual elaboration. To determine the effects of software graphics on childrens' understanding of Newton's laws of motion, **Rieber** selected three forms of elaboration. Software with static graphics, animated graphics and no graphics were presented to students under two conditions of practice. Behavioral practice consisted of five multiple choice questions presented to the children after each of four lessons. Cognitive practice consisted of a structured simulation in which students were given increasing control over an animated starship. The control group received no practice. The author concluded that lower order objectives were easier to learn than higher order objectives regardless of type of animation or practice. Presentation and practice had no effect on attitude. Students using animated graphics learned more than students in the other two graphics conditions. Children with behavioral practice and animated graphics outperformed students in any other combination of graphic presentation and practice conditions.

Reiber, Boyce and Assah replicated their study of graphics and practice with a sample of adults. In this study, there was no effect of graphics on learning. Both types of practice were found to be more effective than no practice but there was no difference in achievement for either type of practice. Cognitive practice interfered with learning when paired with animated graphics. Practice had a greater effect on learning when paired with static graphics or when there were no graphics than when paired with animated graphics.

Computers have also been used to help students understand science texts. **Gillingham, Garner, Guthrie and Sawyer** studied how 30 fifth grade students used three types of microcomputer-based reading assistance programs when reading a computer presented science text. The first kind of assistance consisted of a prompt telling students to reread important parts of the text. The second kind of assistance consisted of a prompt and a list of specific forms of help available such as definitions or background information. The third kind of assistance consisted of a prompt and a prescription of the kind of assistance the student needed. The assessment was a synthesis question presented to the students before they read the 150 word text and which they were to answer after reading the text. The authors concluded that the prescribed assistance was more effective in promoting understanding than the other two forms of assistance. Whether or not students chose definitions and background information predicted the results on the question. Providing assistance did not guarantee that it would be used.

Mikulecky, Clark and Adams, studied the effectiveness of computer aided instruction to teach reading strategies to university students. Fifty biology student were assigned to either a control or treatment group. The treatment group read a text about embryos and blood and three lessons on reading strategies and embryos presented by computer. The control group read the same text about embryos and blood. Assessment consisted of the number and kinds of reading strategies used, knowledge of key concepts, and attitude. Students in the treatment group performed better than students in the control group for knowledge of embryos and blood. The authors concluded that the reading strategies learned in the context of the embryo lesson were transferred to reading the blood text. Students in the treatment group were better at identifying key concepts, using reading strategies of linking summary statements which compared and contrasted key concepts and graphically mapping relationships among key concepts. Students in the treatment group also liked computers better than students in the control group.

In another study with university students, **Milkent and Roth** examined the effect of computer-generated homework on student achievement. Seventy-eight students in a general physical science course were assigned to either a computer generated homework group or a written homework group. Assessment consisted of pre and posttests of knowledge. Additional information concerning GPA, ACT composite, and ACT mathematics and science scores were also collected. Students in the computer generated homework group were allowed to do the assignments as often as they wished, and the highest grade was recorded. Students in the written homework group did the assignments once. The authors concluded that the computer generated homework reduced the effect of ACT scores as predictors of achievement by compensating for initial differences in students. They believed that their study supports mastery learning.

Wainwright evaluated the effects of using a chemistry software package as a supplement to instruction in general high school chemistry. She also examined the effect of the supplemental software on developmental stage. The assessment consisted of the General Chemistry Test and Chemical Formulas Quiz. The software provides immediate feedback and freezes formulas so that students can not change subscripts or chemical species. Students in the control group received the same chemistry instruction and supplemental worksheets. Analysis of the assessments of chemistry knowledge indicated that there was no difference in the control and supplemental groups. Teachers indicated that students needed more direction to use the computer software. The author concluded that the assessment was similar to the worksheets used in the control group which may account for no differences between groups.

Wood evaluated the effectiveness of a computer based physics course, Introduction to Modern Electronics. Sequencing and the use of supplemental materials were investigated. Assessment was based on class quizzes. Material was presented in either a general to specific or a specific to general sequence. Sequencing had no effect on class quizzes. Students in the general to specific group spent, on average, five minutes less per session than students in the specific to general group. Simulations were presented before and after the analysis of a circuit. There were no differences in class quizzes or time spent per session. However, students took different paths through the lesson depending upon the order of presentation of materials.

Meli investigated the effect of supplemental computer instruction in high school physics classes. He compared the level of achievement in two instructional formats. In addition, he looked at gender differences and computer use outside the classroom. In one classroom, students used computers for the first half of a period and received traditional instruction for the second half of a period. In the second classroom, students received traditional instruction. The author reported that there was no difference between groups for understanding and applying physics concepts. There was no difference in achievement between students who had access to computers outside of the classroom for two hours or less a week and those who did not. **Meli** concluded that lecture can be reduced by as much as half and replaced with computer-aided instruction with no decline in achievement.

The effect of simulations on electrical awareness was the focus of **Rosner's** study of sixth through ninth grade students. He was interested in determining whether there were grade level effects, the amount of time needed to complete the simulations, and student-computer interactions. Two hundred and ninety-two students worked through a simulation about home electricity use and supplying a town with electricity from power plants. All students were given a pre and post knowledge test and a post simulation questionnaire to assess attitudes. Analysis of variance led the author to conclude that content learning improved with grade level. However, although statistically significant, the amount learned in sixth and seventh grade was not educationally significant. One or two periods of computer time was insufficient to allow most students to gain proficiency in operating the simulations and to develop strategies to successfully complete the simulations. Students enjoyed working in groups and the group work fostered the development of strategies.

Kinzie and Sullivan investigated the effects of learner control and program control on achievement and motivation among high school students. Students in the learner control condition were given the choice of reviewing portions of the program when they responded to questions incorrectly. In the program control condition, students automatically were presented with a review after responding to a question with a wrong answer. Sixty-four ninth and tenth grade students participated in the study. Assessment consisted of measures of achievement, motivation, and affect. There was no difference between treatment groups for content knowledge. Seventy-nine percent of the students in the learner control treatment chose to return to the learner control format for their next lesson. Nineteen percent of the students in the program control treatment chose to return to the program control format for their next lesson. Students preferred to study science over any other subject when it was presented by computer. Students preferred to study other subjects rather than science when presentation was traditional. Students who were given a choice of studying science or another subject presented by computer chose science.

How should one go about developing instructionally sound programs?

MENDEL is a software program developed for solving genetics problems. **Stewart, Streibel, Collins and Jungck** developed the program to generate problems, provide models, and provide tutoring based on individual student misconceptions. The program has four main components. The Problem Generator simulates the transmission of genetics phenomena and creates organisms with a variety of traits. It fosters the creation of hypotheses and provides a mechanism to check data. The Problem Solver provides models of experts solving genetics problems and provides opportunities to make inferences from phenotypic data. The Tutor provides the user with tutoring and was developed to include human tutoring characteristics. The student modeler and Advisor models novice problem solving and collects misconceptions of students so that they can be used by the Tutor to provide additional instruction.

Hofmeister, Englemann and Carnine reviewed the research on the development of videodiscs to bring about changes in attitude and promote learning. They concluded that good videodisc development should (1) avoid knowledge fragmentation, (2) emphasize instruction clarity and avoid vagueness, (3) attend to instructional sequencing, and (4) be explicit about the role of the teacher. Based on these principles they developed a videodisc to teach physical science concepts to difficult students. Fifteen learning disabled and remedial students participated in the field testing of the videodisc and were subsequently tested for knowledge acquisition. Data analysis indicated that the students in the videodisc treatment did as well on the achievement test as second year advanced placement chemistry students.

What kinds of programs exist that foster problem solving?

Some students may be unsuccessful problem solvers because they initiate procedures before fully understanding the problem. **Kinnear and Martin** developed a computer program that structures the process of problem solving and prevents premature implementation. Eight students who were unsuccessful at solving college genetics problems were presented with problems in two formats. In the first format, two problems were to be attempted using paper and pencil. In the second format, two problems were presented by computer. The data in the problems were not fully explicated and students were required to use inferences. Students were tape recorded and they engaged in think aloud procedures while attempting to solve the problem. Analysis of the protocols indicated that the computer provided structure that did not allow attempts to solve the problems until the students had acquired sufficient knowledge to proceed. The students in the computer format were better than students in the paper and pencil format in their ability to analyze problems, underline key phrases, and make diagrams. Difficulties in getting started on a problem were due to inappropriate or missing declarative knowledge and failure to access or use knowledge.

Apex is a computer based model to foster problem solving created by **Kook**. The model helps students translate problems presented in terms of informal real world objects into formal abstractions. The problem is presented as a data connection network. To help move from the informal to the formal representation, students are introduced to the notion of view which supports multiple representations, i.e., viewing many objects as a single canonical object.

Brna developed a computer program called rockets to help teachers predict students' problems in Newtonian physics. The program is similar to Target using Dynaturtle but has an additional component of programming using LOGO. He tested the effectiveness of the program to provide insights into students' decision making by examining the choices students made. He concluded that the program was helpful in predicting students' problems in some situations. The programming language was too close to machine language and not at a high enough level to be useful to teachers. The program did not guarantee that students with non-Newtonian beliefs would alter them as a result of their experience. The students' decisions while using the program did not provide this information.

What kinds of programs exist to foster the acquisition of process skills?

Vensel evaluated the effectiveness of a computer simulation to foster science process skills among a sample of fourth and fifth grade students. Four hundred and seventy-five students were in the treatment group, of whom 89 were gifted. One hundred and forty-two students were in the control group. The treatment consisted of simulations which were a supplement to regular science instruction. The control group received regular instruction. All students were pre and posttested using the Test of Basic Process Skills. Regression analysis indicated that group membership, giftedness, and hours of simulation experience predicted post test scores. However, the explained variance was only 3%.

Microcomputer Based Lab (MBL) has a skills development module that is intended to teach scientific reasoning skills. **Friedler, Nachmias and Songer** studied the effectiveness of this module to enhance reasoning in a group of 250 eighth grade students. The module was embedded in 16 weeks of science activities using computer and traditional modes of instruction. They concluded that using the module brought about an improvement in the ability to plan, control variables, design experiments, make observations, distinguish between observations and inferences, make predictions and justify them on the basis of experiments. However, the novelty of the context had an initial negative effect on students' ability to reason. Students did poorly on the first activity of each new type of experiment.

Beichner investigated the effect of a video-graphic technique which did not provide kinesthetic feedback for motion problems. Graph production was synchronized with animation so that students saw a moving object and its kinematics graph simultaneously. The author developed his own assessment for graph interpretation. Error analysis of high school and college students' performance on the assessment indicated that students conceptualized graphs as pictures, and had slope-height confusion. Students also had difficulty with interpreting areas under the graph and calculating slopes of line segments that did not pass through the origin.

Graph construction and reasoning skills used in producing free-hand and computer-assisted graphs were the focii of a nine month descriptive study. **Bohren** observed 30 ninth grade students involved in graphing activities in algebra, science, social studies, and English. She pre and posttested the students using The Group Assessment of Logical Thinking, the Test of Graphing Skills, and a test of graph construction. She also interviewed students about their reasoning processes. **Bohren** concluded that software graphing utilities hide student misconceptions. Correctly constructed graphs led the teacher and student to believe that the student knew how graphs were constructed when this was not the case. Despite the fact that students could make correct graphs they did not understand that a graph is a mathematical representation of the relationship between two variables. Scaled axes were not recognized as ratios.

Summary

There seems to be more talk about teachers using computers than actual use. Most classroom settings contained many barriers that made it difficult for teachers to use computers even when they were philosophically in favor of them. Software availability was the biggest barrier to the use of computers in the classroom.

Instruction that employed computers had a generally positive effect on attitude. The effect on achievement was a bit more varied. It has been effective in enhancing text comprehension and bringing about improvements in basic skills but not higher level skills. In one study, homework assignments using computers were effective in reducing the differences in achievement of students with academic deficiencies and those without deficiencies. However, in another study, a CAI format did not affect attitude or achievement of less able students. Computer-aided instruction worked best when students had sufficient time to learn to use the computers and software and there was sufficient time to learn with the computer.

Instructionally sound software has many of the characteristics of a good lesson or curriculum. In addition, it should have some of the characteristics we associate with a master teacher, e.g., the ability to diagnose student errors and to design instruction to remediate the errors. Given these standards, most software, except for that designed for research purposes, is not instructionally sound. In addition, it suggests that the design of effective software is now out of the hands of teachers or others less well versed in computer language and architecture.

The most successful of two programs developed to aid problem solving was highly structured and had as the main feature a blocking mechanism that did not allow students to prematurely attempt problem solutions without sufficient knowledge to proceed.

CURRICULUM

What procedures are necessary to develop a curriculum and insure adoption?

Hardt conducted a case study of curriculum policy development. The intent of the policy development process was to involve teachers in policy making and deliberate inquiry which acknowledged the political nature of decision making. The process followed Walker's model of curriculum development in which a platform was developed and debated. Then, a proposal for curriculum design was developed based on the deliberations.

Proposals for curriculum change were developed and distributed to 337 teachers and science coordinators prior to a day long meeting. During the meeting, the proposals were debated and amended. **Hardt** concluded that the process married the development of curriculum based on research, philosophy, and theory with input from practitioners who would implement the curriculum. The process resulted in revisions that led to greater agreement between the policy makers and the policy implementers.

Blood and Zalewski examined efforts at curriculum reform in Illinois. They focused on the implementation of state goals for knowledge and vocabulary, science technology and society, the scientific enterprise and scientific processes. The vehicle for reforming the curriculum was a series of committees composed of teachers scattered throughout the state. An analysis of the proceedings and decisions of these committees indicated that teachers were not aware of the recent thrusts in science education such as science, technology, and society or the move to greater emphasis on application. Teachers were also unaware of the research on what and how to teach science. Lack of knowledge was a major stumbling block in this educational reform effort.

The Utah Elementary Science Improvement Project was a major effort to change the teacher preparation program at Utah State University. **Daugs** orchestrated this reform through the formation of an advisory board that helped establish the structure and content of the program. Participants on the advisory board included representatives from science departments, the school of education, a laboratory school, and public schools.

What are the roles of research, social issues and educational trends in the development of new curricula?

In Thailand, **Chandayot** was involved in the development of a model doctoral program for science education based on a study of programs in the United States. Data were collected from 23 universities in the United States and 6 in Thailand. Data analysis led the author to conclude that a quality doctoral program should develop in students: (1) respect for the dignity and worth of individuals, (2) a desire and capacity for critical thinking, (3) an appreciation and understanding of scholarship and creativity, (4) the ability to communicate, and (5) a continuing desire for knowledge. Admission requirements, residency, and hours of coursework mirrored the standard science education doctoral program in the United States.

Gifted and talented students have different needs that are not met by acceleration or enrichment. After reviewing the research, **Hoover** concluded that a curriculum that met the needs of the gifted provided opportunities to: (1) acquire a technical vocabulary, (2) represent data quantitatively, (3) add to the knowledge base, (4) question, (5) solve individual problems, (6) make models, and (7) acquire and order symbol systems. He cited the Purdue three-stage model as an example of a curriculum that included these characteristics. In the first stage of the model, students engaged in activities that develop convergent and divergent thinking. The second stage of the model focused on the acquisition of creative problem solving. The third stage of the model provided opportunities for students to pursue research in areas of interest.

The importance of play has always been part of the philosophical underpinnings of early childhood and lower elementary curriculum but is rarely, if ever addressed, in curriculum developed for older students. **Von Aufshraiter and Schwedes** took the position that playing and gaming were significant for cognitive and social development in older students as well. Consequently, they developed a physics curriculum for students ages 9 through 15 based on the importance of play. In addition, they included components that addressed the relationship between personal action and reasoning, i. e., the importance of choosing one's own experiences and the sphere of subjective experience, i.e., the notion that all experiences are considered important by the individual. The curriculum was field tested with 900 students and 32 teachers. The authors concluded that a play oriented curriculum was better than a traditional curriculum for fostering development in the cognitive domain. Students learned more by themselves through their own actions and both students and teachers preferred the play oriented curriculum. There were two drawbacks. Changes in the teachers' role caused adjustment difficulties for some. Sometimes the curriculum provided too little direction for weak students.

Pizzini and Shepardson developed a problem solving curriculum based on the research in cognitive science and problem solving. They called it the SSCS model (Search, Solve, Create, and Share). The Search phase focused on brainstorming and idea generating activities. The purpose of this component was to identify researchable questions and relate science concepts in the problem to the students' own science concept knowledge. The purpose of Solve was to generate plans and reorganize the concepts identified in the Search phase. Students attempted solutions to their problems and could reenter the Search phase. In the Create phase, students created a product that related to the problem/solution generated in the earlier phases. Students conducted their own self-evaluation of their product. The last phase was Share. In this phase students received feedback, evaluated their solutions, and generated potential questions for a new Search phase.

Persuading people to change their beliefs and behaviors about the environment is one of the goals of environmental education. However, we have not always been successful in teaching students to be more caring and concerned about their environment. **Koballa**, using Ajzen and Fishbein's theory, developed strategies to construct a persuasive message to encourage students to practice energy conservation. He used preservice elementary teachers to help him identify a target audience, content of the message, and the desired behavior resulting from the message. He then generated a list of salient beliefs using the information obtained in the preceding steps and selected those to be used in the message. The message was then designed and validated with a sample of graduate students. Chi square analysis indicated that the graduate students believed that the arguments for salient beliefs were present in the message and supported the desired behavior. Koballa believes that the next step is to determine whether persuasive messages actually changed behavior.

Oyeneyin proposed a model of teaching which he called Intellectual Skills Coordination Controls in Teaching (ISCONT). He arrived at his model by surveying 395 teachers on the importance of 38 intellectual skills. The skills were effective ways to gain and keep students' attention during instruction. Factor analysis of the data revealed five factors for the model. These factors were the components of the ISCONT. The factors were knowledge, manipulative/perceptual, cognitive, evaluative/quality, and administrative/personality controls. How individuals vary on these factors determines their effectiveness in gaining and keeping students' attention.

In response to the concerns of students that science is irrelevant to their lives, **Moore** contrasted instruction in genetics using traditional examples to instruction using human examples. Eighty ninth grade biology students were assigned to the two instructional groups. Students were given pre, post, and delayed posttests on genetics concepts and misconceptions. They were also assessed for cognitive growth from concrete to formal thought with a written test. Students in the instructional group that used human examples acquired and retained more correct genetics concepts and fewer misconceptions than students who were instructed using traditional examples. Movement from concrete to formal thought was not differentially affected by instructional approaches.

Another attempt to bring relevance to science instruction and broaden the appeal of science was the development of a multidisciplinary marine science course for students in grades 9 through 12. **Jordan** based his curriculum on the Tyler and Taba models and he emphasized experiences based on learner interest. Goals and content were established by determining: (1) developmental level of the students, (2) societal needs and concerns, and (3) scope of the subject. The curriculum was validated by a panel of experts consisting of marine science teachers and professors. The implementation required teacher reeducation; purchasing of materials and equipment; and a reorganization of secondary science instruction.

Rosenthal discussed two approaches for teaching science, technology, and society. The first approach was science policy studies which was issues oriented. The second approach was the social studies of science which is the study of science from the perspective of other disciplines. **Rosenthal** stated that the recognition of the two approaches is necessary for consensus within the field of science, technology, and society. He also stated that this recognition will lead to a clarification of the relationship of science, technology, and society and science education. He argued for a synthesis approach which would overcome the disadvantages inherent in a single approach.

Doswell explored the extent to which industrial influences have penetrated the classroom. She was concerned with the effects of recession, unemployment, industrial needs in terms of knowledge, skills and attitudes, and technological change on classroom practices and curriculum. In particular, she was interested in the relationship of policy as generated by various interest groups and organizations and actual implementation. She concluded that industrial influence occurred at the level of curriculum but that the impact on actual classroom practice was limited.

Ahearn was concerned with the development of a curriculum that focused on biological diversity as a way to preserve diversity. To create the curriculum, Ahearn conducted a needs assessment which consisted of: (1) a survey and checklist of land management and education/interpretive practices throughout the United States, (2) a study of ecological research, (3) interviews with scientists, land managers and educators, and (4) an analysis of published environmental curricula and activities. The data from this assessment were used to select six topics: open space, marine resources, energy, solid waste, surface water, freshwater wetlands and groundwater. Activities were selected for these topics that focused on developing an understanding of biodiversity from habitat to landscape and the genetic level to the ecosystem.

What factors affect the implementation of curricula?

South Carolina elementary teachers were surveyed to determine: (1) how well their perceptions of science instruction matched the recommendations of the National Science Teachers association, Project Synthesis, and South Carolina's Basic Skills Assessment Program for Science, and (2) to identify reasons for levels of congruence. **Carter's** survey focused on goals, curriculum guides, amount of daily instruction and type of preservice and inservice training of teachers. He concluded that teachers should include more career awareness, field trips and laboratory activities in their instruction. Instructional techniques showed the least congruence with recommended practice. On the other hand, teachers respected the natural curiosity of children and their individual needs and spent more than the recommended 30 minutes per day in science instruction. Impediments to implementing good practice included poor background in earth and physical science, the low number of teachers who were members of national or local science teachers associations and teacher preparation in science methods.

Ellis surveyed biology teachers in Indiana, Kentucky, and Tennessee to determine those factors that affected the teaching of evolution in their classrooms. Data from the surveys suggested that the majority of teachers place only moderate emphasis on the theory of evolution. This resulted from trying to balance their teaching responsibilities, that mandate the teaching of evolution, with their own beliefs and the mores of the community. He concluded that many biology teachers are creationists.

In Indonesia, **Tanuputra** investigated the extent to which science process skills were included in lower secondary science curriculum. Lower secondary science students are 13 and 14 years old. He observed 25 classrooms and interviewed 42 teachers. Analysis of the data led **Tanuputra** to conclude that only a few teachers knew what kinds of activities and teaching strategies were appropriate to promote active student learning. Teachers relied heavily on worksheets and believed that more detailed worksheets or worksheets which included questions for students to think about would promote process skills. Most teachers were not confident about their ability to carry out hands-on science activities.

Gottfreid conducted a case study of textbook-centered and multiple reference biology classrooms to determine their alignment with the desired states of biology education proposed by Project Synthesis. Three textbook and three multiple reference classrooms were selected for study. Classroom profiles were developed. These profiles were then compared with the actual states and desired states descriptions of biology education. From the data, **Gottfried** concluded that textbook-centered classrooms aligned closely with the actual states of biology education while the multiple reference classrooms had approximately an equal number of characteristics of the desired states and actual states. Regardless of the classroom approach, teachers did not integrate desired state criteria into their evaluation of student performance. Factors other th‹ n textbook centered or multiple reference centered approaches aligned with the desired states. These factors included: (1) the goals the teacher used to guide the curriculum, (2) the variety of classroom activities, and (3) the teacher's commitment tc professional and curriculum development activities.

The Science Curriculum Improvement Study (SCIS) curriculum has been available to teachers as an alternative to traditional teaching for a long time. Yet, few teachers have been seduced by this approach. **Atwood and Howard** explored the real and perceived barriers to the adoption of SCIS-II as expressed by the teachers themselves. The authors concluded that teachers for grades 3-6 perceived more barriers to effective instruction and had greater problems with management, equipment, and materials than did teachers of grades 1-2. Perception of barriers was related to the overall perception of the program. The principal stumbling block to the implementation of SCIS II was problems with living organisms. For example, animals and plants died and seeds did not germinate. Much to the authors' surprise, school size, years of teaching experience, the number of days of the week that science was scheduled to be taught, and classroom organization(self-contained or open) were not related to the perception of barriers.

Dunn investigated the factors that affected the implementation of a new elementary science curriculum in a single school district. Forty-five teachers participated in this study and responded to six questionnaires designed to identify factors that affected implementation. Analysis of the responses to the questionnaires led the author to conclude that teachers have many concerns during the implementation of a new curriculum, but that these concerns change during the implementation period. Teachers perceived lack of time, materials and opportunities to share ideas as the major barriers to implementation. Teacher skill level did not affect implementation. Several factors were identified that facilitated implementation. These factors were: (1) the teacher's perception that there was enough time for instruction, (2) textbooks and curriculum guides, and (3) inservice activities. Neither the perceived supports nor barriers were found to significantly affect the implementation of the curriculum.

Nineteen middle/junior high school science teachers attending a science institute were studied to determine the factors that would help or hinder them from serving as resources in their home districts. The institute was established to train teachers to help their colleagues who were out of date or teaching out of field to acquire the necessary knowledge and skills to be more effective. **Swift** investigated the following factors: (1) the participants sense of efficacy to perform various skills and to teach others to perform these same skills, (2) prior leadership experience, (3) professional socialization, (4) years of experience, (5) motivation for attending the institute, (6) knowledge of the desired outcomes of the institute, (7) undergraduate major and/or minor, and (8) institutional/administrative support. Data were gathered using interviews of participants and their principals and pre, post and delayed post institute questionnaires. Data were analyzed quantitatively and qualitatively. The author concluded that four factors affected implementation. Factor one was institutional/administrative support to carry out teacher training in the home districts. Factor two was the teacher's sense of efficacy regarding his/her ability to coach other teachers. Factor three was both the intrinsic and extrinsic motivation of the teachers for attending the institute. Factor four was the teacher's prior experience conducting workshops.

Singham investigated the differences between the intended and actual implementation of science process skills in the Primary Science Project (PSP) in Singapore. She collected her data using classroom observations, video tapes of children engaged in science activities, teacher interviews and questionnaires. From these data, **Singham** concluded that teachers understood the objectives of the curriculum to be hands-on and activity oriented. However, only a few process skills were being practiced. Teachers did not differentiate skills across grade levels and the objective of integrated skills for older students was not being carried out. Teachers had not learned how to vary the emphasis of different skills from lesson to lesson in response to differences in activities. Teachers had a set approach and did not vary their teaching to encourage process skills acquisition.

Swain used the Concerns-Based Adoption Model to assess the success of the state-wide curriculum reform in Texas. The CBAM Stages of Concern Questionnaire was used to assess teachers' concerns and the Innovation Configuration checklist was used to assess the extent to which the activity -based, process science program was actually being used. The data indicated that teachers' concerns about implementing the science curriculum were focused on themselves. Teachers' concerns were personal and also related to their background knowledge. These concerns were stronger than their concerns about issues effecting students. Many areas of the curriculum were not implemented at the ideal level because teachers did not feel that they had the necessary support. The author recommended that the Concerns-Based Adoption Model be used to help develop implementation plans. This approach would identify potential problems before the introduction of a new curriculum rather than after the fact.

What does research in evaluation tell us about current curricula?

Fidler identified variables that would explain performance on the Michigan Educational Assessment Program (MEAP) science assessment. He compared science programs and community characteristics of schools that had done well on the assessment to those that had not. One hundred and three middle school principals were mailed surveys which asked about community and school science program characteristics. Questions were based on the criteria for excellence described in *Focus on Excellence*. The Department of Education provided additional information about schools and districts. The author concluded that socioeconomic status was the greatest predictor of student achievement. When the influence of socioeconomic status was controlled, years of science required and curriculum appropriateness explained the most variance in achievement scores. Reading and mathematics scores on the MEAP were highly correlated with science scores. Variables that discriminated best between low and high scoring schools were years of science required, academic preparation of teachers, and curriculum balance.

Doerhoff was concerned about the present approach to program assessment. He contended that traditional assessment has focused on observable states of the school that do not necessarily coincide with educational outcomes or advantages to students. His study identified variables that would allow the assessment of high school science programs that focus on the real purposes of education. He created a survey instrument based on research on educational outcomes. The instrument was then reviewed by teachers who responded to the relevance of the items as indicators of a successful science program. The instrument was then refined to reflect teacher responses. Twenty-one elements, grouped into five factors, were identified from this exercise as necessary for output evaluation. These factors were objectives, enrollments, initiative, care, and safety and test scores. The author concluded that these factors should now be used to build and test an evaluation instrument.

Miller investigated the level of scientific literacy among a sample of students from the United States and Great Britain using the National Assessment of Educational Progress and other large national data bases. His comparison revealed that the level of literacy in both countries is about the same; six percent in the United States and seven percent in Great Britain. Literacy in both countries was limited to understanding scientific processes, concepts, and terms. Students in Great Britain had a greater understanding of the impact of science on society. Miller then developed and tested a model to predict the level of scientific literacy. He found that employment, especially in scientific areas, college science courses, level of education and gender predicted literacy. Gender was an important variable because females were less scientifically literate than males. Age and high school science courses did not predict literacy.

Modularized Individual Instruction (MII) modules were developed and field tested by **Al-Gattan** in Kuwait. The MII approach was compared to traditional instruction. There were 246 students in the MII group and 251 students in the traditional group. Students were pre and posttested for achievement and attitude. Teachers and students in the MII group were asked to comment on the approach. **Al-Gattan** also made classroom observations. He concluded that the MII approach was more effective than the traditional approach in improving overall achievement. Neither approach was effective in bringing about favorable attitudes toward science.

Estrin and Lash evaluated Project OCEAN (Oceanic, Classroom Education and Networking); a teacher training and curriculum reform project. They found that the project was very effective in increasing the amount of science taught and in increasing teacher confidence in teaching marine science. Most important, they found that the project stimulated collegial behavior in all of the participating schools. Teachers reported that they shared materials and ideas, planned cooperatively, and worked with people who were not usually colleagues. Intrigued by this finding, they then attempted to identify those aspects of the project that would be responsible for the increase in collegiality. **Estrin and Lash** concluded that collegiality was fostered by a need to share materials, ideas and field trips; group planning and organization; and common school-wide activities and themes. The teacher training component also contributed because the teacher training was on the school site; activities and instructional strategies were modeled by experts; and the teachers had opportunities to publicly practice instruction with critiques and support from other teachers.

Science Quest was a locally developed curriculum designed to replace the textbook and worksheet oriented program with one that reflected the current goals in science education. The curriculum was built around selected Delta Science Modules. **Kyle, Bonstetter, Sedotti and Dvarskas** evaluated the curriculum after one year of implementation. They concluded that the curriculum was very successful. Between 50% and 80% of students indicated that science was their favorite or second favorite subject in school. There was no gender difference for attitude. When compared to a control group, students in Science Quest had better overall attitudes toward science. Students preferred the process inquiry approach to science and wished there was more time for science instruction. Students reported that science was fun, interesting, and exciting. They recognized that science was useful in their daily lives and would continue to be so in the future. Students felt curious and successful.

Krockover, Larry and Sinnett evaluated the effects of the Energy Education Curriculum as perceived by elementary and secondary teachers. They surveyed 232 K-12 teachers across the state of Indiana. Responses to their questionnaire indicated that, despite the lack of goals and objectives for energy in the local school curriculum, energy education was being taught. Teachers did not use the curriculum when there was not enough time in the day to teach or when there was not enough time to sift through the materials to adapt them to the local curriculum. Many teachers reported that the materials were not necessarily appropriate for the intended grade and ability levels. The most effective form of dissemination of this state-wide program was through inservice activities and conferences.

Hamilton examined the way information was organized in college courses to teach social issues raised by nuclear energy. He examined a variety of disciplines and concluded that the social sciences provided the organizational base for most courses. Courses emphasized moral responsibility and political choice. Syllabi emphasized technological, strategic, and historical factors.

A revision of the New York State Regents Physics Syllabus had not taken place in over 20 years. At the time of the last revision, the syllabus shifted from a subject-centered to an inquiry-centered curriculum. **Sentman** surveyed 106 physics teachers, professors, and scientists about the topics in the 1967 syllabus. They were given the option of leaving the topics as they were, modifying existing topics, deleting topics, or adding them. Most of the respondents favored retaining the present set of topics with modification. Few deletions were recommended. Respondents also recommended adding problem solving, lasers, and inquiry skills.

Meisel was concerned about graduate education and the need for teachers to be aware of science, technology, and society issues. Consequently, he examined graduate programs to determine what STS issues graduate level policy makers and science teachers believed should be included in graduate programs. Data were collected through questionnaires which asked the respondents to determine the importance of 71 STS issues. One hundred and thirty-five secondary teachers and 65 graduate faculty participated in the study. The data analysis indicated that both faculty and teachers believed that all 71 STS issues should be taught in graduate programs. However, both groups believed that only eight of the issues were actually being addressed in graduate programs.

Science, technology, and society is also the domain of junior high school curriculum.-**Wiesenmayer** evaluated the effectiveness of a seventh grade STS curriculum to meet the goals of STS content acquisition, life science content acquisition, and participation in social action on STS issues. Ten classrooms received instruction in STS and seven received life science instruction for 20 class periods. Before and after instruction, students completed the Actions Taken on Public Issues and Questions About Science and Technology assessments. Data were analyzed using a repeated measures ANOVA. The author concluded that the STS curriculum had a significant impact on increasing STS content knowledge and participation in social action but restricted the amount of life science content that students acquired.

Hood compared the scientific-discovery approach to traditional instruction in the areas of listening comprehension, vocabulary, and environmental skills. Ninety-six first grade students were placed in either a scientific-discovery or traditional instruction group. Both groups received two weekly lessons for approximately five months. The Metropolitan Readiness test was used as a covariate and the Stanford Achievement Test was used as a post test. The author concluded that there were no differences between the treatment and control group for listening comprehension and vocabulary. The group receiving the scientific-discovery instruction performed significantly better than the traditional group in science related skills.

Lipowich was concerned about the frequency of process skills in fourth grade in a school district identified as exemplary through the Search for Excellence in Science Education. The district used science units such as *Clay Boats* and *Small Things* as the curriculum. Units emphasized particular process skills. The author matched 12,680 student and teacher verbalizations collected from 12 schools to 16 process skills categories. Data were collected from observations and frequencies were classified by a computer. Frequencies were counted by class session, class, and instructional unit. The author concluded that process skills occurred 66.7% of the time. All skills were represented in the classrooms. The unit was a better predictor than class as to whether or not a class scored high or low on a particular skill.

Another look at exemplary programs focuses on teacher characteristics and student outcomes. **Brunkhorst** examined key teachers in 10 middle/junior high school science programs to determine how they might differ from teachers in other programs. Teachers responded to two questionnaires; one from the *Report of the National Survey of Science, Mathematics and Social Studies Education* and supplemental questions developed by **Brunkhorst**. She found that the teachers in exemplary programs were highly professional. They read journals and presented papers at professional meetings. They used a rich mix of instructional strategies and allowed students to actively explore. In addition, they were enthusiastic and felt well qualified. An examination of students in the exemplary programs indicated that their performance on the Iowa

Test of Basic Skills, Science Supplement; Science and Society questionnaire and the Preferences and Understandings assessment was also different from students in other programs. Students scored above the national norms on the Iowa Test (87th and 81st percentile). They had a positive attitude toward science and 48% of the students indicated that science was their first or second favorite course. Gender differences indicated that males outperformed females and had more positive attitudes than females.

What does the research say about the role of the laboratory in science instruction?

Research during the past decade on college science laboratory instruction was summarized by **Leonard**. He focused on the effects of specific laboratory teaching strategies on student achievement. He used a traditional literature review technique to come to the following conclusions. First, investigative approaches seemed to have an effect on student thinking. Newer and innovative approaches resulted in inductive thinking and use of process skills by students. Second, students acquired formal operational thought through concrete manipulative laboratory experiences. The more they were involved in laboratory work, the more they learned. Third, faculty were interested in computer based applications. These were, in some cases, more effective than traditional methods in bringing about learning. Fourth, productive laboratory instruction engaged students in inquiry, manipulation of apparatus, and simultaneously taught science concepts and processes. **Leonard** concluded that, overall, the laboratory was more effective in bringing about educational gains than traditional methods. However, he cautions that these gains may be attributed to the novelty effect.

Hudzik developed special laboratory activities to promote higher level thinking among college students enrolled in general chemistry. The activities focused on controlling variables, and proportional and correlational reasoning. Students engaged in nine thinking activities, three for each kind of reasoning, instead of the standard laboratory activities for general chemistry. Activites took place over a nine-week period. Before each set of activities, the instructor gave a demonstration which was to serve as an advance organizer. Students were tested for reasoning using the Classroom Test of Formal Operations, the Longeot test and an assessment developed by **Hudzik**. Pre test data from the Classroom Test of Formal Operations indicated that 71% of the students were transitional thinkers. Pre test data from the Longeot test indicated that 54% of the students were concrete thinkers. At the end of the intervention, 56% (Classroom Test) to 51% (Longeot test) were found to be formal thinkers. Repeated testing during the intervention with the researcher-made assessment indicated that student performance improved over time for all of the tasks, especially controlling variables.

In another study with college students, **Hall** compared a Biological Sciences Curriculum Study (BSCS) approach to laboratory activities to a more directive traditional approach. Sixty students were in the BSCS group and 59 students were in the traditional group. The BSCS approach emphasized process skills, concept development through questioning, and student discretion in how to go about conducting experiments. The traditional approach was prescriptive, highly structured and teacher-oriented. Students were assessed for changes in attitude, biology laboratory concepts, and the Group Assessment of Formal Reasoning (GALT). There were no differences in group means for attitude or formal reasoning. However, students in the BSCS group scored significantly better than the traditional group on the biology laboratory concepts test. The author concluded that a BSCS style laboratory approach can affect student learning.

In another study of the biology laboratory, **Leonard** compared the Extended Discretion Lab (ED) approach to guided inquiry based on the BSCS model. The ED approach gave students more discretion in decisions as a way to enhance learning. The activities provided students with a task to accomplish and a list of resources but did not provide a detailed list of laboratory behaviors. This approach had been used successfully with high school students to bring about learning but had not been tried with older students. Four hundred and sixty-seven non-major general biology students were placed in either of the two treatment groups. Criteria of success were lab exams, lab report scores and six lab quizzes. Analysis of the data indicated that there was no difference between groups for any of the criteria. However, students in the ED group felt that the work was challenging and like real science while the students in the guided inquiry group felt that the laboratory work was too easy. The author concluded that the study was not a true test of the effects of the ED approach because of instructor variance. The ED and guided inquiry courses were not different in implementation despite an attempt to monitor them.

Blakney-Richards also compared different approaches to laboratory instruction. In the first approach, students were enrolled in a community college course in medical laboratory technology which presented microorganisms by taxonomic method. In the second approach, microorganisms were presented by the anatomic method which helped instructors make connections with disease processes. Students were pretested and posttested for achievement. Statistical analysis revealed small differences which favored the anatomic approach. The author concluded that, although the gains were small, the ease of preparation and presentation of the content using the anatomic approach supported curricular change.

Veath also compared laboratory approaches. She was interested in the effect of traditional verification, prediction modified learning cycle and intermediate approach to bring about conceptual change in physics. The intermediate approach was more structured than the learning cycle approach and less structured than the traditional approach. The prediction modified learning cycle and intermediate approaches were based on students' preconceptions. Eighty students were pre and posttested for mechanics misconceptions, cognitive development, and process skills. Attitude toward physics and the laboratory experience were also assessed after instruction. One-way analysis of variance revealed that students in the prediction modified learning cycle and intermediate groups had greater conceptual change gains in understanding mechanics and had acquired more process skills than students in the traditional group. Attitudes were more positive in the prediction modified learning cycle group than in the other two groups. Level of cognitive development, process skills, and final course grade were not related to conceptual change.

Lehman surveyed 500 chemistry teachers and their students to determine perceptions of the advantages and disadvantages of high school chemistry laboratories. He found that they perceived the advantages to be in the affective, psychomotor, cognitive, and process domains. Disadvantages were concerns about time, expense, safety, management, and content of the activities.

Laboratory work is often viewed as a waste of time and money as well as a logistic and management problem for teachers. **Kirschner** developed a new rationale for laboratory work that he feels is more compelling than the present rationale that uses the laboratory to affirm scientific knowledge. He proposed that laboratory work should be used to introduce students to and to help them understand the structure of scientific knowledge. This includes skills such as observing, measuring, and planning as a complement to theory. He believed that the laboratory can be used to learn an academic approach to working as a scientist,i.e., problem solving. The laboratory should be an opportunity to practice learning to investigate. Finally, the laboratory should provide opportunities to experience phenomena so that students gain tacit knowledge of scientific phenomena in context.

How effective are zoos, museums and exhibits as an alternative to formal science instruction?

Bennett studied the effect of an exhibit interpreter to attract and focus the attention of visitors to a science museum. She filmed visitors at two museums in an exhibit area with and without an interpreter present. Each area was filmed once on a week day and once on a weekend. The tapes were then coded and analyzed using chi-square, analysis of variance, and a z-test for proportionality. The author concluded that the presence of an exhibit interpreter increased the amount of time spent in an exhibit area and increased the number of attending behaviors on week days and week ends.

Fourth grade students were introduced to the study of adaption of birds to coastal habitats. **Judd** was interested in the effect that novelty would have on learning and retention, so she varied both the setting and the degree of familiarity of the content. Instruction took place in either a classroom or a museum. Bird study skins were used that were novel, familiar, or that the students were introduced to vicariously. Twelve classes participated in the treatment and two classes acted as controls. Differences in the groups were controlled by an analysis of covariance using a vocabulary test as the covariate. The author designed her own knowledge test which was used as an immediate and delayed posttest. After instruction and data analysis, the author concluded that, in general, students learned the most when novelty was the highest. Students with the highest knowledge scores received their instruction in a museum after some form of familiarization with the museum and the bird skins. Four weeks later, the delayed posttest data indicated that only the novelty effect of museum instruction was affecting performance.

Another study examined the effectiveness of wildlife exhibits to convey information to high school students. **Adams,Thomas, Lin and Weiser** compared the wildlife knowledge of students in high schools where wildlife exhibits had been set up in display cases to the knowledge of students in high schools without displays. Four hundred and seventy-one students in biology were pretested for knowledge about 16 common mammals. Exhibits were chosen based on the pretest and presented mammals that were unfamiliar to the students. After the exhibits had been in place for five weeks, the students were posttested using the same knowledge test. The author concluded that the passive exhibits were successful in increasing student wildlife knowledge. However, 36% of the biology students in the schools with the wildlife exhibited were unaware of the exhibits.

Braverman and Yates studied the effect of enhancing a zoo visit with an orientation lecture/slide show or packet of readings. Subjects were 4-H agents attending a national conference. Both intervention groups and a control group were pretested for knowledge and attitude. The attitude measure consisted of attitude toward zoos, animals, and use of the zoo in 4-H activities. The authors concluded that the educational effectiveness of zoos can be enhanced by using either an orientation or a readings packet. Participants in these groups gained more knowledge from their zoo visit than participants in the control group. There was no difference in attitude posttests among the two intervention and control groups. This was due to a ceiling effect. All participants in the study had high attitude scores before the intervention.

Summary

Curriculum reform is a process that requires the participation of teachers and other constituents with a vested interest in the outcome in order to insure success. However, this process is inherently problematic in that many teachers are not aware of the direction of curriculum reform or of the research base on what and how to teach science. Consequently, successful reform that brings teachers into the process must also include an education component.

Curriculum development reflects the growing concern for problem solving; science, technology, and society; and gifted education. In these areas curriculum is being responsive to both social concerns and the research trends. Other development efforts are being responsive to the large body of research that points out the need for curriculum that is relevant to students and the role of play in development. I believe that recent curriculum development efforts which combined social issues and larger educational trends tempered with a firm grounding in research are indicative of the maturity of the field.

Even the best curriculum is useless if it is not implemented. Researchers have identified a number of barriers to the effective implementation of curriculum that cut across grade levels and nations. The biggest barriers are the teachers themselves. Poor content and pedagogical knowledge, professional participation, self-confidence, and commitment to the curriculum appear again and again in the research. In addition, religious beliefs interfere with teaching evolution. Factors extrinsic to the teacher such as management problems, problems with materials and equipment, and administrative support loom large.

Research on curriculum evaluation indicates that despite all we can do in developing good curricula, SES is still a potent factor in student achievement. However, we might get a different picture of the effectiveness of a curriculium if we increased our desired outcome variables beyond achievement scores. Many innovative and locally developed curricula have been quite successful in achieving their goals, be they process skills or increasing the amount of science taught. At the graduate level, teacher preparation has not caught up with trends in school curricula. Science, technology, and society is only a small part of the science education curriculum. The one area where we fall short is in scientific literacy. Despite the various approaches to develop literacy, citizens of the United States know very little beyond scientific processes.

Laboratory work does not bring about large gains in general achievement or reasoning, but it does provide students with laboratory skills. The problem in evaluating the role of the laboratory may lie in the choice of outcomes. If we want the laboratory to be a panacea for all educational ills in science, we are bound to be disappointed. However, if we view the laboratory as an opportunity to develop a feel for scientific phenomena in context and as a vehicle for students to develop a scientific frame of mind we may be more satisfied with the educational outcomes.

Using non traditional settings and formats for learning science is one of the most recent educational trends. In those areas where it has been tried, researchers have been very successful in getting people to learn from zoos, museums, and exhibits.

INSTRUCTION

What are the learning outcomes for cooperative grouping and how do teachers feel about using this strategy?

Jones and Steinbrink developed and tested the two-level small group model of cooperative learning with 50 inservice teachers. During the first year of the study, teachers attended a cooperative learning seminar before the beginning of a semester and then used cooperative learning techniques with their own students. At the end of the school semester, the teachers returned for an additional seminar where teachers discussed their work with cooperative learning, wrote reports, and analyzed student test score data. The majority of the teachers held favorable attitudes toward cooperative learning. However, there were numerous reservations. For example, teachers were not convinced that group learning increased test scores for all students. They found using team scores and gain scores difficult to implement and integrate into the traditional evaluation schemes. During the second year of the study, the researchers and teachers focused on developing a two-level content study group model using home teams and expert grouped for content learning and task review. This allows students to hold membership in two groups. This approach differs from JIGSAW in that all students must receive passing grades. To develop the study group materials, the teachers (1) selected a chapter or unit with student material to last 4-9 days of instruction, (2) made expert sheets that told the students what was important when reading about or discussing the material to be learned, (3) assembled supplementary material to support the expert group, (4) located and/or constructed a test based on the information on the expert sheets, and (5) developed study items for each question on the test. After the implementation of the model and evaluation of student progress, the researchers concluded that the model was successful in raising test scores, and reducing student reading time. It also had an effect on teachers. The approach allowed teachers to conserve energy and improved their teaching techniques.

One of the claims of the advocates of cooperative learning is that it is superior to the traditionally competitive approach in bringing about learning. To test this assertion, **Sherman** compared achievement of 46 high school biology students in individually competitive and cooperatively rewarded environments. The students received instruction for seven weeks. Before instruction, they were pretested for biology knowledge. The same assessment was used for the posttest. Analysis of the pre to posttest data indicated that both groups increased in biology knowledge. Thirty-six percent of the variance in posttest scores was predicted by pretest scores. There was no statistically significant difference in posttest achievement scores between the class using competitive and the class using the cooperative approach. The author concluded that the result of no difference may have more to do with the timing of the study than the effectiveness of the cooperative approach. The study took place during the last 10 weeks of school after friends had been made. He believed that the establishment of friendships interfered with the functioning of the cooperative groups.

Tingle also compared the effects of cooperative and individual learning on student achievement. She studied stoichiometric problem solving in high school chemistry. One hundred and seventy-eight tenth through twelfth grade regular and honors students were given problems to solve using a prescriptive problem solving strategy. This strategy consisted of the problem statement, a second description which included stated and implied information in the problem, a picture description, mathematical solution, and a check. Students were placed in heterogeneous cooperative groups based on their responses to the proportional reasoning scores on the Test of Logical Thinking (TOLT). In addition to testing the effects of cooperative versus individual grouping on problem solving, the author was also interested in the relationship of math ability, proportional reasoning, age, and sex on problem solving; differences in attitude; and characteristics of successful and unsuccessful problem solvers. Data were collected using video tapes, classroom observations and written work. Analysis revealed no statistically significant differences between regular or honor students in problem solving in individual or cooperative groups regardless of proportional reasoning ability. There were also no differences in attitude, although the students in the cooperative groups enjoyed the instructional format. Successful problem solvers had the same characteristics regardless of their group membership. They were confident, persistent, and had a strong conceptual base to draw upon. The authors concluded that the prescriptive problem solving method used with individual and cooperative groups was so successful in helping students solve problems that it negated any advantages students may have had from working in cooperative groups. It may also be a technique that can help students who are not proportional reasoners become successful stoichiometric problem solvers.

Basili assessed the effectiveness of cooperative groups which incorporated conceptual change strategies to improve concept learning among a group of community college chemistry students. Two sections of introductory chemistry worked in small groups on tasks designed to promote conceptual change for the concepts of conservation of matter and energy; and the particulate nature of gases, liquids and solids. Tasks included answering questions which would identify misconceptions and creating concept maps of the course content. Group work was supplemental to traditional instruction. Two additional chemistry sections served as the control group and received the same traditional instruction. They watched demonstrations instead of engaging in small group work. The student interactions in the small groups were audio taped, transcribed and coded. Students were pre and posttested to determine misconceptions. Statistical analysis indicated that before the intervention, the students in the two groups had the same proportion of misconceptions. After the intervention, the students in the cooperative groups had fewer misconceptions than students in the control group. Transcript analysis indicated that individuals who had verbal behaviors representative of the conceptual change process, e.g., dissatisfaction with preconceptions, perceptions of intelligibility, plausibility, and utility of new concepts, were the same individuals who had correct concepts on the posttest.

How does a process approach affect learning?

Bardsley investigated the effects of a process skills intervention to effect the general readiness of kindergarten students. Eight to six students were placed in two approximately equal groups. Students in the treatment group engaged eight hours of process skills investigations. Prior to the intervention, ability was measured by the Peabody Picture Vocabulary Test. After the intervention, students were assessed using the California Achievement Test, Level 10, Form E. Analysis of the data from the assessment indicated that there were no differences in readiness between the two groups. Significant differences occurred between high and low ability students. There were no gender differences.

The Direct Inquiry Approach to Learning Science Process Skills and Scientific Problem Solving (DIAL(SPS)2) was developed and tested by **Germann.** (DIAL(SPS)2) is a highly structured laboratory curriculum that incorporates directed learning activities, advanced organizers, concept maps, the learning cycle, Vee diagrams, focusing, and writing. Four biology classes taught by the author were used to test the curriculum. To increase rigor, the treatment group consisted of average ability students and the control group consisted of high ability students. Both groups were pretested in August and posttested in May. Assessments consisted of the Classroom Test of Formal Operations, Test of Integrated Process Skills, Process of Biological Inquiry Test, Attitude Toward Science in School Assessment, and the SRA Achievement Test. Data were analyzed using analysis of covariance. The author concluded that the (DIAL(SPS)2) was no better than regular instruction for learning process skills or cognitive development. Concrete thinkers performed better than formal and transitional thinkers in the intervention classrooms. Formal and transitional thinkers performed better than concrete thinkers in the traditional classrooms.

Glasson investigated the effects of hands-on and teacher demonstrations on science achievement when prior knowledge and reasoning ability were taken into consideration. Fifty-four ninth grade students participated in the study. They were randomly assigned to one of the two treatment groups. Instruction consisted of a three week unit on simple machines. Instruction was for 50 minutes daily. In the hands-on class, the students engaged in three laboratory activities. In the demonstration class, the teacher demonstrated the same three laboratory activities. Reasoning was assessed by the Test of Logical Thinking (TOLT), prior knowledge by the North Carolina Science Test, declarative knowledge by a textbook end of chapter test, and procedural knowledge by a researcher-designed test. After analyzing the data, the author concluded that students in the hands-on and demonstration groups did not differ in declarative knowledge. Students in the hands-on group had greater procedural knowledge than students in the demonstration group. There was no interaction of procedural or declarative knowledge with reasoning ability. Prior knowledge predicted achievement on the declarative knowledge test. Prior knowledge and reasoning ability predicted achievement on the procedural test with reasoning being the stronger predictor of the two.

Eighty fifth-grade students participated in a study designed by Sidney to assess the effect of inquiry science on critical thinking skills, achievement and attitude toward science. Forty students were in the control group which received traditional instruction and 40 students were in the experimental group which used the inquiry approach. Both groups received instruction on two science units over a 10 week period. After the intervention, the Harcourt Achievement Test, the Cornell Critical Thinking Test, and Fisher's Science Opionionnaire were administered to the students. The data were analyzed using analysis of variance. The author concluded that the inquiry method of teaching science did not affect critical thinking, science achievement, or attitude toward science. There was no gender effect or interaction between gender and method of instruction.

Harty, Kloosterman and Matkin surveyed 301 elementary school principals about the use of hands-on materials in their schools.They concluded that 50 to 60% have teacher-assembled manipulatives. Commercial materials were beyond the schools' budgets. The principals reported that the schools teach hands-on science more than 30 days a year and that science is taught more and the use of manipulatives is more prevalent in the upper grades. Teachers reported that 70 minutes a week were spent in teaching science with manipulatives and 40 minutes a week without manipulatives. Anecdotal data suggested that these estimates were too high and that non-manipulative science is still the norm.

Is the learning cycle more effective than other instructional strategies?

Rubin and Norman compared the learning outcomes of students who received instruction based on the learning cycle and the systematic modeling approach. The integrated science process skills of middle school students were assessed by the Group Assessment of Logical Thinking (GALT) and the Middle Grade Integrated Process Skills Test. Three hundred and twenty-seven sixth through ninth grade students participated in the study. The treatment consisted of training 13 teachers in process skills and two forms of instruction: systematic modeling and the learning cycle. The modeling approach consisted of introducing the students to concepts and process skills, modeling the skills through demonstration while thinking aloud about the process, and answering questions. The teacher repeats the process with a second demonstration and a new set of questions. Instead of answering the questions herself, the teacher elicits answers from the students. Finally, students have an opportunity to independently practice the skill. The more familiar learning cycle consists of data gathering, invention, and expansion phases. The intervention lasted three months and consisted of 15 lessons. Students in the modeling and learning cycle group were exposed to the same process skills. A nonequivalent control was included in the study. Students in this group were given the same pre and posttests. The authors concluded that the students in the modeling and learning cycle group outperformed the control group on the test of integrated process skills. The modeling approach was more effective than the learning cycle in bringing about improvements in achievement and formal reasoning.

Many students in a Puerto Rican university consistently failed general chemistry. To better understand this phenomenon and to remedy this situation, **Davison** conducted a pilot study to assess the intellectual development, mathematical background, and reading comprehension of the students. The Group Assessment of logical Thinking (GALT), the Longeot Test, Guay Rotations Test, the Science Process Skills Test (TIPS II), and Find a Shape Puzzle were administered as the pilot assessments. Data from these tests indicated that Puerto Rican students score less well than their counterparts on the mainland. Davison then used the data from the pilot study to design laboratory activities based on the learning cycle that would improve the students' level of cognitive functioning. After the intervention, the students were tested again using TIPS II and the GALT, and their performance compared to a control group. Students in the learning cycle outperformed students in the control group on the TIPS II but not on the GALT.

Abraham compared the learning cycle approach to traditional instruction and further investigated the sequencing effect of the learning cycle. Students in six chemistry classes received instruction using the traditional method (reading or lecture) and the learning cycle approach. Within the learning cycle, the sequence of gathering data, invention, and expansion were rearranged (GEI,IEG,IGE,EIG,EGI) and taught to a sample of approximately 180 students. The author concluded that the learning cycle was superior to traditional instruction and that all three aspects of the cycle in their normal sequence (GIE) were necessary for optimal learning.

How does the use of concept maps affect learning?

Okebukola, Akinsola and Olugbemiro explored the use of concept maps as a way to reduce student anxiety and increase concept attainment in biology. One hundred and thirty-five college biology students participated in the study. Half of the students were in the treatment group which consisted of instruction in the use of concept mapping within a unit of ecology and a unit of genetics. The other half of the students were in the control group and received instruction using lecture, discussion, and field work with a unit of ecology and a unit of genetics. Students were given pre and posttests that assessed level of anxiety and perception of topic difficulty. After statistical analysis, the authors concluded that the treatment group had lower anxiety about genetics and ecology than the control group. The treatment group also perceived ecology and genetics to be less difficult than the control group.

Spaulding also studied concept mapping to determine the effect of the technique on achievement in biology and chemistry. One hundred and seven biology and 44 chemistry students participated in the study. All students were pretested on material to be covered during the subsequent three weeks of instruction and given the Comprehensive Test of Basic Skills (CTBS). After the pretesting, the treatment group was taught concept mapping techniques for one week. Then all students received regular instruction in biology and chemistry. During the last 15 minutes of each class period, the students received a list of concepts covered during the class period. The students in the treatment group were asked to construct concept maps of the concepts and the students in the control group were asked to define the concepts. Maps and definitions were turned in to the teacher who graded and returned the work to the students the next day. After three weeks, students were given the posttest for content and the Comprehensive Test of Basic Skills. Data were analyzed using ANCOVA. The analysis led the author to conclude that concept mapping was no more effective than writing definitions in bringing about increases in achievement. However, there was an interaction effect on achievement of treatment and prior achievement as measured by the CTBS. Students with low CTBS pretest scores did better on the achievement posttest when using concept maps and students with high CTBS cores did better on the achievement posttest if they were in the concept definition group. There was no interaction by content area.

What new instructional strategies are being investigated?

Healy studied the effects of advance organizers and prerequisite knowledge on learning and retention of science concepts. She prepared two reading passages; one that served as an advance organizer and one that served as prerequisite knowledge. Each passage had four inserted questions. Fifty-nine ninth-grade students read either the advance organizer passage or the prerequisite knowledge passage and answered the inserted questions. Half of the students in each group were asked to complete either the multiple choice framework test or the prerequisite knowledge test. Both tests assessed comprehension of the passages. Students then received regular physics instruction for 20 days and were given a content test. Forty days after instruction the students were again given the framework test and a retention test. The posttest and retention test consisted of the same items in different order that asked low level recall and high level application questions. Data analysis (ANOVA) indicated that students who read the advance organizer passages performed better on the framework test than the students who read the knowledge passages. Students who read the knowledge passage performed better on the knowledge test than students who read the advance organizer passage . After 20 days of instruction, there was no difference between groups for level of question, posttest scores or retention scores. The author concluded that the passages had the intended effect as preinstruction treatments. However, there was no evidence that advance organizers were better than prerequisite knowledge for learning.

Pearson investigated the effects of teacher-generated versus student-generated questions on achievement in natural science. Seventy-seven community college students with high and low reading ability participated in the study. Students in Group 1 received and used teacher generated questions at various levels of Bloom's taxonomy (referent, literal, interpretive, inferential, self- critical) as study aids. Group 2 received training to generate and use their own questions as study aids. The questions were to be at the same taxonomic level as those provided by the instructor to Group 1. The intervention lasted five weeks. Students were pre and posttested for content knowledge and were given five weekly quizzes. From the analyses of data, the author concluded that: (1) high reading ability students made greater gains in content knowledge from the pretest to the posttest, (2) weekly quizzes indicated that teacher-provided questions at the literal level were more effective in facilitating learning than any other kind of question, and (3) training students to generate their own questions had a positive effect on learning.

Many studies indicate that home variables have a strong influence on student learning but little is known about parental teaching strategies. Consequently, **Wirga** studied the effects of fathers' perceptions of their sons and daughters on the ways they teach them science. Thirty father-child dyads participated in the study. Half of the children were male and half female. The children were in grades seven and eight and the fathers were college graduates. The fathers were asked to help their child design an experiment to evaluate six different brands of toothpaste. The fathers responded to a questionnaire designed to determine the father's perception of his child's overall ability, science ability, personality, and whether the father held stereotypical beliefs about males and females in science. The fathers were observed teaching their children and behaviors were categorized into eight behaviors: (1) directing, (2) questioning, (3) monitoring, (4) providing information, (5) positive and negative reinforcement, (6) emphasis on English skills, (7) use of memory aids and (8) goal evaluation statements. The author concluded that fathers of boys spent a greater proportion of their time using questioning strategies than fathers of girls. Fathers of girls spent a greater proportion of their time using informing strategies. Despite this gender difference, fathers' perception of ability was the best predictor of teaching strategies. Fathers' perception of personality was the best predictor of the use of negative reinforcement.

Shrigley and Koballa reviewed the research on anecdotes as an instructional strategy and identified what they believed to be the benefits and risks to their use in science education. Overall, they concluded that the benefits of using anecdotes were that they gained student attention, enhanced comprehension, and aided memory. The risks of using anecdotes were confined to the problem of high inference. That is, that students will use the anecdote to make inferences beyond what is reasonable. The authors concluded that the benefits of using anecdotes outweighed the risks and that the risks can be controlled by using low inference anecdotes.

Another novel approach to enhancing science learning is the use of drama. **Butler** defined drama as a process that actively engages students in processes such as analyzing and sharing feelings, attitudes, ideas and perceptions. He argued that the drama process in science should focus on attitudes rather than characters. He argued that using drama will connect science to the real world and change instruction from a passive individualistic experience to an active group experience. It also allows teachers to deal with the social implications of curriculum.

Doorish proposed and tested a mathematical method for studying and teaching stellar and protostellar structure. The model is based on four differential equations which describe the structure of a star including mass, pressure, temperature, and luminosity. The author presented his equations to a class of college physics majors who were then asked to construct a stellar model. Afterwards the students responded to a questionnaire about the technique. Most of the students felt that the approach was a simple and effective method to introduce stellar structure.

Summary

The effect of cooperative learning still depends upon the context in which it is used. For example, two recent studies of cooperative learning found positive effects on achievement and two studies found no effect. Cooperative learning had a positive effect on student attitude and could free up teachers' time, but teachers still remain a bit skeptical about the technique.

The recent research on process skills and the learning cycle has not added much to our knowledge base in these areas. The effect of process skills instruction was limited to increasing students' process skills, not in general achievement or other areas such as logic. This is not a surprising finding considering what we know about transfer and domain specific knowledge. The learning cycle had been found to be better than traditional instruction but not necessarily better than other more innovative forms of instruction such as modeling. Research in these areas has been going on for a long time without any additional insights being gained. It is now time to accept what we know about these two approaches and move forward with research on other instructional techniques.

Concepts maps did not have a dramatic effect on achievement. They have been helpful with students whose prior knowledge is poor. However, their impact in the affective domain was significant. Concept maps as an instructional technique have been successful in reducing student anxiety about science and the perception that science is a difficult subject.

Questions were also an effective technique to increase achievement whether the questions were teacher generated or student generated. I believe that focusing on questions forces the teacher to think more carefully about planning instruction and forces the student to think more carefully about learning.

Two less traditional instructional techniques have been suggested for use in science. These are anecdotes and drama. Although neither of these areas has been tested extensively in science education, intriguing arguments have been presented in favor of their use.

LEGISLATION AND POLICY ISSUES

How successful has legislation been in solving educational problems?

Kuehn examined the validity of teacher licensure tests to assess the actual task of teaching science and mathematics. The author sent questionnaires to 2,801 mathematics and 2,468 science teachers asking them to rate tasks taken from the Teacher Certification Test. They were to indicate whether they actually performed the task,its importance to the learning process, and the possibility of successful performance by minimally qualified teachers. Cluster analysis and comparison of group means were performed on the data. There were significant differences based on race for science teachers, but no effects for race for mathematics teachers or gender or age effects for either group. Black teachers rated the general pedagogy and science specific tasks higher in importance than whites. In general, science teachers' ratings of the importance of the content area tasks varied according to the degree that the teacher was familiar with the task and the frequency with which the teacher taught the content associated with the task.

In 1983, Florida 's Educational Reform Act established standards and requirements that defined the desired state of education. **Spector, Davis and Van Sickle** conducted a study to determine the extent to which elementary teachers were aware of the requirements established by the legislature and how well they were able to implement instruction to meet the standards. The authors used a discrepancy model that compared the desired state to the actual state. The characteristics for the desired state were derived from a list of minimum standards for science, a list of the state standards for excellence in science, and science course descriptions. The actual state was determined by a state-wide self-report survey of elementary school teachers. The results of comparing the actual to desired state of education revealed that 71% of the teachers surveyed were aware of the state guidelines, 28% used a hands-on approach, 74% knew safety procedures, and 80% were confident about teaching science. The authors caution the readers that despite what the teachers say, there was no evidence that the state guidelines were being implemented.

Meister examined the extent to which educational research was used to develop national policy regarding the shortages of science and mathematics teachers in 1957-58 and 1983-84. She took a case study approach in which congressional documents were examined to determine: (1) whether systematic knowledge was available to legislative policy makers and (2) whether that knowledge was used in framing the National Defense Education Act of 1958 and the Education for National Security Act of 1984. **Meister** concluded that systematic knowledge was available and used to a significant degree in developing legislation to combat teacher shortages. Less knowledge was available in 1983-84 than 1957-58 and it was less systematic. The author was unable to determine the relationship among popular or controversial solutions and enacted legislation.

The Education for Economic Security Act was studied to determine whether the act reflected the recommendations of the educational reform literature. **Daniel** examined the text of the act using item analysis and comparative content analysis techniques. He then attempted to verify his conclusions through interviews with individuals who were knowledgeable about the law. The author concluded that the law was established to: (1) increase the quality of instruction being provided by teachers currently in mathematics and science classrooms, (2) determine the needs of school districts, (3) produce new curricula and develop new ways to train teachers, (4) improve the image of teaching as a profession, (5) expand the school's constituency, and (6) attract more highly qualified individuals into the teaching profession. The law also established two implementation change strategies. The first was based on the equity model of the Department of Education and the second was based on the excellence model of the National Science Foundation. The author concluded that the law does reflect many of the issues raised in the educational reform literature. However, the change strategies recommended in the literature were more specific than those in the law and there were inconsistencies between the provisions of the law and the rules and regulations of the implementing agents.

The National Sea Grant Program was developed to promote programs that would lead to increased public awareness and understanding of the marine environment **Fortner and Mayer** examined the funding pattern of the Sea Grant Program from 1976 to 1987 to determine if the stated objective of the program had been met. They determined that the true focus of the program has been graduate education. Funding for K-12 curriculum development has steadily decreased and funding for teacher education was low. The authors recommended that science educators be assigned to the program to help Sea Grant develop and evaluate educational programs for K-12 students.

Cleghorn, Merritt and Abagi investigated the educational consequences of Kenya's language policy on science education outcomes.

The policy restricted the use of the local vernacular and promoted instruction in English. Three schools with different responses to the state mandated language policy were studied in depth. In the first school, English was taught from the earliest grades but Swahili was allowed as the second or primary language of instruction. The school norms favored English and English was taught as a school subject. In the second school, there was an English-only policy. English or Swahili was the initial language of instruction and both languages were taught as a school subject. No instruction was delivered in the vernacular language of Kikuyu. In the third school, English, Swahili and Luo were taught as school subjects and the initial language of instruction was Luo. English-only instruction began at grade four. The authors concluded that few teachers were able to adapt the use of English to the needs of the learners or to increase their knowledge of English. The policy in school one resulted in increased language exposure but meaning was not established because there were no language bridges. The problem was the same in school two. The lack of a language bridge resulted in a failure to establish meaning, especially for abstract concepts. In the third school, the use of the local language allowed teachers to use culturally relevant examples. The consequences of the language policy also affected the way the teachers taught. The teachers themselves had a poor command of English, especially for abstract concepts, so that science was presented in a disconnected way. Their vocabulary lacked precision and reformulation, expansion, and clarification were rare.

Summary

Legislation in the United States has been firmly based in research in science education. However, because of the need to satisfy many constituencies, the interpretation of the research has been more general than specific. Implementation of the legislation has been somewhat problematic. For example, the National Sea Grant program has not funded educational programs at the level it was charged to do in the enacting legislation. In Florida, teachers were aware of the reform legislation but there was no evidence that they implement it. Teachers taking licensure tests did not necessarily agree with the items on the test or the importance of those items to their effectiveness in the classroom. In Kenya, the educational legislation has not been firmly grounded in the language realities and educational problems of the country. As a result, implementation varies and science education suffers.

MISCONCEPTIONS

What are the philosophical issues surrounding research into misconceptions?

Coburn asserted that most researchers in the area of misconceptions make a fundamental mistake when they assume that there is homogeneity among students. That is, that despite gender, racial, and cultural differences among students, students come to secondary or college science capable of assimilating and valuing science when it is presented in a traditional inquiry fashion. He argued that a worldview theory must be developed that will allow students from disparate backgrounds to be successful in science. He stated that we must first determine what aspects of worldview among disparate scientists (western/nonwestern, male/female, Christian/nonChristian) are held in common that allow them to be successful in science. Second, we must identify the logico-structural items of a scientifically compatible worldview. Finally, we must identify variations in worldview which have an effect on attitude and achievement. This is especially important for the self-nonself concepts held by individuals as they relate to the natural world.

Hill also questioned what he believes is an underlying assumption in the misconceptions research. This assumption is that whatever we call children's views of science, they can be interpreted as embryonic science. **Hill** does not believe this assumption is substantiated by the research because the research does not address the roles the student's views play in the broader framework of their beliefs about the natural world. Nor does the research address the role student's worldview plays in everyday practical contexts. He argued that until further research takes place we should take the position that students are working with an alternative to a scientific framework. Research should focus on discovering what concepts and frameworks children bring to their initial encounters with science instruction. Assuming that children are primitive scientists impedes further understanding of the real phenomena and leads to premature educational interventions.

How do students view the natural world?

Treagust and Smith developed a paper and pencil diagnostic test to determine students' understanding of gravity and planetary motion. To develop the test, 24 tenth-grade students were interviewed using a set of cards which assessed knowledge of gravitational force, planetary rotation, and planetary revolution. Based on the interview data, the authors produced a paper and pencil test with questions and sketches identical to those found on the cards used in the interviews. Students were asked to respond to the questions twice. The second time the students responded to the question, they were to include a short statement giving the reasons for their answer. The authors concluded that the results of the diagnostic test supported the interview data. The majority of students did not understand gravity or planetary motion. The students believed that surface temperature affects gravity, rotation depends upon density, rotation affects gravity, gravity is related to the planet's distance from the sun, and that the sun's gravity influences the planet's gravity and orbit about the sun.

Another study examining misconceptions in earth science looked at how misconceptions varied by grade, gender, and race. **Schoon** administered an 18-item questionnaire to 1,213 students in fifth, eighth, and eleventh grade and adults in college and trade school. Analysis of the questionnaire indicated that all the students held many misconceptions about earth science but that the absolute number of misconceptions varied by gender, race, and grade level. In general, females had more misconceptions than males. White and Hispanic females had more misconceptions than white and Hispanic males. The exception occurred in the black sample where black males had more misconceptions than black females. Blacks and Hispanics had more misconceptions than whites. Grade level differences indicated that fifth and eighth grade students had more misconceptions than trade school students. Whether or not a student had taken an earth science course did not influence the number of misconceptions held.

In the biological sciences, **Julyan** studied high school students' understanding about trees. The author conducted weekly sessions over a three month period in which the students observed leaves changing color and attempted to explain how this phenomenon occurred. Each session was tape recorded and students drew pictures to help explain their beliefs. The author concluded that, although many of the students held beliefs different from those of a scientist, the belief structures were internally coherent and logical.

How does students' reasoning about natural phenomena reflect their worldview?

Cho investigated fifth and eighth grade Korean students' misconceptions about photosynthesis. He was interested in the relationship of misconceptions to logical ability and the textbook approach to instruction. He developed three instruments for his study: the Photosynthesis Concepts Test, the Piagetian Logical Reasoning Test, and a questionnaire to collect information about background variables. The instruments were given to 210 fifth and 239 eighth grade students. Twenty of the students were then interviewed. The author also conducted a textbook analysis of fourth through eighth grade texts to determine how many of the concepts on the Photosynthesis Concepts Test were covered by the texts. Regression analysis indicated that prior knowledge and logical reasoning were the best predictors of achievement on the photosynthesis test. These two variables accounted for 22% of the variance at the fifth grade and 40% of the variance at the eighth grade. All the students had many misconceptions despite the fact that the concepts had been covered in the textbooks used in classrooms. Students were unclear about making food, the definition of food, how plants use light, the function of roots and leaves, and photosynthesis products. The number of misconceptions declined from the fifth to the eighth grade.

Metaprocedural reorganization is the process learners use to develop a theory that explains both specific and general phenomena. **Zaid** attempted to develop instruction based on using key aspects of metaprocedural organization to help students understand the biochemical activity of the cell. The instruction consisted of seven lessons stressing the logical and historical development of contemporary theories about cells. Ten eleventh-grade female Jordanian students were assigned to the treatment group and 10 to a control group. Students in both groups were pre and posttested with a researcher made open-ended essay. Lessons in the treatment group were audiotaped and textbooks were analyzed to determine the extent to which they addressed the historical development of biochemical cellular processes. Data were analyzed using ANCOVA. The author concluded that in spite of gains in functional knowledge from the pre to posttest, students did not acquire the correct propositional knowledge. The students maintained coherent and integrated misconceptions. Misconceptions at the beginning of the intervention contributed to misconceptions exhibited at the end of the intervention. For example, students who before the intervention believed that plant mass was formed from nothing but water were the same students who at the end of the intervention believed that water was used to produce energy. The author concluded that textbooks contributed to students' confusion by presenting present and past theories without establishing the reasoning that led to their evolution.

Bar investigated Israeli children's views of the water cycle. She interviewed 30 students from kindergarten through ninth grade and analyzed the transcripts for the emergence and transition of schemes. She found that children's first ideas about clouds and rain is that they are the product of God or some kind of man-made equipment. The schemes move from the concrete to the abstract. The development of schemes about evaporation paralleled the development of ideas about rain and clouds. The schemes were stable and resistant to arguments presented by interviewers and the schemes were internally consistent. She concluded that understanding evaporation was a necessary condition for developing a correct explanation for the mechanism of rain that included the ideas of condensation and heaviness.

Shapiro conducted six case studies of fifth grade students' conception of light. These in-depth investigations led him to conclude that the differences in children's worldviews were greater than the similarities and that these differences should have a major impact on instruction. Each child experienced science in a different way because each child had different anticipations and expectations. These anticipations and expectations affected the thought and action of individuals in unique ways. Children also differed in their motivation to learn, which was in turn affected by prior achievement, love of the subject, and curiosity. The conditions for learning were also varied and individualistic. For example, some children had to see the light rays reflected from an object to believe the concept while others were willing to accept the authority of the teacher. **Shapiro** concluded that, given the large differences among children, individualized instruction was the only way to insure that all children had an opportunity to learn.

Basili argued that it was language confusion rather than reasoning that led to misconceptions in science. She conducted a study on conservation of matter and energy with introductory chemistry students in which she sought to bring about conceptual change. Her intervention was not successful, so she analyzed transcripts of small groups as they discussed the concepts of conservation, in hopes of developing more successful lessons. During this process, she identified language confusion as one of the major stumbling blocks to understanding. Students were using the common or vernacular definitions of words when the scientific definition should have been used. For example, students understood destroy to mean dismember, break, or render useless. This is the common nonscientific definition of the word. They were not able to see that a scientist would define destroy as going from a state of being to nonbeing. A similar problem was found with the word create. Students understood create to mean to reassemble parts as a designer would or going from a state of being seen to unseen. She concluded that a first step in bringing about conceptual change was to understand how students define the scientific vocabulary.

Are interventions successful in changing students' understanding of natural phenomena?

Fazio compared the effectiveness of a teacher centered reception learning model and a student centered generative learning model to bring about changes in students' conceptions of gases. Subjects were six classes of ninth grade earth science students. The classes were randomly assigned to one of six treatment groups. These groups were generative learning and reception learning with personal awareness of naive views, awareness of alternative naive views, and no awareness of naive views. The dependent variables in the study were: (1) knowledge and application of the kinetic theory of gases, (2) ability to support or refute concepts, (3) resistance to relinquishing the misconception and embracing the scientific conception, (4) achievement motivation, and (6) the acquisition of scientific concepts. Data were collected using both quantitative and qualitative methods. The data analysis revealed no significant differences for any of the dependent variables for teaching method. There were, however, treatment by awareness interactions. Students in the generative learning group retained more when aware of alternative misconceptions while students in the reception learning group retained more when they were not aware of any naive conceptions. Students in the generative group were more resistant to change under conditions of awareness of alternative world views and awareness of their own naive conceptions and students in the reception group were more resistant under conditions of no awareness. The author concluded that it may not be necessary to make students aware of their own naive conceptions and that instructional methods interact with levels of awareness to bring about varying degrees of change in students' conceptions in science.

The leading conceptual change model recommends that instruction creates dissonance so that students are dissatisfied with their conceptions of the natural world. Then, the teacher must provide alternative correct models that are plausible and intelligible. Next, students must be brought to see the fruitfulness of the new models through the experiences of explaining and predicting observations. **Targan** tested this model in the context of instruction about the phases of the moon. Students were tested on their knowledge before, during, and after instruction. A coding scheme was developed to interpret the students' responses and characterize their models. The coded data were used to identify changes in student models through the period of instruction. **Targan** concluded that this approach was an effective way to bring about conceptual change. All but one of the students who started the instruction with alternative models replaced them with more scientifically correct models. Students who began instruction without alternative models made significant gains in acquiring additional correct conceptions. Students who developed alternative conceptions during instruction relinquished them by the end of the instructional period. The author described the changes in student conceptions as piecemeal additions and deletions of key propositions that occurred against a background of stable propositions.

Ziedler and McIntosh contended that the effectiveness of conceptual change strategies can be enhanced by the addition of imagery inducing instruction, especially for abstract concepts. To test this assertion, they used a videodisc to present a dynamic model of the kinetic theory of gas. Thirty-six general science and physical science college age students participated in the study. Half of the students served as a control and half as the intervention group. Conceptual change was measured by the Test About Particles and Revealing Events Test. Students were also given a battery of spatial tests from the kit of Factor-Referenced Cognitive Tests produced by the Educational Testing Service. Instruction was a single session that was the same for both groups except that the students either viewed four minutes of a laserdisc presentation or reviewed the main points of the lesson with the instructor. The authors concluded that although both groups experienced conceptual change, the change was greater for the videodisc group. Students with low spatial ability profited most from the videodisc intervention.

Another instructional strategy to bringing about conceptual change was the use of analogies. **Dupin and Joshua** conducted a series of discussions with 64 fourth, 42 eighth and 87 tenth grade students in which they used analogies to create conceptual bridges. The intervention lasted between 20 and 34 hours depending upon grade level. The discussions emphasized metaphor and used analogies, such as a continuous train without an engine moving in a circle, to create connections to electrical concepts. The analogies contained no numerical or algebraic calculations. Students were assessed before the intervention and one month after the intervention. Students responded to a written test of electrical knowledge and participated in clinical interviews. A control group was also given the written and clinical tests. Analysis of these data indicated that the students in the treatment group had significantly more correct electrical concepts than the students in the control group.

Brown and Clement also looked at analogies as a means of bringing about conceptual change. They conducted four case studies of tutoring sessions designed to use analogies to overcome misconceptions. From these case studies, they distilled a preliminary list of factors that should be included in instruction that uses analogies to overcome misconceptions. First, the teacher must identify a usable anchoring conception. Second, the bridge between the anchoring conception and the conception that the student is to learn must be developed explicitly through processes that include the use of intermediate analogies. Third, students must be actively involved in instruction. Simply presenting the analogy in a text or a lecture will not bring about conceptual change. Finally, the student must construct for his or herself a new explanatory model for the concept to be learned.

Linn, Clement, Pulos and Sullivan investigated the effects of science topic instruction combined with instruction in reasoning under two conditions. In the first condition, students received instruction in blood pressure knowledge. In the second condition, students received instruction in controlling variables followed by instruction in blood pressure knowledge. A third group acted as the control. All students were pretested and posttested for blood pressure knowledge, controlling variables knowledge, and controlling variables within the context of a blood pressure problem. Ninety-one high school students participated in the study. Topic instruction consisted of five 45-minute lessons. Reasoning instruction consisted of one 40-minute session with each student individually. The analysis of variance results indicated that group 1 and 2 had attained the same degree of knowledge about blood pressure on the posttest and delayed posttest. Group 2 performed better than group 1 on the bending rods task which was used as a measure of the controlling variables strategy. The authors concluded that acquisition of topic knowledge influenced reasoning. Reasoning instruction followed by instruction in topic knowledge produced more generalizing reasoning than instruction in topic knowledge alone.

Another approach to overcoming misconceptions is to have students of various degrees of understanding resolve their misconceptions through small group discussions. **Scharmann** used this approach with two classes of college freshman biology students. The classes were pre and posttested for knowledge of evolutionary biology concepts, attitude toward evolution, and understanding of the nature of science. Both classes received identical instruction as to topics and course outline. After the initial lecture on evolution, students in the experimental group were given the opportunity to discuss their position regarding the theory of evolution. The students in the discussion group were told to resolve conflicts arising from the discussion and present the consensus position. An interactive lecture and discussion was used to resolve misconceptions that arose from the small group discussions. Analysis of posttest data for the two groups revealed no significant differences for evolutionary concepts. The experimental group had a greater understanding of the nature of science and a more positive attitude toward evolution.

Summary

Conceptual, methodological, and terminology issues still remain to be resolved in this new and burgeoning area of research. Children had misconceptions about the water cycle, plants and trees, light, motion, and the earth. These misconceptions are stable, internally coherent, logical, and very resistant to change. Misconceptions were greater among females than males and greater among minority students than white students. This is another example of the greater educational problem of access to and experience with science for women and minorities.

Textbooks were not effective in bringing about changes in scientific conception and appear to contribute to students' confusion. So too, the difference between ordinary language and the more precise use of words in science led students to have misconceptions about the world. The conceptual change model alone and with videodiscs, analogies, and metaphors have all been successful in helping students relinquish their misconceptions. Instructional strategies interacted with the students' level of awareness of their own misconceptions. Reasoning and background knowledge also played a part in conceptual change. Whether or not we shall be successful in helping students understand the world in a more scientific manner depends upon how consistently researchers find that the differences between children are greater than the similarities. If differences are greater than similarities, we will be faced with the problem of individualized instruction for every student in a science class.

SCIENTIFIC LITERACY

How should we define scientific literacy?

Yager argued that scientific literacy is a part of cultural literacy because a truly literate person in today's world must understand the use of science and technology. In order for this to be more clearly understood, **Yager** directed us to the goals of Project Synthesis. These goals call for a reformulation of science education so that students are prepared to participate in decision making in a technological society. They call for a reorganization of curriculum beyond the limitations imposed by a single discipline focus which in turn implies changes in teacher preparation and certification. They call for new materials, new ways of translating research into practice, and new ways of evaluating students that include the affective and creative aspects of science. Finally, they call for better support systems for exemplary teaching. Science programs that address these goals should be science for meeting personal needs, science for resolving current social issues, science that assists in career choice, and science that prepares students for further study. Students who are fortunate to experience science as envisioned by Project Synthesis will be scientifically literate.

Fleming believes that scientific literacy should be defined as literacy for a technological age. He argues that we need a more appropriate and useful view of technology which he calls sociotechnology. This view sees knowledge as something created by society and science which is placed at the disposal of people in general for personal, institutional, or social goals. In order to develop this sociotechnology view, education must make the relationship between science and technology explicit. That is, technology is not just applied science, but a useful form of knowledge. This knowledge comes in four parts: scientific concepts, problematic data, engineering theory, and technical skill. **Fleming** cited computers in the schools as the best example of misuse of technology which has resulted from technological illiteracy. He argues that democratic decision making will be furthered by an understanding of the true nature of technology and the relationship of technology to society.

What is the level of scientific literacy nationally and internationally?

Scientific literacy can be influenced by cultural and societal values. For example, **Coburn** conducted a study comparing the responses of Nigerian and American preservice teachers on the Nature of Science and Scientists (NOSS) profile. Thirty-two Nigerians and 21 Americans agreed to respond to questions on the NOSS. A comparison of the responses of the two groups indicated that they had, for the most part, similar worldviews. However, Nigerians differed from Americans in that they saw the purpose of science as the development of useful technology. They also saw the scientist as secretive and nationalistic. These views reflect the national needs of Nigeria for technology and the belief that scientists should work for the good of Nigeria rather than for the world community. Neither of these positions is surprising for a third world country, but the author was concerned that teachers may be transmitting a view of science that can have long term international consequences.

In Italy, **Conforto, Giova and Signorini** investigated high school and college students' awareness of the risks of nuclear energy for military and civilian use. One thousand twenty-three students responded to a questionnaire which was administered to groups of students prior to and after the Chernobyl incident. The authors also collected demographic data on family background. Analysis of the responses on the questionnaire indicated that there was no relationship between demographic variables and knowledge. In general, knowledge was low, especially medical knowledge. Most students believed that the risk from nuclear energy was high but they did not understand the relationship of civilian and military use of nuclear power. Most surprising to the authors was that students who responded to the questionnaire after the Chernobyl incident had fewer concerns about nuclear energy and less knowledge than students who had responded before the incident.

Miller compared the scientific literacy of adults in the United States and the United Kingdom and proposed a model that predicts the level of literacy from the research in this area. Using the 1988 National Assessment of Educational Progress (NAEP) data he concluded that only 6% of the adults in the United States and 7% of the adults in the United Kingdom could be considered scientifically literate. Both populations had about the same level of understanding of scientific concepts and terms and the scientific process. Adults in the United Kingdom had a greater understanding of the impact of science on society than adults in the United States. The factors in the predictive model included employment, especially in a science related area, level of education, the number of college level science courses a person has had, and gender. Age and the number of high school science courses taken were not predictive of scientific literacy.

Fleming conducted a survey of 1,200 Canadian teachers' views of technology. In particular, he was interested in their views of technology and the quality of life, employment, health care, food production, and social well being. He found that most teachers viewed technology from an artifact perspective, i.e., technology results in the manufacture of things. Medicine was the most often cited example of the benefits of technology. About 50% of the teachers believed that technology improved employment prospects and 50% believed that it did not. Only half of the respondents were in favor of technology in general. These views were not significantly different from those held by graduating high school seniors.

In the area of energy literacy, **Barrow and Morrisey** compared a sample of 452 students from New Brunswick, Canada, to a sample of 492 students in Maine, United States. Literacy was assessed through a questionnaire. The authors concluded that students in the United States were more knowledgeable about energy issues than students in Canada. However, males in both countries were more knowledgeable than females in both countries.

Brody, Chipman and Marion assessed the level of scientific literacy in the area of natural resources in a group of 175 fourth, eighth, and eleventh grade students. Each student was interviewed about their knowledge and understanding of acidic deposition. The students had very little knowledge or understanding of the phenomena and what they did assert to know was incorrect. There was no increase in knowledge from the fourth to the eighth grade.

Pickard conducted a meta-analysis of the research on scientific literacy among teachers and students. She was able to identify four studies out of the 663 that were appropriate. One of these studies was also a meta-analysis. Effect sizes were largest when the studies measured aspects of literacy that were similar to the NAEP criteria. Curricula that emphasized the integration of science, technology, and society were more likely to produce literate students. The author was cautious about the conclusions because of the small sample size.

Teachers have a concept of science that they convey to students through their thoughts and actions. **Zeidler and Lederman** investigated the power of a teacher's choice of language to influence students' conceptions of the nature of science. Eighteen high school biology teachers and 409 of their students participated in this study. Conception of science was measured by the Nature of Science Knowledge Scale (NSKN) which was used as a pre and posttest. Each teacher was also observed three times during the fall semester and data from chalkboard notes, assignments, handouts, and the physical setting were also collected. Ethnographic data were coded for examples of a realist (science is a reflection of the real world) or instrumentalist (science is tentative and consists of models of knowledge) position. These data were examined in relation to changes in students' conceptions of science from the pre to post NSKN test. Teachers' language was found to be directly related to changes in students' conception of science toward an instrumentalist or realist position. The authors concluded that the implicit messages conveyed through teacher language are in part responsible for how students perceive science.

Summary

Scientific literacy is part of cultural literacy and consists of the skills and knowledge that allows a person to live in a technological age. Nationally and internationally, literacy was low. Scientific literacy was greater for males than females and appeared to be linked to curriculum and how teachers present science.

TEACHERS

How qualified are our science teachers and how does that affect their practice?

Garnett and Tobin studied two exemplary chemistry teachers to identify the personal and intellectual characteristics that made them effective. They used the ethnographic approach and collected data from classroom observations, interviews with students and teachers, and examination of instructional materials. Each teacher was observed for at least 20 lessons over an 8 to 10 week period. Conclusions were reached after discussions with other researchers involved in the Exemplary Practice in Science and Mathematics Education project. Although the two teachers each had different and distinctive teaching styles, they were effective because they were able to integrate their content and pedagogical knowledge. Each teacher taught for understanding. Their instructional strategies were consistent with their personal educational philosophies. They had strong content knowledge and good classroom management strategies. These two strengths allowed the teachers to focus on teaching for understanding. When they taught for understanding they: (1) asked appropriate questions, (2) responded to student questions, (3) engaged in cognitive monitoring strategies, and (4) provided regular feedback.

In another study of exemplary teachers, **Rubba** assessed the semantic meaning teachers assigned to concepts in science, technology, and society (STS) as well as their opinions on STS instructional practices. The sample consisted of 65 secondary science teachers. The teachers responded to the Science Teaching Issue Opinionnaire, and questions about demographic variables. A variety of statistical procedures were used to analyze the data including repeated measures analysis of variance. The author concluded that exemplary science teachers held positive opinions of science, technology, their own understanding of science and their ability to teach science. The teachers held slightly positive opinions of students' understanding of STS issues, students' need to understand STS, their own understanding of STS issues, and their ability to teach about STS issues. The teachers also believed that 15% of class time should be spent teaching STS but they also said that they did not spend this much time. Of the 23 STS issues that appeared on the questionnaire, only 2.5 were integrated into traditional science classes. The issues chosen reflected the teachers' areas of expertise. The teaching strategies used to integrate STS issues into the curriculum were predictable: lecture, films, and discussion.

Barrow investigated the reading patterns of another group of outstanding teachers: the Presidential science honorees. Four hundred and twenty-two teachers who had been selected for the Presidential award between 1984 and 1986 participated in a Delphi study. They responded to two surveys that asked the participants to answer questions about (1) which science and education journal indexes preservice secondary science majors should read and (2) which science and education journals and indexes they read. The data were analyzed by compiling frequencies. The author concluded that both the material recommended for preservice teachers and the reading of practicing teachers had a practical orientation. Almost 60% of the respondents said that they read one-third or more of each issue of *The Science Teacher*. *National Geographic, Discourse, Science News, The American Biology Teacher,* and *Chem Matters* were the next most frequently read materials. However, the number of general education reading materials was limited.

Academic preparation was the focus of **Cain's** research. She investigated the specialized training in earth science disciplines, related fields of science, mathematics, computer science, and science instruction pedagogy of 65 eighth grade earth science teachers. Data were obtained from the South Carolina Department of Education files of Basic Educational Data System reports and the college transcripts of the participants. These data sources provided information on academic qualifications as well as demographic information. Several relationships between demographic characteristics and academic qualifications emerged from the data. First, the typical South Carolina earth science teacher is a white 41 year old female with a Master's degree and 13.1 years of teaching experience. Second, the teachers were found to be adequately prepared in the biological science and submarginally prepared in the earth sciences when academic preparation was compared to the NSTA standards for earth science teachers. Third, only half of the teachers had adequate preparation in physical science, mathematics, and pedagogy and the majority lacked any training in computer science.

Bowen examined the number of secondary teachers certified to teach the various high school science subjects to determine if there was a shortage of qualified teachers in Tennessee. Data were obtained from the Tennessee State Department of Education Preliminary Report Forms for Staff. The geographic focus of the study was the upper Eastern region of the state. The author analyzed the 1984-85 teaching assignments for in-field and out of field assignments and to determine the size of the reserve pool of certified teachers who were not teaching. The results indicate that there was a shortage of qualified teachers in all but one regional school system. Twelve percent of chemistry, 91% of earth science, 22% of general science, 34% of biology and 34% of the physics teachers were teaching without certification in these areas. Except in the area of earth science, the number of qualified but not employed science teachers exceeded the school district's needs. The author concluded that although the number of qualified teachers in the state is adequate to meet demands, the number who choose to teach creates a shortage.

In another case study, **Martens** followed an elementary teacher as she began to learn about teaching science as problem solving rather than information giving and observed her attempts to modify instruction to reflect science as problem solving. The author collected data over a one year period which included classroom observations, interviews, and document analysis. **Martens** concluded that environmental factors such as administrative support and flexibility, availability of science materials, school philosophy, parental support, and the teacher's status strongly influenced the teacher's efforts to change. Personal factors such as science background, the ability to see interdisciplinary teaching opportunities, organizational skills, beliefs about students, need to cover a textbook, emphasis on success, the need to maintain control over students, activities, and thinking and openness to change also had a strong influence on instructional practices. For example, the teacher was not reflective because she had a teaching record of success. There was no motivation to change or think about why previous instructional approaches were not successful. Because she was not reflective, she did not see discrepancies in what she was being taught and how she was teaching. Efficiency overruled opportunities for spontaneous problem solving. In general, the culture of the school blocked change. Efficient teaching, high standardized scores, and making the administrators look good were the recognized and approved ways of being a successful teacher.

What are the effects of teacher beliefs and decision making on practice?

Teachers' beliefs about science influence whether or not they will be effective in the classroom. **Brickhouse** examined how belief and knowledge shaped instruction in a case study of two junior high and one high school science teachers. The author used interviews and classroom observations over a four month period to determine the teachers' knowledge of the nature of science, their roles as teachers, and their students' roles as learners. Using the ethnographic method, data were used to build, validate, and alter hypotheses. This process led to the following conclusions. Teacher one believed that scientific theories and processes were a stepwise cookbook procedure. Consequently, this teacher's instructional goals were to teach the steps of the scientific method and provide a great deal of structure for students. Teacher two saw theories and processes as a tool to solve problems. The goal of his/her instruction was to use the theories to solve problems. The third teacher believed that scientific theories and processes were truth uncovered through experimentation. Consequently, the goal of instruction was to learn the truth. Since the theory of evolution contradicted this teacher's religious belief, evolution was avoided. When the teacher did deal with the theory, it was demoted to a hypothesis not a scientific truth. These teachers also held positions on the philosophy of science that influenced their teaching. Teachers one and two believed that science was accumulated knowledge and taught science as such. However, teacher two thought it was possible for student to make jumps in knowledge that went beyond accumulated fact. Teacher three believed that goals-oriented research and technological research were not science. Therefore, instruction did not include discussion of the political concerns and the ramifications of science even when instruction focused on STS issues.

Benson also conducted a case study of three secondary biology teachers and the relationship of their epistomological beliefs to how they taught. Again, teachers were interviewed, observed in their classrooms, and lessons were audio-taped. The author concluded that although teachers tell their students that biological concepts are important, they teach detailed information about specific organisms. The teachers had a commitment to scientific realism (objects exist independent of a scientist's activities) and their teaching reflected this orientation. The author challenged the teachers about the contradiction between what they said they believed about science and the way they taught. The teachers responded by saying that the teaching situation constrained them. They said the curriculum was noncontroversial because it was imposed from the outside. The author believed that the teachers were reifying knowledge and then justifying their behavior by citing external circumstances. The author argued that this approach was contradictory to the constructivist view of knowledge and that significant changes will have to take place in the way teachers and students view knowledge, learning, teaching, and the curriculum before this view becomes prevalent in schools.

In another case study, **Mitchner and Anderson** examined how teachers' beliefs resulted in the acceptance, rejection, or alteration of a STS curriculum (TOPICS) that many science educators believe is an innovative high quality curriculum. Two schools with a total of 14 teachers and 2,000 students participated in the study. Data were collected over a period of six months using observations, interviews, and document analysis. Data were aggregated to provide a profile of teachers who accepted, rejected, or altered the curriculum. Teachers who accepted the curriculum did so because it caught the students' interest by using real life situations. They agreed with the instructional goals of developing awareness and interest, decision making, and group skills. They also liked the science and social studies applications. They did, however, have some reservations. Many were uncomfortable teaching unfamiliar material. They had difficulty evaluating the topics and worried that students would suffer when they took standardized tests. They were also concerned that this course, as a replacement for physical science, would reinforce low functioning students' weaknesses. Teachers who rejected the curriculum did so because the curriculum lacked real science topics and they disliked the social studies content. They also disliked the activity, decision making, and social skills orientation and the cooperative grouping and nontraditional teaching that these goals required. They perceived the evaluation as too subjective. They also believed that instruction about application had gone beyond acceptable limits. The target students for the course were not the kind of students that these teachers liked to teach. The teachers saw themselves as scientists not educators and felt that the TOPICS course was demeaning and lowered their prestige. The teachers who altered the curriculum felt that the approach was too time consuming and energy draining. They added content because the course was not substantive enough. They were uncomfortable with the new teaching techniques and diminished the amount of cooperative learning. They too believed that the evaluation was too subjective. Lastly, they altered the curriculum because they believed that the students' skill levels in reading and mathematics were too low for the activities.

Trumbull and Kerr argue that the major influence on the development of teachers is the way that they have been taught. Since most secondary science teachers have been exposed to more university science instruction than education coursework, **Trumbull and Kerr** examined science instructors as models for good practice. They conducted a case study to determine the conceptions of teaching held by university science instructors. Several scientists and three teaching assistants were interviewed about their views on teaching. The authors concluded that both the teaching assistants and the scientists did not believe that it was possible to do research on teaching. They took the various aspects of teaching for granted and viewed teaching as a series of routines. Both groups felt that the students in lower level classes were not ready or eager to learn. They did not understand developmental issues about how students come to understand how knowledge is generated and validated. They wanted students to communicate better and be more critical but they could not think of any teaching situations or strategies that would bring about the desired results. They had no goals or objectives for their courses beyond getting students to learn information. They held no theories about teaching that served as underpinnings for decisions about teaching, learning, or evaluation. They lacked a political perspective about schools. They were unaware of the effects of testing and evaluation procedures or the sorting function of low level classes. They accepted as natural the high failure rate in low level courses. The authors concluded that the poor teaching in content areas was responsible for the fact that students were not learning how scientists make knowledge claims and use this knowledge.

Tobin and Fraser examined the barriers to higher level cognitive learning in high school science. They made classroom observations, interviewed teachers and students, and measured the classroom environment with the Individualized Classroom Environment Questionnaire and the Classroom Environment Scale. Two teachers and 62 students participated in the study. The data were organized into five categories: (1) beliefs for specific teaching roles, (2) metaphors used to conceptualize teaching, (3) knowledge limitations, (4) student perceptions of the learning environment, and (5) individual differences in student perceptions of the learning environment. The teacher called Peter believed he was an entertainer and the captain of the ship. This resulted in whole group instructional behaviors. The teacher called Sandra believed that all students should have opportunities to learn. This resulted in directed learning experiences for students. Peter had less knowledge and was less confident. He memorized many of the facts he was to teach. Sandra's lack of knowledge resulted in management problems. The students' perception of the classroom environment reflected the teaching styles of the teachers. In Sandra's case the preferred and actual learning environments as expressed by students were very close. For Peter, favoritism toward attractive girls created differences in the way students responded to the classroom environment. For some, the preferred and actual were very close and for others very far apart. Peter's favoritism did not result in more learning for the targeted students.

Teacher decision making was the subject of a study by **Duschl and Wright**. They wanted to determine the degree to which teachers consider the nature of the subject they are to teach when making decisions for planning and instruction. The authors used an ethnographic approach to generate grounded theories. Data were collected through classroom observations, formal and informal interviews, surveys ,and document analysis. Thirteen high school teachers participated in this study. The authors concluded that teachers make decisions based on student developmental needs, curriculum guide objectives, and pressures of accountability. Teachers did not include the nature of the subject matter or the structure and roles of scientific theories in modern science. Decision making was dominated by factors other than the nature and structure of science. Teacher decision making was influenced by lack of knowledge about the nature and structure of science and content knowledge. Decision making was also influenced by district policy which emphasized how to teach according to a prescribed method over content knowledge and instruction based on flexibility and the structure of the discipline.

Abu-Sneineh also looked at how teacher knowledge affected decision making. He studied two physics teachers over a four month period, observing their classrooms for 9 to 12 hours a week. Each teacher was also interviewed four times for an extended period of time (50- 90 minutes). Handouts, worksheets, and other classroom material were also sources of data. Ethnographic techniques were used to interpret the data. The author found that teachers' knowledge and conceptions of physics could be placed into four major categories: vocabulary of physics, higher order relations, mathematics, and history of physics. Each teacher held a mixture of incongruent views, both traditional and relativistic, about the nature of physics knowledge. These views were shaped by the textbook used and the teachers' formal education and were passed on to the students via instruction. Instruction was driven by planning needs. Abstract knowledge was avoided and knowledge was made concrete and restructured in order to cover a wide range of content. The author concluded that the teachers had compromised their professional ideals to cope with the realities of the workplace.

Eve and Dunn were concerned about the level of psuedoscientific beliefs held by teachers and the consequence of holding these beliefs on instruction. Three hundred and eighty-seven life science teachers who were NSTA members responded to a questionnaire prepared by the researchers. Analysis of the responses to the questionnaire indicated that one-third of the teachers supported beliefs associated with creationism, especially special creationism which asserts that the earth is young, and that mankind and dinosaurs coexisted. One third of the teachers would choose to teach creationism if they had to choose between creationism and evolution. Sixteen percent of the teachers reported that they were encouraged to teach creationism. Biblical literalism was correlated with self-reported religiosity, formal religious education, and political conservatism. It was not correlated with age, sex, level of education, or region of the country. Belief in non-religious pseudoscientific assertions ranged from 10% to 35% depending upon the topic.

Wolf examined the influence of classroom discourse on students' perceptions of science. She analyzed the lesson interactions of one teacher and 23 gifted seven and eight year olds during a four-week summer school. Class activities and interactions were tape recorded for future analysis and the teacher was interviewed about the objectives of the lessons. The interactions were analyzed looking for examples of three views of scientific inquiry: sensational, in which the focus is in sensory experiences; formalist, in which the teacher's knowledge establishes the purpose and direction of the class; and rational, in which both teacher and students have varied experiences that they bring to science and apply them to new materials. The author found that the sensational view of inquiry dominated the interactions. The rational view was introduced by the students rather than by the teacher.

Although scientific literacy is often stated as a goal of science education, content information still dominates instruction. To illuminate this phenomenaon **Hatcher** decided to determine the support for scientific literacy among practicing teachers and principals. He sent a questionnaire to teachers and principals in Kentucky to identify level of support, activities that foster literacy, and the extent to which literacy activities were incorporated into science teaching. The data indicated that teachers and principals supported scientific literacy as a goal of science education. Teachers believed that the traditional activities such as interpreting and analyzing data that they used were important for fostering scientific literacy. The author concluded that teachers were convinced of the importance of teaching for scientific literacy and needed help in finding appropriate instructional techniques and activities.

Metzendorf investigated the practices of secondary science department heads that influenced teachers' instructional practices. He sent a questionnaire to teachers and department heads asking them to rate 95 practices as to perceived influence on practice. Forty-seven department heads and 82 teachers participated in the study. The author concluded that teachers and department heads viewed most practices as positive influences on practice. Negative practices for teachers were those that interfered with autonomy. Department heads supported some but not all practices that promoted teacher autonomy.

In another study of classroom practices, **Siow** investigated the perceptions of classroom practices of chemistry teachers and science education faculty in Malaya. Eight science education faculty members and 286 chemistry teachers responded to a questionnaire that required them to rank the desirability of 36 classroom behaviors. They were also asked to answer questions about their background. In general, there was a great deal of agreement between teachers and faculty. Teaching the SI metric system, maintenance of a safe and orderly laboratory, and serving as role models were ranked as the three most important classroom behaviors. Most respondents believed that classroom behaviors that required the teacher to consider the community environment to be an extension of the classroom, be proficient translating their knowledge of and practice in research methodology to effective pedagogy, and participating in the development of a national curriculum were undesirable. The author concluded that these beliefs influenced practice and that this knowledge should be used to improve preservice preparation.

What does the research tell us about recent trends in preservice teacher preparation?

Hall, McCurdy, Tilaner and Staley examined the effect of a science methods course that stressed hands-on, inquiry, science processes, social interaction, and microteaching on a sample of 74 preservice elementary teachers. In particular, they were interested in the effects on science anxiety, content achievement, and intellectual development. The preservice teachers were given pretests before the beginning of the course and posttests at the end of the 14-week course. The data analysis indicated that reasoning and content achievement were enhanced and science anxiety diminished as a result of the course. Anxiety, content achievement, and final grade correlated moderately with reasoning ability. There was no correlation of anxiety, content achievement, or reasoning with microteaching scores. However, the final course grade was moderately correlated with microteaching scores.

A microteaching course was the focus of **Lederman and Gess-Newsome's** study. Seventeen preservice teachers were required to present four lessons using lecture/recitation, a laboratory activity, a general inductive model, and a general deductive model. After each lesson, the students received feedback in the form of informal verbal feedback from peers, formal written feedback from the instructor, and a videotape of their lessons. Students also conducted self- critiques. In addition, the preservice teachers responded to a questionnaire that asked about perceptions of teaching, instructional behavior, and decision making. Qualitative analysis of these data resulted in 12 categories of concerns that the preservice teachers had for themselves and for their students. The first concern was for themselves. They were concerned about their physical appearance and speech. They were concerned about how they would get through the mechanics of the lesson, e.g., how to use the audiovisual equipment, finding and following their lesson plans. Student concerns centered around awareness and reactions to student behavior, getting students involved in instruction, choosing relevant instruction, using questions and AV equipment properly, good management, and planning. There was a slight shift of concerns from self to students as the course progressed, but this shift focused on how students can cause teachers to flounder or execute their instructional plan. Planning was viewed as a two step process in which the lesson plan was written and then mentally rehearsed.

Wright, Powers and Brown investigated the effects of intensive instruction in cue attendance on the thought processes of preservice elementary teachers engaged in inquiry skill tasks. Seven preservice teaches were assigned to the cue attendance treatment and seven to the control group. The intervention was designed to enhance the ability to observe details, ask questions, and to generate hypotheses when engaged in inquiry skills tasks. A comparison of the treatment and intervention group indicated that the students in the treatment group performed better on inquiry skills tasks than the control group because the students were able to observe and consider a greater number of alternative relevant cues.

Loving was concerned about the role of the philosophy of science in science teacher preparation. She explored the need for a philosophy of science course and evaluated the current status of such programs through the analysis of textbooks, a 17 institution survey, and a literature search. She concluded that science teachers, graduate students in science education, and science education professors had little background in the philosophy of science or the structure of science disciplines. Philosophy of science was seen as irrelevant to science education. If it appeared in programs of study, it was an incidental part of methods courses. The author recommended that science education programs include a course in the philosophy of science that explores the various philosophical positions to explain what scientists do and the dynamic structure of science. The course should include how theories are viewed as real world representations and how they should be evaluated.

Elementary teachers have frequently been found to have poor attitudes toward science. **Stefanich and Kelsey** attempted to improve attitudes by developing a pragmatic, success-oriented content course for teachers. This course combined physical and biological concepts that were appropriate for the elementary school and hands-on teaching strategies. One hundred and fifty students were enrolled in this course. In addition, the students were required to take two general education science courses and a science methods course. The control group consisted of 318 students who enrolled in two general education science courses prior to taking a science methods course. Both groups were given the Shrigley Science Attitude Scale for Pre- Service Elementary Teachers. Chi square analysis was performed on the data. The authors concluded that the success-oriented course was successful. Students in the course had more positive attitudes toward science content, handling science equipment, and science teaching than the control group.

Jones and Norman investigated the effects of a preservice elementary science methods course which emphasized mastery learning of process skills on process skills acquisition and logical thought. Eighty-one students in the experimental group and the control group were given the TOLT and TIPS to assess logical and scientific processes before and after the methods course. The authors compared the pre and posttest scores and performed correlational analysis. The results indicated that there were pre to post gains for concrete, transitional, and formal thinkers among students in the experimental group. Students in the experimental group performed better than students in the control group on the TOLT and TIPS.

In another study of process skills, **Scharmann** examined four different approaches to presenting pedagogy, content information, and field experiences. In the first approach, students were enrolled in three semesters of integrated coursework of pedagogy, content, and field work (n= 64). In the second approach, students enrolled in three unintegrated courses that dealt with content, pedagogy and field experiences (n=49). In the third approach, students enrolled in content courses followed by pedagogy courses (n=22). The fourth group served as a control and consisted of students enrolled in a science process skills course (n=29). Data were collected using the TOLT for logical thinking, the Internal-External Locus of Control Instrument for locus of control, the Metropolitan Achievement Series-Science Subscale II for content knowledge, and the Nature of Science Scale for understanding the nature of science. Because of the small sample size in some of the groups, the data were subjected to nonparametric analysis including the Kruskal-Wallis ANOVA and the Wilcoxon tests. The authors concluded that the organization of instruction had no effect on locus of control or the development of logical thinking. Students in group three learned the most content and students in group four learned the least. No patterns or pairwise contrasts for understanding science emerged. The greater the integration of content and pedagogy emphasizing process skills the less either was understood by the students.

Wilson conducted another study that looked at the effects of integration of field experiences, microteaching, and coursework for preservice elementary teachers. Forty students were enrolled in a science methods course and assigned to one of four treatment groups. Students in group one participated in four weeks of microteaching on campus. Students in group two participated in two weeks of microteaching on campus followed by two weeks teaching in the field. Students in group three participated in two weeks of teaching in the field followed by two weeks of microteaching on campus. The fourth group served as a control and the students participated in four weeks of teaching in the field. The author used ANOVA with repeated measures to analyze the data from an instrument he had developed, the Attitude Toward Teaching Elementary School Science. This instrument was based on the Fishbein and Ajzen's model of reasoned action. The author concluded that microteaching used in conjunction with early field experiences or used alone did not affect attitude scores.

Thirty male preservice science teachers participated in a study of the use of video tape to enhance competencies for stating behavioral objectives and selecting instruction. **Abdu-Munim** assigned 10 students each to 1 of 3 treatments. Group 1 received instruction through a videotaped lecture. Group 2 received instruction through a videotaped panel presentation and discussion. Group 3 received instruction through the video taped panel. Each group viewed five different tapes with the same content but different presentations. Students were assessed by seven tests developed by the researcher to measure competencies in stating behavioral objectives and selecting appropriate instructional activities that matched the objectives. Analysis of variance revealed that the students in the videotaped panel and discussion outperformed students in the other two formats on all of the seven assessments. There were no interactions. The author concluded that the discussion provided elaboration of the ideas and improved retention and information processing.

Baird, Fensham, Gunstone and White were involved in a three-year naturalistic study of educational improvement through group change. The study had both a preservice and an induction year component. Thirteen preservice teachers, 9 veteran teachers and 64 secondary students were involved in reflection on practice that focused on what it means to be a teacher and learner of science. The preservice component consisted of a year of coursework in a Diploma of Education program that was designed for reflection on practice and the learning experience. Students were placed into groups of 15 to 18 in which two professors participated. Throughout the year the students were continually involved in activities that encouraged reflection on practice that examined classroom content and context, and phenomenological reflection that examined essential life experiences as a teacher or learner. These reflective activities resulted in personal development in the cognitive realm. The students made improvements in task-related competencies such as management skills. They also made improvements in the more general areas of competence in the affective realm such as self-confidence and beliefs about the nature of teaching. These affective competencies were the most valued areas of growth. These same students continued to participate in seminars that emphasized reflection as they were engaged in student teaching. The students reported that this support system resulted in group work and interpersonal relationships that had a fundamental and profound influence on the continued affective and cognitive development of the participants. Again, the participants reported the greatest influence on affective development. In the third year of the study, the student teachers entered their induction year as novice teachers. Both the novice teachers and the high school students in the study became part of the research team. This experience deepened the nature and extent of the teachers' reflection and increased the level of satisfaction with their profession. The high school students became more responsible for their own learning and the teachers became more perceptive, resourceful classroom practitioners. The authors concluded that reflection in the cognitive and affective realm was needed in order to bring about significant and lasting change.

As part of this three-year naturalistic study, **Gunstone, White, Baird, Mitchell and Fensham** looked closely at the development of the preservice teachers from three broad areas of constructivist learning: student teachers' view of teaching and learning, their understanding of the content they teach, and their views of self. Data from diaries, individual and group interviews, written evaluations, and summative reports were used to arrive at conclusions. The authors found that personal and intellectual growth was influenced by incoming competencies. The preservice teachers believed that intellectual growth and reflection were important aspects of the program but group work and the interpersonal relations that developed were valued the most. Many students claimed to have changed as a result of the program but the researchers could find no evidence of change in some while other students had undergone great change and were not aware of it. The authors concluded that self needs were an appropriate focus and starting point for a teacher preparation program.

Krajcik and Penick evaluated the effectiveness of a teacher preparation program for secondary science teachers called Iowa-UPSTEP. The program consists of four field experiences, three semesters of methods coursework, two courses in the history and philosophy of science, and 15 taped critique sessions. The purpose of the program was to develop teachers who had a research based rationale for the decisions they make in the classroom. Thirty-seven graduates of the UPSTEP program were compared to 75 participants in a highly selective Honors Workshop. The workshop participants were Presidential Award Winners and others who had been identified as exemplary teachers.

Both groups of teachers completed the 1985 version of the National Survey of Science and Mathematics Education. Students of the UPSTEP graduates responded to a modified version of the Preferences and Understandings Questionnaire which served as a measure of their perceptions of science, science teachers, and science teaching. Comparing the responses on the national survey, the authors concluded that the UPSTEP teachers were not different from the Honors Workshop teachers. They had similar course objectives and teaching strategies, and used materials and equipment in the same way for similar amounts of time. The authors also concluded that the UPSTEP teachers had a positive effect on students' attitude toward science. They taught differently from the norm and, as a result, their students were different from the norm. The authors believed that the structure of the UPSTEP program was successful in developing, in relatively novice teachers, characteristics of exemplary teachers.

Oats and Baird used a sample of 491 secondary teachers with Master's degrees in a study to determine whether preservice preparation of science teachers differed from that of other teachers in the perceived source of general teaching knowledge. Teachers were mailed a survey with 34 questions about instruction and class management, instructional strategies and technology, the learner as an individual, and the social and professional aspects of teaching. The science teachers' attribution of sources of personal teaching knowledge differed from teachers in general on only four items. These items were use of media, adapting materials for individual differences, relating materials to student experiences, and working effectively with multicultural students. The authors concluded that science teacher preparation was undifferentiated from general teacher education and that science teachers see their source of knowledge as their own experiences.

In a philosophical piece, **Moon** argued that preservice science teacher preparation must be rethought. In particular, preparation programs must provide opportunities for prospective teachers to reflect upon their role as a translator of science. As a translator, the teacher must interpret the historical and philosophical underpinnings of science that help students understand the connections between scientific processes and thinking or science and society.

What does research tell us about the recent trends in inservice teacher preparation?

Hill evaluated the effects of a peer training program to change the science teaching practice of third grade teachers. The first step in the program was to train classroom teachers to be resource persons for all the third grade teachers in one school district. The training consisted of hands-on activities. The second step in the program was to assign the third grade teachers to one of three treatments: teachers receiving visits from a consultant once, twice, or not at all. Teachers who received visits from a consultant kept a record of the science activities and lessons they taught. The author performed analysis of variance on the data from the records. This included the amount of time spent on science instruction, the number and type of science activities (hands-on vs. lecture or reading). The author concluded that the visits were effective in increasing the amount of time spent on science and the number of science activities used in instruction. The intervention was not effective in changing the kinds of science activities used because there was no difference in the percentage of hands-on activities by group. There was no significant difference between the group receiving one visit and the group receiving two visits.

In a related study, **Tobin and Espinet** examined the effectiveness of two coaching models to bring about changes in the classroom practices of a single teacher called Jonathon. In the first model, science educators provided the coaching and in the second model, peers provided the coaching. Coaching took place over a six month period and was based on classroom observations of peers made by Jonathon, observations of Jonathon made by the peer coach or science educators, analysis of videotapes, and discussions. Weekly analysis and discussions by the researchers concerning Jonathon's teaching and attempts to change led to the following conclusions. Jonathon was having discipline and management problems that had a negative impact on his ability to implement the curriculum. This stemmed from his high tolerance for misbehavior. He was also limited in content knowledge which also interfered with the successful implementation of the curriculum. His instruction consisted of the transmission of facts through lectures. He did not point out the interrelationships among ideas or concepts, ask higher order questions, or teach for understanding. In addition, he did not include a laboratory component in his instruction. As a consequence, he felt that written lesson plans were unnecessary. Planning was in terms of his needs and not the students'. Neither coaching model was effective in bringing about changes in Jonathon's teaching. His content and pedagogical knowledge limitations rendered the coaching useless. He had difficulty diagnosing his own weaknesses because he saw his role as knowledge dispenser and did not perceive a management problem. He was unable to simultaneously change his teaching strategies and teach new content.

Zielinski and Bernardo evaluated the effectiveness of a summer in-service program to bring about changes in attitudes, concerns, and knowledge about science, technology, and society (STS) concepts in a group of secondary science teachers. The inservice experiences were based on the Concerns Based Adoption Model. The workshop lasted 10 consecutive days. After the workshop, teachers were to design and teach a 10-day STS unit. Prior to and after the workshop the participants responded to a questionnaire designed by the researchers to identify concerns, attitudes, and knowledge. The students of the inservice participants and a control group of students were also tested for knowledge, attitude, and concerns about STS concepts before and after the 10-day instructional unit. The authors concluded that the inservice was successful in reducing teacher concerns about teaching STS concepts and increasing their knowledge. It was also successful in increasing positive attitudes toward STS. The students of the inservice participants scored 13 percentage points higher than the control group students in knowledge about STS concepts.

A video cassette was developed by **Winnett** as an alternative to a live presentation for inservice workshops. He developed and validated a video cassette to instruct teachers in how to teach the Elementary Science Study (ESS) module Batteries and Bulbs. To test the effectiveness of this approach, he trained 20 fifth and sixth grade teachers to teach Batteries and Bulbs, using just the video cassette. A comparison group consisted of 20 fifth and sixth grade teachers who had attended a traditional live presentation workshop to train them how to teach Batteries and Bulbs. The 40 teachers then taught the unit to 891 students. The students were assessed by the Basic Electricity and Magnetism Test used as pre and posttests. ANOVA was used to examine pre and posttest differences. The author concluded that small but statistical differences existed that favored the live workshop approach for inservice training. However, he felt that the actual educational differences were not large enough to warrant choosing the live workshop over a video cassette approach to inservice training.

Spence conducted a study to determine the status of marine education in K-12 science and the inservice needs in this area. Responses to a statewide survey indicated that 86% of the teachers responding taught some marine science concepts. The importance of marine science instruction was highly correlated with the teachers' confidence in teaching marine science topics. Preparation to teach was based on personal experiences. Inservice opportunities varied by grade level. Primary and middle school teachers had fewer opportunities than secondary teachers. Primary teachers wanted inservice experiences to be short and involve videos so that the teachers could see the marine environment. Primary teachers also wanted ready-to-use materials that would require little preparation or involvement from them. Secondary teachers were more mobile, willing to travel to marine sites for workshops and more able to modify materials and curricula for their own use.

Fraser-Abder describe a workshop model that was used to develop elementary science curriculum in Trinidad and Tobago. She also reported on the effects of the workshop on teacher attitudes toward science. Each workshop consisted of 10 days of meetings over a 7 week period. The workshops focused on science content, hands-on activities, videotaping of teaching, supervisor, peer and self evaluations, teach\reteach activities, confidence building activities, and information about child development in the context of science instruction. Spreading the meeting times over seven weeks gave the participants an opportunity to try out what they had learned and to return to the workshop for discussions and further education. Fifty teachers participated in the workshop. Each teacher responded to the Science Attitude Scale for In-Service Teachers before and after the workshop. The pre to posttest changes indicated a shift to a more positive view of science. Science was no longer too complex to understand. Fewer teachers reported they feared to teach science because of inadequate subject matter knowledge. More participants reported that science was their favorite subject after the intervention than before. The participants especially enjoyed manipulating the equipment. A follow up posttest indicated that the changes in attitude were sustained over time.

The evaluation of an inservice college course for middle school teachers was the focus of **Norman's** study. He was involved in designing a college course that would teach basic and integrated process skills so that the participants would be exposed to both a generic and specific science activity that called for the application of a skill. The students were also exposed to two ways to teach the skills: the learning cycle and a modeling strategy. Students were given the opportunity to practice their teaching skills during the workshop. Students also had a resource book that accompanied the activities in the workshop. The workshop met once a week for 3 hours over a 10 week period. Few of the participants had science teaching majors despite their teaching assignments as middle school science teachers. Few were formal thinkers. The author concluded that although the participants were capable of learning the process skills and made gains in logical thinking, they were not able to translate their knowledge into instructional strategies to teach process skills. The problem was so severe that the participants were unable to write lesson plans that would effectively teach process skills.

In another study of middle school science teachers, **Abell** examined the effectiveness of a problem solving in-service program on instruction and attitude. Forty-four middle school teachers participated in a program that consisted of five meetings during the spring semester followed by a three-week summer program and monthly support meetings during the fall semester. Participants in the program and a control group were given the Science Attitude.Inventory as a pre and posttest measure of attitude. Inservice participants were also videotaped as a way to assess instructional changes in the classroom. The author concluded that the inservice program on problem solving had no effect on attitude when compared to the control group or within group from the pre to posttest. Instructional behavior moved from a teacher-centered approach to a more student centered approach that focused on problem solving activities such as probing for clarification. The teachers reported more changes in their teaching than the author actually observed.

Finson also conducted a study that looked at the effectiveness of an inservice program to change attitudes and concerns. Twenty-one elementary teachers participated in an earth science program that consisted of 3 pedagogy workshops of 10 hours each and 64 hours of content instruction during summer school. The workshop focused on inquiry, cooperative learning, and other nontraditional and informal forms of instruction. Teachers had the opportunity to practice using their new skills in their classrooms, to conduct self- evaluations and to receive feedback and analysis from their peers. All the participants were assessed before and after the inservice program using the Scientific Attitude Measure and the Stages of Concern instrument. A control group was selected to participate in the study and was also given the assessment measures. The data analysis indicated that the inservice participants had a more positive attitude toward science than the control group. Changes in teacher concerns from pre to posttest were as follows. Personal concerns remained the same, concerns over information declined, and concerns about management and collaboration were increased. Overall, there was a shift from self-centered concerns to concerns about what would benefit students.

Roseman and Brearton reported on a project designed by the Johns Hopkins University and the Baltimore Public School System to help teachers acquire the skills needed to effectively integrate computers into the science curriculum. One hundred teachers participated in the project from 1986 to 1988. Their level of experience with computers ranged from novice to expert. The inservice consisted of teacher training, acquisition of hardware and software, the development of model lessons, and the establishment of a diverse and extensive support system. The preliminary results indicated that 90% of the teachers who participated in the project were using computers to manage instruction. Seventy-five percent were using computers in their science instruction in the form of probeware and data base software. Seventy percent were using commercial software. The authors concluded that most of the teachers had been successful in integrating technology into their science lessons.

Motivation is an important aspect of learning. **Johnson** investigated how motivation affected 15 K-6 teachers who participated in a Title II science update inservice program. The inservice program took place over a two-week period and was designed to focus on process skills. Participants were asked to respond to the Science Attitude Survey and a content knowledge instrument as pre and posttests. Qualitative methods were used to provide further information about the quantitative data. A follow up questionnaire was sent to the participants six months after the conclusion of the workshop. The data analysis indicated that there was a substantial gain in content knowledge from the pre to posttest. There was no such change for attitude because of a ceiling effect. The incoming attitude of the participants was so positive that no change could be measured. The factors that motivated the teachers to change were self-satisfaction gained from learning experiences, a desire to remain current, student needs, and their dissatisfaction with themselves. The participants expressed a need for modest resources, up-to-date textbooks, administrative support, and background materials to use in their classrooms.

Baird and Rowsey conducted a needs assessment of 11 inservice centers and the 797 high school teachers associated with the centers. The results of the assessment indicated that inservice needs are for: (1) information and activities about materials that will motivate students, (2) information about where to obtain instructional materials, (3) instruction in computer use, (4) updating personal content knowledge, (5) methods of assessing personal teaching effectiveness, and (6) instruction in the construction of laboratory equipment. Teachers did not express a need to know how to do clerical tasks, assign grades, administer tests, communicate with parents, or write lesson plans.

The Saint Louis University Science Education Resource Institute (SERI) was a summer institute for elementary and middle school teachers. The institute stressed process skills within the context of content instruction. **Shugart** evaluated the effectiveness of this institute by comparing the science knowledge of students who had been taught by SERI participants and those who had been taught by non-participants. The students were in the second, fourth, fifth, sixth, and seventh grade in suburban public schools. All students were given the Comprehensive Tests of Basic Skills (CTBS). T-tests were performed to compare the results of the CTBS scores of the students at each grade level. Students in the second, fourth, and fifth grades taught by the SERI trained teacher did not do significantly better than students taught by teachers who did not participate in the institute. Students in the sixth and seventh grade who were taught by SERI trained teachers had higher achievement scores on the CTBS than students taught by non participating teachers.

Barnes and Barnes observed teachers in a two-week summer institute designed to change misconceptions. The institute focused on process skills, physical science concepts, and strategies that facilitated self questioning in situations where the learners identified conceptual difficulties. The participants were 11 elementary teachers. After an introduction to the basic and integrated process skills, the teachers completed a questionnaire that was designed to identify misconceptions about density. A two-day treatment was developed based on the misconceptions identified by the density questionnaire. The treatment consisted of strategies that encouraged the teachers to ask themselves and their colleagues questions about density as they engaged in hands-on activities. After the treatment, the teachers responded to the same questionnaire used for the pretest. Analysis of the pre and posttest differences indicated that several teachers corrected some of their misconceptions. Other teachers maintained their original misconceptions or changed their original ideas but replaced them with another misconception. The authors concluded that further remediation was needed to completely replace the misconceptions with more accurate concepts.

Taking a slightly different perspective, **Gurney** engaged in collaborative research with teachers to develop and try constructivist teaching strategies that resulted in changes in the teachers' classroom behaviors. Strategies were developed that: (1) created a safe environment where mistakes were acceptable, (2) modeled attitudes and behaviors, (3) provided objective and non-evaluative feedback, (4) helped teachers view instruction from the learner's point of view,(5) helped teachers guide inquiry into classroom phenomena, and (6) recognized the need to assimilate a new language. Data sources that encouraged reflection on practice were teacher anecdotes, audio and video tapes of lessons, interviews with students, teacher-developed instructional materials, and student products. The author concluded that this experience blurred the distinction between theory and practice and contributed to greater understanding of the components and processes of restructuring teaching.

Another collaborative effort in action research was reported by **White, Baird, Mitchell, Fensham and Gunstone**. They worked with classroom teachers to understand the nature and mechanisms of classroom teaching and learning in secondary science. Their efforts consisted of four phases: (1) establishing trust between the teachers and researchers, (2) training for the teachers to understand the goals of reflection and action research, (3) autonomous teacher-initiated collaborative projects, and (4) developing new partners by bringing the students into the collaborative research. Teachers read research, identified factors that might influence attitudes, and created working groups to investigate the factors. Students provided feedback in the form of lesson critiques and discussions. The authors found that the teachers had simplistic views of student learning and many misunderstandings. Consequently, they concluded that the intellectual development of teachers must be fostered before collaborative work can proceed. All the participants in the research found that student learning was difficult to change, understand, and generalize about because the factors that influenced learning changed with time, individuals, and context.

What factors affect the employment and retention of teachers?

Hounshell and Griffin were interested in the career patterns of the students who graduated from three teacher education programs at the University of North Carolina at Chapel Hill between 1977 and 1983 (n=77). They found that 37 (48.1%) of these graduates had left teaching one and a half years after their initial employment. The authors were able to contact 31 of the 37 to ask them to give their reasons for leaving the teaching field. Salary was the number one reason for leaving. They reported that most teachers will reach the top of the salary scale after 12-15 years in the profession with no prospects of increasing salaries without leaving the classroom and entering administration. The second reason was social. Teachers did not want to remain in a profession for which the public, students, and parents had little respect. The third reason given for leaving was professionalism. The teachers did not feel that they had the power to make professional decisions and the relationship between teachers and administration was strained. The last reason given was teaching conditions. The teachers felt that the rooms, equipment, and teacher workspace were poor.

Moe conducted a study of faculty inbreeding in chemistry and physics departments in universities to determine the effects of the practice on the life of university teachers. Questionnaires were sent to selected departments in doctoral granting institutions in the United States. The author concluded that inbreeding has negative effects on academic advancement, faculty mobility, scholarly productivity, institutional vitality, and institutional reputation.

Summary

Exemplary teachers integrated pedagogical and content knowledge. They had a positive attitude toward science and technology and confidence in their ability to teach science effectively. They read professional literature that focused on practical issues and their content background was appropriate to their teaching assignment. Ineffective teachers lacked appropriate background for their teaching placement or were in situations where the culture of the school did not allow good science education practice.

Teachers' decisions about practice were influenced by their beliefs about the nature and structure of science and scientific concepts. These beliefs influenced the choice of instructional strategies, whether or not a particular curriculum is accepted, rejected or modified, as well as student interactions, and classroom environment. Even when teachers held appropriate beliefs about science, they could not always translate them into practice because of situational constraints. Unfortunately, many beliefs about practice can be formed through interacting with instructors in content area disciplines who do not believe that teaching can be a subject of research or that there are alternatives to traditional instruction to teach and assess students.

Few commonalities exist among the studies of successful preservice teacher preparation. Mastery learning, reflection on practice, group work, special content courses, and courses that include cue attendance or which emphasize the role of research in decision making have all been successful approaches. Microteaching or attempts to alter the sequence of content, pedagogy courses, and field experiences had no effect on improving practice. What appears to be missing in all of preservice teacher preparation is an understanding of the history and philosophy of science and the relationship of these topics to teaching.

The majority of studies on inservice work with teachers reported some success. Again, the range of characteristics of effective programs was wide and included: (1) peer training, (2) self evaluation and peer evaluation, (3) Concerns Based Adoption model or other attempts to change the focus of teacher concerns, (4) process skills alone or in the context of content coursework, (6) problem solving and questioning strategies, (7) reflection, (8) opportunities to try out strategies and engage in teach reteach activities and (9) activities spread over a long period of time. In one case, coaching was not successful due to the severity of the problems to be remediated. Some researchers found that teachers had difficulty translating their knowledge into practice or that teachers believed that they had implemented more good practice into their classroom than observations supported.

Most teachers left the profession because of low salaries, lack of respect for teachers, poor working conditions, and poor relations with the administration.

TESTING AND ASSESSMENT

What new assessment instruments have been developed in 1989?

Germann developed and field-tested a Process of Biological Investigations (PBIT) instrument for high school biology students. The test was intended to measure developing hypotheses, making predictions, identifying assumptions, analyzing data, and making evaluations. The test items were selected from the *BSCS Resource Book of Test Items*. The test was reviewed three times and was determined to have a Spearman-Brown R=.82, a KR-21=.80 and Cronbach's alpha=.81. The difficulty level favored the more able students. The test was then used to determine the effectiveness of the Directed Inquiry Approach to Learning Science Process Skills and Scientific Problem Solving [DIAL(SP)2]. Two classes of more able students received traditional science instruction and two classes of less able students received instruction using [DIAL(SP)2]. After instruction, the students were given the Test of Integrated Process Skills (TIPS) to assess process skills, the Classroom Test of Formal Operations to assess formal operations and the PBIT test to assess process skills. The correlation of the PBIT and the TIPS was .73. The intervention was more successful with concrete than formal students.

Hansen reported on the validation of the Adaptive Test of Biology (ATB), a computerized secondary school biology test. To determine the validity of the test, the author administered the ATB and the conventional paper and pencil biology test of the National Association of Science Teachers (NSTA) and the National Association of Biology Teachers (NABT) to a group of 225 students completing a high school biology course. Eighty-seven percent were in introductory biology. The correlation between the NABT/NSTA Biology Test and the ATB was r=.80. The correlation of the first 13 items with the NABT/NSTA test was r=.70. The author concluded that the test had a high degree of validity and that the computerized format was an efficient way of doing large scale testing.

Pugh and Lock were also interested in ways to assess practical work in biology through the analysis of pupil talk. They developed an instrument that was a modified version of the Breen-Goodal linguistic framework. The framework consisted of elements, a corresponding category, and subcategory. Elements were initiating, uninitiating, and responding talk. The categories were general questions and general answers. The sub-categories were contact, requests/information, rhetorical; ruminative self-talk; positive, passive and rejection; information and verbatim. The authors applied the linguistic framework to transcripts of tapes of students working in three groups composed of three students. Each group had a different gender composition. Four coders analyzed the transcripts. Interrater reliability at the level of element was 72.1 to 83.3, at the category level 60.6 to 90.0. Reliability for code-recode were 82.4 to 94.4 for elements and 80.8 to 100.0 for categories. The responding element was the most difficult to code. The authors found that students made more initiating utterances than responding utterances. Students made many statements, asked many questions, and gave orders but no one responded to them. Most utterances that sought or required an answer were framed as commands rather than questions. Group interactions varied from democratic to dominance by one individual. Most talk focused on procedures. There was little talk about underlying concepts.

Blum worked on the establishment of taxonomic subclasses of application test items in biology. He used facet theory and small space analysis to analyze test item responses of 429 seventh grade students from 13 Israeli schools. He found that the test items could be distinguished by the number of principles needed to answer them correctly: one, two, or an unlimited number. He concluded that the complexity of an application item as indicated by the number of principles that must be applied to solve it was the major criterion for a taxonomic system.

In the physical sciences, **Peterson, Treagust and Garnett** developed a diagnostic instrument to evaluate misconceptions in covalent bonding and structure. The content of the instrument was defined by the authors through concept maps and propositional statements. Student understandings were determined through difficulties identified as a result of classroom teaching, interviews, student concept maps, and responses to open ended questions. These data were used to construct a two-tiered test of 15 items. Tier 1 assessed content knowledge and Tier 2 assessed understandings in areas such as bond polarity and molecular shape. The understanding tier was used to determine the reason why a student had selected his/her Tier 1 answer. The instrument was field tested on 245 eleventh and twelfth grade chemistry students in Australia. The reliability of the instrument was found to be $r=.73$, item difficulty ranged from .13 to .60 and the discriminant values ranged from .32 to .65. In addition to determining these instrument characteristics, the field testing led the authors to conclude that the students did not learn the concepts of covalent bonding and structure despite instruction and that the test was successful in identifying misconceptions in these areas.

Mulkey developed and validated an Early Childhood Attitude Toward Women in Science Scale (ECWISS). She used the Women in Science Scale as a template for the development of her items. Reliability studies indicate an alpha=.90, a split half =.87, .84, and .81 for the three sections of the instrument. Validity was established using the known groups procedures in which the null hypotheses of no differences among groups was rejected. Principle components evaluation yielded the following components: (1) specific self- concept, (2) home related sex-role conflict, and (3) work-related sex-role conflict. The instrument correlated with the Occupational Inventory ($r=.50$) and teacher observations ($r=.51$). Administration of the instrument to 791 K-3 students revealed that attitude toward women in science was affected by gender, race, age, ability, and SES. Older females from high SES backgrounds were most likely to agree with the concept of women as scientists. White males from lower SES backgrounds disapproved of the idea. More males than females disagreed that women could be scientists regardless of ability. More whites than other races disapproved and more older students than younger students disapproved.

Suspecting that the belief system of elementary teachers could influence whether science was taught, **Riggs and Enochs** developed a Science Teachers Efficacy Belief Instrument (STEBI). The instrument consisted of items from the personal Science Teaching Efficacy Belief scale and the Science Teaching Outcome Expectancy scale. Both scales were administered to a sample of teachers and the scale items were subjected to a factor analysis to create the new instrument (STEBI). The selection of items, as indicated by factor loadings, resulted in two factor-pure scales: efficacy belief and outcome expectancy. The resulting alphas were ($r=.91$) for the efficacy scale and ($r=.73$) for outcome expectancy. The authors concluded that the STEBI was a valid and reliable instrument for assessing teacher beliefs.

What are the best ways to use tests?

Yamin examined the effects of frequent versus conventional testing on chemistry achievement, test anxiety, and attitudes toward science. Conventional testing was defined as a midterm and final examination. Two hundred and seventy-eight university chemistry students were assigned to either the control group (conventual testing) or the experimental group (frequent testing). All other aspects of the chemistry course remained the same. Pre and posttest instruments were the State Trait Anxiety Inventory, the Science Attitude Questionnaire, and a chemistry knowledge assessment instrument. Data were analyzed using analysis of covariance. The analysis revealed significant differences between the control and experimental groups. Students in the experimental group had higher achievement scores in chemistry, and lower anxiety scores than students in the control group. There were no differences between groups for attitude toward science.

In another study on periodic testing, **Strawitz** examined the achievement of students in a self-instructional process-oriented science methods course. Fifty-four students participated in the study. One group of students was given weekly quizzes on the process skills assigned each week. The second group of students was instructed to learn the process skills and be prepared to take an end of course assessment. The end of course assessment was The Test of Integrated Process Skills (TIPS). Analysis of variance indicated that there was no significant difference in process skill acquisition between the two groups. These results contradicted much of the previous research, leading the author to conclude that the structure of the self-instructional course may have been responsible for the lack of significant difference. The materials included mastery tests and self checks that may have functioned in the same way as the periodic quizzes.

Zoller and Ben-Chaim examined the interaction between exam type, anxiety, and academic achievement in college science. The sample consisted of 83 preservice biology teachers. Students responded to the Hebrew version of the State Trait Anxiety Inventory and the Type of Preferred Examinations (TOPE) survey. The TOPE was designed to determine the preferred format for examination and the reasons why the format was preferred. Student responses indicated that they preferred examinations on understanding and analysis rather than on knowing and remembering. They preferred exams where they were permitted to use relevant materials to help them answer questions and formats where there was no time limitation such as take home exams. Anxiety correlated with the type of exam. Preferred types of exams reduced anxiety. A reduction in anxiety was correlated with higher grades, especially for lower achievers. Test anxiety varied by subject. Biology caused the least anxiety. Physics and chemistry caused more anxiety than biology but less than mathematics. Mathematics caused the most test anxiety. Overall, test anxiety was greater for females than males. Despite the fact that instructors are aware of student test format preferences, they insist on using their own favorite type of test.

What effect does testing have on curriculum?

Aloa examined the impact of the Nigerian national examination policy on teaching chemistry in secondary schools. A case study approach was used in which public figures involved in formulating educational policy were interviewed, documents were analyzed, teachers, school administrators were interviewed and given surveys, and a school and classrooms were visited. The author concluded that the examinations were an effective way of communicating educational policy because teachers were more responsive to the requirements to pass the examination than to textbooks or syllabi. The examinations fostered stability, uniformity, and quality in the curriculum.

In Australia, **DeLaeter** found that prior to 1960 the physics curriculum was based on the university entrance requirements. The curriculum reflected the old British model and did not have a significant amount of modern physics or address issues of application. The influence of the Physical Science Study Committee (PSSC), Harvard Project Physics (HPP), and the Nuffield courses was brief and did not last beyond the 1970's. Overall, between 1937 and 1987 university entrance exams had not changed except to become more mathematical. The author concluded that now that Australia has moved beyond using matriculation examinations as the sole determinant of university entrance, the biggest impediment to curriculum reform was changing teachers' beliefs and attitudes.

What reliability and validity issues concern science educators?

Another look at biology tests was conducted by **Brown and Njabili.** They explored the construct validity of a public examination used to determine employment and entrance into higher education. The multitrait method and factor analysis techniques were used. The exam had three parts: theory, practical, and O level exam. The analysis revealed that the correlations between the three parts of the exam were low. The two parts of the practical test were not factor pure. For example, the observation component of the practical section of the exam also tested for knowledge of theory. It was difficult to classify the test items into Bloom's taxonomy. The test did not consistently assess particular constructs. The authors concluded that the exam was not robust and did not have discriminant validity.

Practical exams are often assessed by teacher observation. **Hubbard and Seddon** conducted a study to determine if the size of the group to be assessed influenced the teacher's judgment of performance. Eight teachers carried out assessments of students' performance in a laboratory practicum observing groups of 5 or 20 students. The teachers were instructed on acceptable and unacceptable performance for tasks relating to the use of the Bunsen burner. Then the teachers were divided into two groups. The first group of teachers observed the 5 and then the 20 member teams while the second group of teachers observed the 20 and then the 5 member teams. The authors concluded that the size of the group observed did not influence the reliability of the assessment or the grade assigned for the practical work.

In a similar study **Hubbard and Seddon** examined whether there would be changes in assigned grades and reliability of assessment for two consecutive assessments. Eight teachers observed 80 students in groups of 20 preparing a salt by reaction of an oxide with an acid. Students were required to produce a salt and perform a filtration at an intermediate stage. Observation 1 took place in the morning and observation 2 took place in the afternoon of the same day. The teachers were instructed on what to look for and were allowed to observe the students in any order that they wished. A comparison of the evaluations from the first to second session indicated that the standards and reliability changed from the first to second observation. The majority of changes occurred when the teachers had to make judgments about filtrates and residues. A sex bias was found for both male and female teachers in favor of female students. In the second round of assessment, the teachers found satisfactory performance on items that they had been unsure of during the first round of assessment.

Terwilliger, Halley and Heller conducted a content validity study of the GRE Physics Test. Fifty-nine colleges and universities responded to questions about textbooks, physics courses and graduate programs. A panel of experts consisting of 16 physics professors was assembled to rate the textbooks and curricula on how well they would prepare a student to take the GRE in physics. The areas evaluated included: mechanics, electricity and magnetism, thermodynamics and statistical mechanics, modern, and quantum physics. The panel prepared two indices: R1, how well the text covered the GRE content and R2, how well the GRE covered the text content. Interrater reliability for R1 was good but was poor for

R2. The panel concluded that the undergraduate physics curriculum prepared students well in mathematics. About 60% of the material found on the GRE in electricity and magnetism was covered by textbooks. Schools with graduate programs in physics were more likely to use textbooks that covered the content of the GRE than schools without graduate programs. This was especially true for modern and quantum physics. Many items from commonly used textbooks were not found on the GRE but the authors could not determine whether this was a real mismatch of content or the result of the random selection of textbooks. The authors concluded that students who attend academic institutions that were strictly undergraduate institutions were at a disadvantage when they took the GRE in physics.

Kyle, Wolf, Bonstetter and Gadsen raised the issue of whether process science instruction and standardized testing were incompatible. The Iowa Test of Basic Skills Complete Battery and science supplement was administered to all sixth grade students in a single school district completing one, two or three years of science process instruction. The analysis of test performance indicated that the students who were exposed to process science for three years and consequently were exposed to only 42% of the content items performed as well as students who were exposed to 86% of the content assessed. There were no gender differences for the higher cognitive domains if the items were congruent with the curriculum taught and no gender differences for the lower cognitive domains even if the items were not congruent with the curriculum. Males did better than females only on items that were covered by traditional textbook-based programs and on items that were not part of the school curriculum.

Robottom was concerned about the appropriateness of applied science approaches to evaluation in environmental education. He argued that the technicist approach was not appropriate because this approach was derived from a positivist position in which evaluation is value free, objective, and the evaluator is outside of the problem. Environmental education is essentially values education. Therefore, he argued for alternative approaches to evaluation that are interpretive such as illumative evaluation, phenomenology, case study, portrayal, and democratic evaluation. All of these approaches place the evaluator within the problem and acknowledge the political orientation and values that are embedded in making judgments.

Summary

Test development has focused primarily on biology. Tests have been developed to assess biology process skills, general biology using a computer delivery system, and practical biological skills using an observational instrument to code language. In the physical sciences, a test for assessing misconceptions has been developed. In the affective area, an early childhood attitude scale has been developed and a scale to measure elementary teachers' efficacy beliefs. All of these instruments seem promising and have reasonable reliability and validity.

In one study, frequent testing led to increased achievement and decreased anxiety. However, in another study frequency did not affect achievement. This negative finding was at variance with the majority of the research in this area and may be the result of a design flaw. When students were given the choice to be tested using their preferred exam type, achievement increased, especially for lower achievers, and anxiety was reduced.

Reliability and validity issues were the concern of several studies. These included the effect of group size and frequency of evaluation on grades, the match between GRE content and physics instruction, the match between standardized tests and process instruction, and evaluation in environmental education. With the move toward greater teacher and school district accountability and state mandated testing, this area of research in science education should be expanded. For example, two studies indicated that where there is a national examination program, the examinations drive the curriculum. Another study indicated that a national examination had poor construct validity.

TEXTBOOKS AND TEXT COMPREHENSION

What does textbook analysis tell us about the quality of science textbooks?

Dazler conducted a gender analysis of high school chemistry textbooks. She compared seven current texts to their earlier editions (1970-73) for gender fairness in illustrations and analogies. Data were analyzed using descriptive statistics, Chi square tests, and proportion reduction in error. The author concluded that there were no significant differences in the relative frequencies of illustrations of boys and girls between the 1970 and current editions. Parry, Basssow and Merrill's 1987 chemistry text was the only one that had achieved a balance between male and female illustrations. The other six textbooks overwhelmingly favored illustrations of males. Texts by Choppin and Summerlin (1982) and O'Connor, Davis, McNab and McClellan (1982) had more analogies in their text than earlier versions but only the Choppin and Summerlin text favored female images.

Chiang-Soong analyzed 12 secondary science textbooks from the perspective of: (1) use of page space, (2) emphasis on technical terms, (3) readability, (4) laboratory activities, (5) inserted questions, and (6) coverage of science technology and society (STS) issues. She found that no more than 45% of the page space was devoted to narrative, but in the case of chemistry, the narrative was written above the intended readers' ability. More narrative and technical terms were found in trade books than in texts that support NSF-sponsored science programs. Many of the laboratory experiments were not open ended, but provided the problem, procedures, and desired results. Questions were less than 4% of the total sentences in the text and were primarily rhetorical. Less than 3% of the text was devoted to the nature of science and appeared as an introductory chapter, especially in junior high textbooks. Less than 7% of the narrative was devoted to STS issues or activities and the coverage of these issues decreased as the intended grade level of the text increased. The author concluded that science textbooks were limiting students and would not help them reach the current goals of science education.

Holt Rinehart and Winston high school biology textbooks (Modern Biology) were the focus of a longitudinal study. Eltinge conducted a content analysis of these texts spanning 1956 to 1985. The 1956, 1965, 1977, and 1985 editions were chosen for in-depth analysis. The focus of the analysis was the presentation of science as inquiry. Chapters on genetics, leaf structure, and the introduction were analyzed using a process of linguistic content analysis. The categorical data arising from the content analysis were subsequently used in a regression equation. The results indicated that the level of inquiry varied across the four editions. Inquiry was higher in 1965 and 1977 than in the 1957 and 1985 editions. An emphasis on inquiry was highest in introductory chapters and lowest in the chapters on leaf structure. Inquiry received the most emphasis in the beginning of chapters, at the beginning of paragraphs, and in sentences that did not contain technical words.

Hehr conducted a content analysis of Texas state adopted textbooks in the life, earth, physical, and biological sciences. The purpose of the analysis was to determine if the textbooks contained concepts, content, attitudes, and process skills that had been identified as the minimum competencies for high school graduates to be considered scientifically literate. The sample consisted of 25 texts from which chapters were randomly selected. The author developed her own evaluation instrument and a set of procedural rules. She used this instrument and the procedural rules to train five secondary science teachers to analyze the texts. A total of 11,784 pages of narrative were examined to identify 53 life science, 42 physical science, and 20 ecological concepts. The concepts were coded as defined, partially defined, explained, or example. Scientific attitude and processes were coded as present or absent. The author found that the degree to which students are exposed to concepts, attitudes, and processes necessary for scientific literacy varied from text to text. Scientific attitudes were usually confined to the chapter devoted to the scientific method. On the other hand, there were many process skills. However, some of the laboratory activities were so poorly written that it was difficult to identify the process the activity was supposed to teach. Few concepts were defined or even partially defined. **Hehr** concluded that students had to learn the concepts by an inductive process using the explanations and examples given in the text.

Another study of Texas state adopted textbooks focused on the biology texts. **Fillman** analyzed 11 introductory biology texts to ascertain the degree to which they addressed four aspects of scientific literacy. He found that science as knowledge represented 65-80% of the text. Science as investigation represented 10-20% of the text, and the interaction of science, technology, and society represented 1 % of the text. Science as a way of thinking was not represented in the text.

Hamm and Adams analyzed sixth and seventh grade textbooks for the coverage of global problems and issues. They were looking for examples of population growth, world hunger, air quality and atmospheric issues, water resources, and war technology. Ten textbooks were selected that represented 90% of the texts used in the state of California. Five coders were trained to use an instrument developed by the authors. Four thousand, three hundred and ninety-three pages of text were coded. Each text was compared with all the others at the same grade level and Chi-square analyses were performed. The authors found that less than 2% of the texts devoted any space to global problems and issues. Population, air, and water issues were more frequently addressed than hunger and war technology. There were no differences among the various publishers' series.

In Malaysia, **Dali** analyzed four chemistry and biology textbooks. He concluded that the textbooks were generally inadequate in the areas of design, the structural patterns of paragraphs and chapters, the density of difficult or unusual vocabulary, and the way editorial features were used. The author concluded that this analysis had implications for science education in Malaysia because teachers were not adequately prepared to teach reading or diagnose reading problems and students did not have adequate reading skills.

In one of the few analyses of elementary textbooks, Staver and Bay examined 11 K-3 texts in terms of conceptual structure and reasoning demands. They applied the technique of conceptual maps to depict conceptual relationships within 17 segments of text on air and water. The conceptual structure of the material varied from text to text but most of the structures were well defined. However, the reasoning demands of the material were well beyond the ability of K-3 children. The texts demanded classificational, interrelational, and observational reasoning which was difficult to apply to the pictures and the text. The level of reasoning required concrete operations but most of the target audience of the textbooks could be expected to be preoperational or transitional at best. The authors concluded that writing a science text for preoperational children was difficult and that their findings supported hands-on instruction.

Evans examined fourth grade science teacher's manuals to determine if they were discovery/inquiry/process oriented and included concrete hand-on activities. He was also interested in the reading and vocabulary demands of the texts. Seventeen fourth grade teachers and 360 of their students rated textbooks published by Silver Burdett and by Merrill. The instrument they used was a modified and shortened form of the instrument developed by CASST (Criteria for the Analysis and Selection of Science Text) project. The teachers reported that the Silver Burdett manuals were more activity oriented than the Merrill texts and the texts were more appropriate for below-grade readers. The students using the

Silver Burdett texts reported that they remembered doing more activities and remembered more content. The Merrill teacher's manual provided more background information for the teachers.

Strube examined the language of physics textbooks from the perspective of literary style. He found that textbook writers employed a distant authorial voice, were concerned with precision, had limited context, limited syntax, and used a rhetorical style. The authorial voice was remote, anonymous, formal, and lacking warmth. Concern for precision was evidenced by an over emphasis on logical arguments, definitions, and formal reasoning at the expense of concept development. The context was inappropriate for the students' world and lacked vivid figurative language. The syntax was represented by long, involved, complex sentences without alternative flexible ways of presenting information. The presentation style was rhetorical, traditional and rigid. The author argued that style is a neglected aspect of readability that should be attended to when selecting a text.

In another study of physics and chemistry texts, **De Berg** examined the emergence of quantification in pressure-volume problems. Twenty-eight texts were examined for sequencing from simple to complex and qualitative to quantitative. The author found that gas properties were presented from qualitative to quantitative and from verbal to algebraic material in accord with learning theory. However, the qualitative properties of gases were given minimal presentation and the ideas were not placed in a historical context. Few texts stated the purpose of the gas laws so students were unable to see the need to understand them.

How much do teachers rely on textbooks?

Yore and Denning explored teacher reliance on textbooks and the inclusion of reading instruction in secondary science. They conducted interviews and collected survey information from 428 secondary science teachers in British Columbia, Canada. The teachers indicated that reading a textbook was fifth out of nine possible instructional techniques they used. However, the activities below reading were never used at all. Reading, when used, appeared late in a lesson. Most teachers did not provide reading instruction and never used the text with classes of slow learners. Teachers did not do a reading assessment of their classes before making decisions about textbook use. Despite these responses, the teachers believed that reading was important to learning science. Since textbooks play an important role in science instruction, the authors recommended that science educators and teachers go back to the reading research, especially the research on cognitive and metacognitive skills, to inform their practice.

How successful is textbook-based instruction in comparison to other instructional approaches?

Skaggs compared the effectiveness of traditional (text alone and text with pictures) textbook presentation of the digestive system and intravenous therapy to two other nontraditional presentations. These consisted of a map alone and a map with pictures. One hundred and three students participated in the study. Students were also tested for verbal and spatial skills as predictors of information recall. In the first session, students were given training on map processing and tested for verbal and spatial ability. In the second session, the students studied the content. In the third session, the students were given free recall tests. The data analysis indicated that format affected recall. Students who studied the maps remembered more of the main ideas and students who studied the text remembered more details. Pictures did not affect recall in either the text or map format. Verbal ability was a stronger predictor than spatial ability for recall across all conditions. Spatial ability was important for the recall of main ideas in the text groups.

Gottfried compared the alignment of textbook-centered and the multiple reference approach to instruction to the Project Synthesis desired and actual states for biology education. Three textbook-centered and three multiple reference classroom were selected for a microethnography. The author used the ethnographic data to compile composite profiles of textbook-centered and multiple referenced biology classrooms. She then compared these profiles to the desired and actual states descriptors. She found that the textbook centered profile aligned very closely (95% of the data entries) with the actual state descriptors. The multiple referenced classrooms aligned 50% with the actual and 50% with the desired states of biology education. Regardless of approach, the teachers did not integrate the desired state characteristics into the evaluation process. Several other factors besides textbook-centered or multiple referenced affected whether classrooms were aligned with the desired states. These factors included: (1) the goals the teacher used to guide the curriculum, (2) the variety of classroom activities used to implement the curriculum, and (3) the teacher's commitment to professional curriculum development activities.

Text alone and text with extended verbal analogies were compared in a study conducted by **Radford**. The control group treatment consisted of text dealing with evolution and cellular respiration from the students' biology textbook retyped to look like the intervention text. The intervention treatment consisted of the same biology text and researcher-written text that linked the biological concepts to analogous familiar concepts. Students from nine biology classrooms were randomly assigned to the two treatments and their level of cognitive development was assessed using the Group Assessment of Logical Thinking (GALT). During the first day of the study, the students read one topic and immediately took a recall content achievement test. The next day the second topic was read and tested. Two weeks later a delayed recall test was administered to all the students. Analysis of covariance was used to identify the effects of gender, cognitive development, and prior biology grades. Significant differences were found in favor of the analogies group for the immediate recall of evolutionary concepts and on the delayed recall for both topics. Differences in achievement were related to cognitive development but not gender. There were no interaction effects.

Myers compared student outcomes in ninth grade physical science with a science technology and society (STS) science focus and a traditional textbook based focus. Two ninth grade teachers taught one class each of the STS and textbook focused courses. Students were given pre and posttest assessments in the areas of: (1) knowledge of science, (2) processes of science, (3) attitude toward science, (4) creativity, and (5) applications of science. A career interest survey was also administered. Growth from the pre and posttests occurred in the STS classes for creativity, applications of science, and knowledge of science. Students in the STS classes were more aware of and interested in careers in science and technology than students in the textbook focused classes.

How can we increase text comprehension of scientific materials?

Friend, Karsch and Siegel evaluated the effectiveness of *Newsday*'s science education series program on reading comprehension. The program consists of using the newspaper to extend the curriculum. Students read newspaper articles and answered questions on the accompanying worksheets. One hundred and thirty-six ninth grade students participated in the study. Half of the students were two years or more above grade level in reading and mathematics and half were on grade level in reading and mathematics. Students were assigned to three groups. The first group read the *Newsday* article and used the accompanying worksheets. The second group read the science articles (different from the *Newsday* articles), engaged in discussion, and responded to teacher prepared questions. The third group did not read any science articles, but the teacher prepared a lesson based on an article he/she had read. The intervention lasted for 10 weeks and students were engaged in activities for one period per week (41 minutes). The Degrees of Reading Power Test was administered after the intervention. Students who were above grade level in mathematics and reading who were in the group that read science articles, discussed them with the teacher and responded to teacher-made questions were the most successful on the reading assessment. Students whose reading and mathematics scores indicated that they were on grade level had higher scores on the reading assessment than any other group when taught using the *Newsday* articles and worksheets.

Gilbert investigated the effect of using analogies, metaphors, and similes in science texts to increase learning and affect attitudes toward science. Two hundred and one ninth and tenth grade general biology students participated in the study. They were assigned to a literal treatment which used the biology text or the analogies treatment. The analogies treatment consisted of materials developed by the author for two teaching units based on the biology text. The units dealt with the topics of embryo and seed development and Mendelian genetics. Two teachers also participated in the study and taught one class each of the literal and analogies approach. Teachers were free to work through the units or text chapters at their own speed. Achievement was measured by an instrument developed by the author which assessed near and far transfer. A short recall test and a Likert-style attitudes measure was also administered to the students. Analysis of covariance indicated that the analogies format did not affect achievement or recall and had a negative effect on attitude. The analogies seemed to confuse the students, especially in the genetics unit. The author concluded that the extra reading and assimilation of material that it entailed interfered with student learning. The extra effort also led to negative attitudes.

In the area of special education, **Horton and Lovitt** examined the effectiveness of using study guides with learning disabled and remedial students enrolled in secondary science courses. Regular education students served as the comparison group. Fifty-four students were assigned to a self-study group or a study guide group. Activities in the self-study group consisted of reading and rereading a science text for 15 minutes. The text was then studied by taking notes for 20 minutes. These activities were followed by multiple choice tests that students worked on for 10 minutes. During these activities, the teacher provided a variety of self-study helps. Activities in the study guided group consisted of reading and rereading a science text for 15 minutes and then completing a study guide with the help of the teacher. The teacher worked with the study guide on an overhead projector and read the questions aloud to the students. The teacher asked students for answers, showed the question on the transparency, and directed the students to write on their guides. The students then had five minutes to complete the study guide. This was followed by 10 minutes of testing. A student-directed study guide lesson was also presented that followed the same format as the teacher-directed lesson except that there was less teacher and more student involvement. The authors concluded that the teacher-directed and student-directed study guide lessons were more successful, as indicated by performance on the short tests, with learning disabled, remedial and regular students than the self study approach.

Harder conducted a study to increase comprehension of technical science materials. She instructed 117 adults in community college physiology and anatomy courses in effective reading strategies. Group 1 was instructed in the SPAR method: scan, plan, act, and revise. Group 2 was instructed to record their affective and cognitive responses to passages in the margin of the text. Group 3 was given a placebo activity. The instruction lasted for three weeks. The students were given a pre and posttest attitude questionnaire developed by the author and assessed for reading comprehension after the intervention. Data analysis revealed that positive responses on the attitude questionnaire increased from pre to posttest for groups 1 and 2 and decreased for group 3 indicating that both reading interventions had a positive effect on attitude. There was no effect for reading comprehension.

Investigating the role of prior knowledge in text comprehension, **Schmidt, De Volder, DeGrawe, Moust and Patel** conducted two studies of knowledge activation. In the first study 39 college students were placed in three groups and asked to write down everything they could remember about the behavior of red blood cells in salt water or placed in three control groups which discussed how jets take off. Each group had an instructor who acted as a discussion leader and asked questions. Students were then tested on osmosis. The group discussing red blood cells performed better on the osmosis test than the group discussing jet planes. The authors concluded that the discussion activated prior knowledge and enabled the students to perform better on the osmosis test. The second study built on the first and was designed to used activation of prior knowledge to enhance text comprehension. Groups were composed of 88 ninth and tenth grade students. The ninth grade students had not finished biology and were labeled novices and the tenth grade students who had completed biology were labeled experts. The experimental and control groups were comprised of both novices and experts. Discussion procedures and topics were the same as in study 1. After the discussion, the students read a passage about osmosis and diffusion which did not make reference to red blood cells and took a free recall test. The analysis of the recall tests indicated that the discussion of red blood cells increased text comprehension. There was no difference for novices or experts. The authors again concluded that the activation of prior knowledge enabled the students to make a bridge from what they knew to what they were to learn.

Alvermann and Hague were also interested in prior knowledge on text comprehension with counterintuitive texts. They selected 55 poor readers with misconceptions about Newtonian motion to participate in the study. Students were placed into two groups. Group 1 students read texts that referred to their misconceptions and refuted them in the text. Group 2 students read a passage that described the topic of Newtonian motion. Passages were crossed with levels of activation: (1) no activation, (2) augmented activation in which a statement that provided the correct answer and a warning that advised the reader to follow the subsequent text carefully, and (3) augmentation where subjects had to draw the path of a marble as it shot off a table and provide an explanation for the pathway. Students were given a pretest for application and a true-false test on statements of Newtonian motion. The posttest consisted of a short answer test and the same true false and applications tests. Analysis of covariance was performed on the data which indicated that activation with the warning was more effective in increasing text comprehension than activation alone or no activation. The text that contained refutations of misconceptions was more successful in increasing comprehension than text without the refutation.

Summary

The research on textbook quality indicated that there is little good to say about an instructional tool that is relied on so heavily. Gender inequities still appeared in illustrations and text in favor of males. The readability level was above the target audience, concepts were rarely defined, the vocabulary was dense and technical, and the writing style was horrible. Huge gaps appeared in coverage. There was little text devoted to science, technology, and society issues; scientific literacy; inquiry; or the development of positive attitudes, and concepts were not placed in a historical context. Elementary texts required reasoning beyond the capabilities of the students.

Given this, it should not be surprising that textbook or text-based instruction was less effective than other methods of instruction or that textbook-based instruction had to be augmented in some way to bring about significant learning. Some successful ways to augment text included using study guides, group discussion, and activation of prior knowledge. It strikes me that looking for ways to improve a method of instruction that has been consistently proven to be less successful than other methods is a strange activity for science educators. However, many researchers will argue that textbook-based instruction is the reality of schools. My response is that responsible science educators should not capitulate to poor practice because it is the reality. They should continue to argue for good practice and conduct research that makes the implementation of that practice easier for teachers.

WOMEN AND MINORITIES IN SCIENCE

What are the barriers to participation in science for women and minorities?

Kerr interviewed nine women scientists about their learning, teaching, and research experiences. Interview data were subjected to concept and proposition analysis and concepts maps were created. This information was then used to construct an interpretive narrative. The author found that women scientists were constructivist learners in their approach to research. Understanding the structure of science helped them to understand the natural world. Their research was based on the notion of order rather than a search for laws. Learning and thinking in science were connected to intense and positive feelings of commitment. They were not aggressively competitive. These beliefs were at variance with the female scientists' expression of public beliefs about science and the positions taken by male scientists. The author argued that these female views on science are different from the societal and cultural beliefs about science which serve to discourage women's advancement in science.

Frederick examined the structure of curriculum and the status of students as barriers to participation in mathematics, computer science, and science. She applied case study methodology to analyze the transcripts of 254 high school students. She found that SES was associated with differential participation between the programs of mathematics and science, but that gender was not. A larger percentage of high SES students were in the college preparatory mathematics and science programs than low SES students. Within programs, SES and gender were associated with differential participation in mathematics. High and medium SES students and males completed more mathematics courses than low SES students and females. Advanced courses in mathematics, science and computer were dominated by high SES students and males. In the general studies program, neither gender nor

SES was associated with differential participation because of the floor set by graduation requirements.

Race, class, and gender effects in science education research were the focus of **McDowell's** study. He examined research articles from 1980 to 1990 and conducted interviews with scholars in the field to determine the extent to which race, class, and gender were part of the body of research and to determine the factors that led scholars to include these variables in their research. These variables, when present, were found in studies of children's thinking about scientific phenomena. Race, class, and gender were absent from the theory formation stage of research. Scholars gave both political and social reasons for not including these variables in their studies.

What kinds of interventions have been successful in increasing female participation in science?

Mason and Kahle studied the effects of a program developed to promote a gender-free learning environment. Twelve biology teachers and their students participated in the study. The program was a one-day workshop designed to provide teachers with information and hands-on activities. Teachers were given the opportunity to engage in small group discussions. The workshop was based on a needs assessment. Half of the teachers participated in the workshop and half served as the control group. The workshop teachers were visited periodically throughout the school year and given help and support in implementing what they had learned in the workshop. The workshop teachers also filled out a weekly report sheet that was a record of their activities and served to remind them to engage in the workshop activities. At the end of the school year, students completed the Perception of Science and Scientists, Attitude Toward Science and Scientists, and the Science Experiences scales. Analysis of variance and post hoc analysis led the authors to conclude that the students of the teachers who had participated in the workshop had a more positive attitude toward science, greater participation in science, greater interest in science related careers, and more extracurricular science activities than students in the control group.

Another intervention program developed by **Sabar and Levin** placed 18 bright Israeli high school students in internships with working scientists. The students were volunteers enrolled in an eleventh grade biology research class. The program consisted of three additional hours of biology a week and one day a week working with a research scientist for one year. The students were required to conduct an individual research project under the supervision of the scientist and their biology teacher. Data gathering techniques were naturalistic and employed observations, self-evaluations, questionnaires, and teacher evaluations. From the data, the authors concluded that males were more active in classroom discussions than females (63.4% vs. 36.6%). The females were more tentative and were more likely to say that they didn't understand or ask for a second explanation. They would not respond until they completely understood the question. Males and females were equal overall in the teacher's evaluation of attitude, comprehension, task completion, the quality of tasks, and engagement in classroom activities. The students' self-evaluations were lower than the teacher's for both males and females. The scientists evaluated both males and females highly. The authors concluded that males and females were equal in all respects except assertiveness which should be developed in the females.

Rand and Gibb developed a model program for gifted girls in science. The model consisted of the following components: (1) female participation only; (2) female role models; (3) hands-on investigations; (4) activities that were non-traditional, stressed enjoyment and built self-confidence; and (5) parent and teacher participation. The model was tested with gifted females in grades 1-3, 4-6 and 7-9. Students participated in two evening sessions of one and a half hours each or two all day sessions during the summer. The evaluation of the model used questionnaires, videotaping, instructor discussions, and student drawings which were collected before and after the program. The program was successful in that students made more drawings of female scientists and self-portraits as scientists after the program than before the program. Students expressed an increased liking for science and more confidence in their ability to do science. Parents learned not to overhelp their daughters, especially with equipment. Teachers were more confident about their ability to teach science.

Johnson evaluated the effects of role models on female attitudes toward traditionally male careers. The successful role models were encountered through a series of readings about women in science and engineering and discussing their lives with a trained instructor. One hundred and fifty-three female students (tenth - twelfth grade) enrolled in advanced elective science courses participated in the study. All the students had completed two to seven courses in mathematics and science and planned to go to college. Many aspired to graduate work. Students were placed into either the experimental group (readings and discussion) or the control group. After the intervention students were assessed to determine career interests, attitudes, and confidence. In general, students were more confident in their ability to participate in science related careers. There was no change in their perceptions of gender appropriate careers and the intervention did not increase interest in science careers.

Summary

Women viewed and practiced science differently from men and their values were different from those of traditional science. This difference may be one of the barriers to female participation in science. Another barrier for both males and females was socio- economic status. The lower the SES, the less likely a student was to take higher level mathematics and science in high school. However, the number of insights we have into the role of race, gender, and class in relation to access to science and success in science is limited. Most researchers avoided these variables in their scholarship because of political and social reasons. Consequently, we are still looking for robust explanatory mechanisms that take into consideration these variables.

Intervention studies in the area of equity have been limited to increasing female participation in science. Most of these interventions have been successful in changing the attitudes and behaviors of teachers, students, and parents. The most successful interventions consisted of teacher training and the introduction of gender free, non-traditional hands-on science activities into the classroom.

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