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ABSTRACT

This summary of research in science education continues a long tradition of review and analysis of research in science education by the ERIC Clearinghouse for Science, Mathematics, and Environmental Education. The summaries provide an overview of recent research, provide research information in a succinct form for practitioners and development personnel, stimulate ideas for future research, and track trends in science education research. The research selected was published in 14 refereed journals during 1991. (These journals were considered to be the primary journals for the dissemination of science education research.) Over 50 dissertations reported in 1991 are referenced but not summarized. The summary is divided into two broad categories: (1) research on teaching, and (2) research on learning. Category 1 is subdivided into four areas: (1) curriculum and instruction (e.g., nature of science, reading and writing, strategies and methods); (2) cognition and achievement (teachers' knowledge of students' knowledge and of content and pedagogy); (3) affect and characteristics (teachers' attitudes, beliefs and characteristics); (4) science teacher education. Category 2 is subdivided into three areas: (1) curriculum and instruction (e.g., process skills, scientific literacy, learning in small groups); (2) cognition and achievement (reasoning and problem solving, conceptions of science, cognitive style and study strategies); (3) affect and characteristics (e.g., gender issues, science competitions, course enrollment). A "Brief Guide to ERIC" concludes the document. (Contains over 150 journal references.) (PR/CW)

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A Summary of Research in Science Education—1991

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January 1993

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Table of Contents

Preface	vii
Acknowledgments.....	ix
Forward	x
RESEARCH ON TEACHING	1
Curriculum and Instruction	1
Nature of Science	1
Science Technology and Society	3
Informal Settings	4
Technology	5
Reading and Writing	6
Critical Thinking and Problem Solving	12
Strategies and Methods	13
Changing Misconceptions	13
Other Studies on Pedagogical Strategies	16
Comments	18
Related Dissertations	20
Cognition and Achievement	21
Teachers' Knowledge of Students' Knowledge	21
Teachers' Knowledge of Content and Pedagogy	22
Comments	22
Related Dissertations	23
Affect and Characteristics	24
Teachers' Attitudes Toward Teaching Science	24
Teachers' Attitudes Toward Science Teaching Techniques	24
Teachers' Beliefs and Teaching Behaviors	25
Characteristics of Teaching and Teaching Contexts	27
Comments	28
Related Dissertations	29
Science Teacher Education	31
The Status of Elementary Science Teacher Education	31
Preservice Teacher Preparation	32
Inservice and Professional Development	33
Comments	34
Related Dissertations	36
RESEARCH ON LEARNING	37
Curriculum and Instruction	37

Process Skills and Reasoning	37
Problem Solving	40
STS and Scientific Literacy	42
Group Learning	44
Textbooks and Written Text	45
Museum Exhibits	47
Technology Integration	49
Rural Science	49
Comments	50
Related Dissertations	51
Cognition and Achievement	53
Conceptions and Alternative Conceptions	53
Elementary school level	53
Middle school level	55
Middle/high school levels	57
High school level	57
Postsecondary level	59
Longitudinal studies	60
Reasoning and Problem Solving	61
Elementary school level	61
Elementary/high school level	62
Middle/high school level	63
.....	63
High school level	64
Postsecondary level	65
Conceptions of Science	69
Cognitive Style and Study Strategies	71
Comments	72
Related Dissertations	74
Affect and Characteristics	76
Science Related Affect	76
Gender Issues in Science	79
Science Competitions, Course Enrollment, and Career Selection	81
The Relationship Between Cultural Beliefs and Scientific Beliefs	83
Comments	85
Related Dissertations	87
REFERENCES	89
DISSERTATIONS	101
A Brief Guide to ERIC	107

Preface

Synthesizing and summarizing the empirical research on science teaching and learning during 1991 was certainly a formidable task. After completion of our task, one perception remains clear. The science education literature base continues to expand each year exceeding the research reported during the previous year. The efforts that will be expended by the reviewers of the research for the 1992 calendar year have our appreciation in advance.

The enormous volume of research reported during 1991 necessitated some justifiable deviations from previous reviews. Of most prominence was the limitation of this review to only those reports of research published in refereed journals. This criterion insured that only research already subjected to the highest level of peer review would be included. In previous reviews, selected paper presentations and ERIC documents were included. It has not been uncommon, however, for reports from these sources to eventually appear in refereed journals and, consequently, be included in a subsequent review of the research. We have attempted here to avoid the redundant reporting of the same research report and creating false impressions with respect to the importance afforded to a given line of research by the science education community.

There is one **exception** to the aforementioned criterion. We have referenced (but not summarized or reviewed) dissertations reported during 1991. We felt that dissertations provide the best representation of the interests of emerging scholars in our field and quite often are indicators of emerging research agendas. Dissertations have been cited in the most appropriate sections throughout the review and a **separate reference list** has been included following the primary reference list.

The "published report" criterion resulted in a through review of the following journals: *American Educational Research Journal*, *International Journal of Science Education*, *International Journal of Qualitative Studies in Education*, *Journal of College Science Teaching*, *Journal of Elementary Science Education*, *Journal of Science Teacher Education*, *Journal of Teacher Education*, *Journal of Research in Science Teaching*, *Review of Educational Research*, *School Science and Mathematics*, *Science and Children*, *The Science Teacher*, *Science Education*, and *Teaching and Teacher Education*. These were considered to be the primary journals for the dissemination of science education research. We do, however, realize that important works may have been published elsewhere. It was not our intent to derogate other journals or the research reported within their pages. Limited space and time necessitated difficult selection decisions. Our apologies are sincerely offered to those who have been omitted from this review.

A priori categories or section heading were not used in the conceptualization of the review. We independently reviewed the total set of research report titles. Each reviewer then formulated three levels of primary and subsection headings based upon the existing research reports. These section headings were then

discussed as a group and revised when appropriate. Each reviewer was assigned approximately one third of the articles to be reviewed. After a thorough review of each research report, primary and subsection headings were revised individually and by the group. Consequently, the section headings used to format the review serves as a "rough" summary of the lines of research currently evidenced in the published science education literature. Each primary section and some subsections (when volume warrants) are followed by a "Comments" section in which the reviewer discusses topics such as general findings, design issues, and future research.

The section and subsection headings have been provided primarily to facilitate your use of the review. Please be assured that we are well aware of the problems inherent in any categorization scheme. We are also aware of the significant limitations that exist when a brief summary is designed to capture the essence of a researcher's arduous efforts. We apologize, in advance, to those colleagues whose ideas and efforts have been misrepresented. Above all, we recommend that you use this review as a secondary source and that you refer to the original research reports for those details and salient points that could not be included in this review.

Acknowledgments

As is often the case, ambitious efforts such as this review of research could not have been completed without the altruistic efforts of certain individuals. First and foremost, we would like to thank **David Haury** of ERIC and The Ohio State University for his tireless efforts with respect to the organization and management of this entire endeavor. David's guidance was essential to the comprehensiveness and overall quality of the review.

We sincerely thank **Peter Rillero** of ERIC for his efforts in document acquisition, library research, and computer file management. Without his assistance, we would still be searching for some of the more difficult documents and research reports. **Carolyn Taylor** of the University of Utah provided critical clerical and proofreading assistance on the numerous drafts and revisions of this final document.

Finally, the significant faculty support provided by university computing centers is rarely acknowledged. We are indebted to the **University of Utah Computer Center Staff** for consistently providing the file management expertise which was needed for the timely completion of this review of research.

Forward

As the knowledge base and professional literature in science education continue to expand and diversify, it is becoming increasingly difficult to gain an overall sense of how research in science education is evolving. Periodic summaries of research provide "snapshots" of work in progress, as well as evidence of changing priorities and the emergence and decline of research agendas. This *Summary of Research in Science Education* continues a long tradition of review and analysis of research in science education by the ERIC Clearinghouse for Science, Mathematics, and Environmental Education (ERIC/CSMEE). The intent is to consolidate and critique research findings related to teaching and learning in the sciences as they are reported during one-year intervals. The summaries are developed in consultation with the National Association for Research in Science Teaching (NARST). Individuals identified by the NARST Research Committee work with staff members at ERIC/CSMEE to identify, review, evaluate, analyze, and summarize research findings. The purposes of the summaries include: (a) providing an overview of recent research activity for scholars in the field, (b) providing research information in succinct form for practitioners and development personnel, (c) stimulating ideas for future research, and (d) tracking trends in science education research. I hope you find this Summary both professionally useful and intellectually satisfying.

Thanks to the authors for their efforts in producing this summary. The task of reviewing such diverse bodies of research over a relatively brief period of a few months is formidable, and it is always a challenge deciding how to cluster research findings in seemingly natural and useful ways. We have broken with tradition somewhat this year by not including reviews of dissertations and conference papers. The authors were also asked to add their comments within each section of the review, helping us contextualize the collective efforts reported during the year. Since this review process is evolving as the research evolves, you are encouraged to submit comments and suggestions after reading this *Summary* for 1991. In the final analysis, we are making this effort to serve readers like you.

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RESEARCH ON TEACHING

Curriculum and Instruction

This section on Curriculum and Instruction has been sub-divided into the following sections: Nature of Science; Science, Technology and Society; Informal Settings; Technology; Reading and Writing; Critical Thinking and Problem Solving; Strategies and Methods. The last section has been further broken down into: Changing Misconceptions, and Other Pedagogical Strategies.

Nature of Science

In an effort to develop a model that would enable preservice and inservice teachers and graduate students to analyze their own views on the nature of science, Loving conducted a survey that was sent to 17 active NARST members from different institutions of higher education to determine the extent to which philosophy of science topics were incorporated into required courses. Responses indicated that 13% of undergraduate science education majors and 19% of graduate students have a philosophy of science course in their program. No undergraduates and only 25% of graduate students, however, consistently examine texts and curricula to determine the philosophical orientations of authors or philosophical underpinnings of programs.

Based on descriptive responses from the survey, Loving constructed a model named the Scientific Theory Profile identifying 12 key scientific philosophers who are tentatively placed into one of four quadrants. These consisted of: The Natural Anti-realist (Kuhn, Feyerabend, Holton, and "Sociologists of Science"); The Rational Anti-realists (Toulmin, Shapere, and Laudan); The Rational Realists (Hempel, Popper, Lakatos, and Glymour); and The Natural Realists (Giere). The author acknowledged that the categories of philosophers may be viewed differently at various historical points in time inasmuch as their ideas and positions became modified and refined over time. The model described by the author can be used as a focal point for philosophy of science courses and encourages the use of concrete activities for what is often perceived as an abstract topic in science teaching.

Solomon reported from past studies cursory findings which suggested that mere exposure to laboratory work does not automatically produce understanding

of the nature of science. In Britain, a sample of 141 seventeen year-old students' views revealed that 62% believed laboratory work yielded "certain" knowledge, and 50% believed scientific knowledge is based on logical thought. The author also found that 71% of the sample chose to define a theory as a "well-established explanation" as opposed to "a hunch" (22%), or a "well-proven fact" (16%). Finally, as to why scientists may disagree about certain subjects, 65% of the students selected the option that indicated there are "different theories;" 48% reported that "no one has all the facts" (represented a more theoretical option); and 21% selected options that raised questions about scientists' motives (scientists were more influenced by personal career or political interests). The author notes that prior research indicates that children are interested in how they are learning science. Research on how younger children (i.e. junior high school age) may derive notions about the philosophy of science as they undergo process-oriented laboratory instruction also warrants attention.

Gallagher raised two fundamentally important questions about teachers' knowledge and beliefs about the philosophy of science. First, what viewpoints are being conveyed to students, and second, how do teachers' conceptualizations about the nature of science influence their teaching? Secondary school textbooks were reviewed, and ethnographic studies of teacher behavior were conducted to address the first question. Two popular texts, *Modern Biology* by Towle (1989), and *Conceptual Physics* by Hewitt (1985), were examined. The author concluded that while the textbooks may begin with one or two chapters on the nature of science and how scientific knowledge is formulated, these concepts are not interwoven in the presentation of subject matter in subsequent chapters.

In ethnographic observations of 27 secondary teachers from five schools in two districts, Gallagher observed over 1000 science lessons. Twenty-five of those teachers devoted no time to concepts related to the nature of science, tended to emphasize terminology, and presented science as a body of knowledge. The author reported that secondary teachers are not encouraged in their teacher-training programs to enroll in history, philosophy, or sociology of science courses and infers that this lack of study produces a serious deficiency in their knowledge of history and philosophy of science. Conceptualizations that are associated with an instrumentalist perspective within teacher-training courses are suggested as a partial remedy for these deficits.

Beginning student teachers expressed similar views in a study by King who questioned 13 subjects using a 14-item survey on the first day of their introductory course in curriculum and instruction in science. The questionnaire elicited the students' views as to what science is, how scientific knowledge is produced, why it is important, and how science should be taught. At the end of the course after at least one week of student teaching, 11 of the 13 students were again interviewed and provided the opportunity to revise their original comments. Although most students were interested in history and philosophy of science concepts, they were concerned about the "practical" aspects of science teaching (i.e., lesson planning, conducting laboratory activities, evaluation). Although most felt that history and philosophy of science should play an important role in their teaching, they had

never had a course in this area. At least three students were not even sure what "philosophy" meant, and nine students felt unprepared to incorporate these ideas into their teaching. King pointed out that while most of the beginning teachers in his study did not at first stress the imparting of "facts" to students, the research reveals that most science teachers are "scientific" and positivistic in their views. Questions remain as to whether the students in this study were atypical or if something happens to new teachers causing them to revert to positivistic views.

Science Technology and Society

A common concern that cuts across the teaching of science in a social context is how to improve the quality of student discourse. **Geddis** examined this issue by using an exploratory case study approach of one teacher's class with respect to how students discuss controversial issues. The class consisted of 21 tenth grade, non-college bound students. The teacher was trained in the use of constructive feedback, a conceptual scheme developed by the author in which the teacher considers knowledge, ideology of teaching, and the intellectual context of instruction. In short, instruction was set in an explicit epistemological and pedagogical context that was foreknown to students.

Discussions during the last week of a unit on chemical change were observed while competing controversial claims were presented to students concerning the sources of acid rain. Although a description of the lesson is too lengthy to be reported here, the study illustrates the ontology of student discourse based on continued monitoring and intervention with teaching strategies. The author demonstrated that adaptations in teaching strategies can occur during a lesson in a way that takes into account multifaceted perspectives of students and makes provisions for their intellectual independence.

Zoller, Wild, and Beckett conducted an *ex-post facto* study to determine (a) if there are differences between the STS beliefs and views profiles (SBVPs) of science and non-science teachers, (b) levels of STS literacy among teachers, and (c) the extent to which STS education may be indoctrination. Six representative items from the Views on Science, Technology, and Society (VOSTS) inventory were selected to identify teachers' and students' beliefs about STS issues. Each item allows the subject to select from five to eight "active" choices and three "passive" choices that reflect a SBVP for that individual. Comparisons were made among 183 teachers of schools with STS programs (49 were teachers of STS courses) and 149 grade 12 students who had taken STS courses. The results revealed that the subgroup of STS teachers were not uniquely different from other teachers in their SBVPs. Some gender differences were found favoring female teachers who appeal to authority on certain issues and tend to view technology as tools/instruments. The authors also report that the STS literacy of teachers with respect to conceptualizing the differences between science and technology, and their interrelationships, was questionable. They make the claim by inference that the literacy of those teachers' students would also be questionable. Finally, the authors concluded that the magnitude of differences between STS teachers' and

students' SBVPs suggests that teachers educate, rather than indoctrinate, they permit students to construct their own positions on various STS-related issues. An appendix of the inventory is included in this report.

Informal Settings

Ault and Herrick were intrigued by the opportunities that museum exhibits offer for conducting research about "everyday" conceptions of natural phenomena. They suggested that such opportunities can benefit science educators and exhibit designers as well as preservice and inservice science teachers. The researchers had students in an elementary science methods course participate in the evaluation of prototype museum exhibits. In one evaluation, visitors to an exhibit that involved manipulating variables related to trajectory motion showed no evidence that they attended to variables related to the motion of a projectile; nor did they conceptualize motion in terms of changing velocity and continuous motion. Over two dozen visitors concentrated on manipulating the launch variables and target position that would allow them to "hit the target." This fact indicated that science museum exhibits may be ineffectual for imparting conceptual understandings, while process objectives are more readily conveyed.

A second evaluation of an exhibit that demonstrated the transmission of light in flexible plastic tubes permitted preservice teachers to observe 75 visitors and interview 20 of them. The authors propose that this is a novel and effective strategy which allowed teachers to observe the role of prior knowledge held by visitors with respect to their expectations and conceptualizations of museum exhibits in general, and scientific knowledge in particular.

Wellington makes the case that learning through newspapers is an instance of informal science learning. While difficult to assess, it can be a viable technique in formal science education. Using all 12 national newspapers in the United Kingdom for a one-week period, a cursory content analysis was performed. In that time period, over 100 scientific terms were used in the newspapers ranging from the relatively common (e.g., "smog") to the rather obscure (e.g., "nuclear magnetic susceptibility"). Knowledge and understanding of scientific language is one of the main components of scientific literacy. Several examples that especially misrepresented science were found. Most took the form of gross distortions of "whizz-bang breakthroughs" that stand in contrast to the progression of scientific knowledge. The author argues that science teaching should foster the development of critical thinking to equip students with a healthy skepticism. Hence, using print media of all "shapes and sizes, ethical and political persuasion" (Table 2, pp. 368-369) in deliberate ways can enhance formal science teaching.

Price and Hein report efforts of the Program Evaluation and Research Group (PERG) in providing formative and summative evaluations of zoos, museums, outdoor education centers, and an aquarium in the Boston area. These evaluations have been part of a 15-year effort and tend to focus on science programs in informal settings, predominantly in grades K-8. The authors evaluated some 30 programs that included a wide range of science content. They

provided a summary of the program characteristics which consisted of the following variables: program content in relation to student age, program content, size of working groups, staffing, space, number of sessions, number of years in program, session length, site, staff training, and classroom teacher involvement.

The PERG evaluations provided an extensive set of guidelines and recommendations that teachers and museum program coordinators may use to promote the effectiveness of science field trips. Although informal program lessons should be well planned, staff must remain flexible to the unique interests and questions of the group. Because student questions are an index of knowledge, interest, and misconceptions, ample time must be allocated for them. A variety of activities, particularly interactive, hands-on experience and demonstrations will engage students' interest and will benefit students more than programs where students are taught in classrooms that are removed from exhibits. Programs that provide opportunities for hands-on experiences followed by concept introduction are more successful than programs that reverse the order.

Interestingly, informal science programs provided opportunities for non-academic and non-English speaking students to become engaged in science. The less structured settings also provided the opportunity for most students to demonstrate that they knew more about science areas than their teachers realized. This knowledge has the potential facilitating effect of raising teachers' expectations about student interest and learning. The authors also noted that field trips tended to affect positively teachers' attitudes towards science and to increase their confidence in teaching science topics in their classrooms.

Lucas reported that interest in informal science learning has risen over the last 25 years. Using the ERIC database as an indicator of interest, 85 entries from 1966 - 1976 were retrieved; 99 entries from 1977 to 1983; and 163 entries from 1983 to June 1991. The author noted that the preponderance of these articles consisted of arguments for the importance of informal science learning or descriptions of programs in museums; very few are research studies examining the process of learning science outside of the classroom.

The present review of the science education literature for 1991 confirms this trend. Whereas some articles, such as Kingsland, describe how nationally organized formal science clubs outside the classroom can positively affect science interests, and others, such as O'Donoghue and McNaught, and Maddock, describe the development of grass-roots movements of outdoor programs and curricula, few articles actually deal with empirical studies that examine transfer of knowledge, how students process information in settings that are primarily designed for entertainment, how teachers can enhance achievement by complementary teaching strategies in conjunction with field trips, and other critical issues related to teaching and learning science in informal settings.

Technology

Ellis and Kuerbis presented a report of a BSCS initiated ENLIST Micros (ENCourage the Literacy of Science Teachers) project, which is designed to

promote effective use of microcomputers in science classrooms. The project entailed a review of the literature in this area in which school objectives were identified and reduced through a factor analysis of survey data to a core set of six major constructs of essential competencies for computer literacy in science teaching. These included: awareness of computers; applications of microcomputers in science teaching; implementation of microcomputers in science teaching; identification, evaluation, and adoption of software; resources for educational computing in the sciences; and attitudes about using computers in science education. Experimental curricular materials were developed on the basis of these competencies and field tested on 18 groups of preservice and inservice teacher education programs across the country. Based upon feedback from those groups, BSCS revised and disseminated 50 sets of the final curriculum to field test coordinators and offered 16-hour workshops averaging 25 participants on using the new program.

In general, the participants gave the materials high evaluations. One test of computer literacy (with no reliability indices reported) was administered, and one computer opinion survey (with high validity and reliability) were administered to the workshop participants; both indicated significant differences between pre and posttest responses suggesting overall satisfaction with the program.

Mandell suggested appropriate ways in which the microcomputer can be used in preservice preparation of science teachers, while Andaloro, Donzelli, and Sperando-Mineo discussed the importance and value of using the computer as a pedagogical tool for modeling simulations in physics teaching. Only O'Brien and Korth presented the use of videotaping as a mechanism to foster teachers' understanding of cognitive science and self-development. The fact that only one study on technology by Ellis and Kuerbis was found in this review points to the paucity of research in this important area.

Reading and Writing

Lumpe and Scharmann investigated whether two widely used biology textbooks, *Modern Biology* (1989) and BSCS Green Version (1987), adequately conveyed contemporary goals through their laboratory activities. Two judges were trained to perform a content analysis of all the lab activities associated with each text. Twenty-four task categories which reflected scientific inquiry, problem-solving skills, manipulative skills, and observational skills, were placed in four major groups (planning and design, performance, analysis and interpretation, and application) to form the content coding scheme. It should be noted that while interrater reliability was 0.80, both judges did not evaluate all laboratory activities.

It was reported that neither textbook provided many opportunities for students to develop their own problems, construct their own procedures, or design their own methods of investigation. Furthermore, neither textbook allowed for the formulation of new problems or extended investigations related to a given activity. Most investigations called for students to manipulate equipment, perform calculations, and define and discuss variables. Each text allowed, to a

limited degree, for students to make predictions and form hypotheses. The authors concluded that biology textbooks have changed little when compared to content analyses done more than ten years ago. They caution teachers to recognize the inadequacy of texts in meeting the needs of students as problem solvers and decision makers.

Vachon and Haney introduced a new concept, level of abstraction (LOA), not usually considered by traditional readability formulas, to investigate the level of cognitive demand of science text materials. LOA was operationalized in this study as the ratio of the number of concepts having no concrete exemplars to the total number of concepts in a text passage. (Nonconcrete concepts are defined as those referents that cannot be experienced directly or with the aid of instruments.) A group of 24 science educators were used in the validation process of developing procedures for identifying LOA concepts. Sixty-one science teachers representing elementary, middle, and high school levels were used to determine the LOA for nine samples of 200-word passages selected from grades 5, 7, and 10 life, earth, and physical science textbooks. Using Cronbach's alpha and other criteria, a composite LOA score was constructed for each passage. Next, 11 classroom teachers at grades 5, 7, and 10 read passages written for students at their level, and using the teacher as a judge, predicted the level of student comprehension. They then administered a cloze procedure for the same passages.

The authors found that the LOA method produced an average agreement rate of 90% among the 24 science educators whereas Cronbach's alpha coefficient ranged from .24 to .75 for teachers using only written directions to score the passages, indicating great variability of reliability scores. Correlations between LOA scores and readability levels within grade levels were medium to low, which lead the authors to conclude that readability and LOA measured different constructs. High correlations between levels of success predicted by teachers and LOA scores suggested that the teachers recognized the abstractness of the passages in relation to their students' comprehension. Finally, because the cloze scores were not found to correlate highly with readability as they do with LOA scores, they concluded that the level of abstraction influences reader comprehension to a greater degree than the variables used in calculating readability. Hence, LOA was viewed in the context of this study as a means to measure the deep structure (i.e., cognitive-load) of written materials and is a factor that directly contributes to student comprehension.

Another important issue in the area of reading and writing in science education is the issue of gender equity in textbooks. **Bazler and Simonis** addressed this issue by replicating a previous study of early 1970 high school chemistry texts and applying the same criteria for analysis to current chemistry texts. The texts included: *Reactions and Reason: An Introductory Chemistry Module*, (Atkinson & Heikkinen, 1973; 1978); *Chemistry* (Choppin et al., 1973; 1982); *The Delicate Balance: An Environmental Chemistry Module* (Gordon, 1973; 1978); *Modern Chemistry* (Metcalf, Williams & Castka, 1970; 1986); *Chemistry: Experiments and Principles* (O'Connor et al., 1973; 1982); *Chemistry: Experimental Foundations* (Parry, Steiner, Tellefsen & Dietz, 1970; 1987); and

Foundations of Chemistry (Toon & Ellis, 1973; 1978). These texts represented new editions to those formerly used in the 1970's. The central questions under consideration were whether a measurable shift toward gender balance in illustrations, frequencies of named and unnamed male and female youth and adult illustrations had occurred from early to present editions, whether the relative frequencies of male and female verbal analogies had changed, and whether gender depictions approximate the 50/50 ratio of men and woman in society.

Coders conducted frequency counts on the 1970s textbooks and were able to achieve a 0.98 reliability coefficient with the original coding scheme used at that time. The same coding scheme was followed on the current textbooks and the average interrater reliability was approximately .89.

The analyses revealed mixed answers to the question of gender fairness. Only one text out of the seven reviewed was found to have significant changes in the overall proportion of male/female images having gender fairness. Two texts had significant changes in the direction of gender fairness in named and unnamed adult illustrations, and one text yielded significant changes in gender fairness of youth illustrations. Only one text had significant changes in the direction of gender fairness in the use of verbal analogies. The authors caution that the assumptions used in the original coding scheme of the 70s may reflect orientations that may not be valid today; that is, some issues that were originally the prevalent concern of one sex may now be of concern to both sexes in today's society. The authors warn that teachers (and authors of textbooks) need to recognize the subliminal messages that texts may convey to students.

Shymansky, Yore, and Good conducted a survey of elementary school teachers' beliefs about and perceptions of science textbooks and instructional factors related to using text material. The authors claim that while reading entails more than extracting meaning from printed symbols, current practice remains at the level of simple isolated decoding skills. Improving the selection of science textbooks for use in the classroom first requires assessing existing beliefs and practices. A descriptive and comprehensive interactive-constructive model of reading that was derived from the positions of Piaget (experience), Vygotsky (language), and Karplus (learning cycle). This model, based on current research, seems to hold the most promise for science education.

The purpose of the survey instrument was to capture elementary school science teachers' perceptions of factors associated with this model. The sample consisted of 522 teachers representing 299 schools in all 50 states, including Puerto Rico and the Virgin Islands. A 33-item questionnaire with Likert-type and rank-ordering items was developed; validity was first established by an expert panel. Then these data were used to factor analyze items and establish validity for four conceptual clusters of items: teachers' beliefs about the purpose of elementary school science instruction, beliefs about elementary school science reading, perceptions of elementary school science textbooks, and beliefs about supportive instruction for science readings. Reliability using Cronbach's alpha yielded coefficients ranging from 0.54 to 0.77 (which are probably low due to the low number of items of each subscale) with an overall reliability of 0.80.

The results suggested that teachers do not view reading science as different from other narrative material. The authors suggest that this is a major concern inasmuch as scientific writing embodies its own particular structure, lexicon, syntax, and semantics. The authors caution that these characteristics of scientific reading should not be overlooked and their importance in teaching should be recognized through the use of generative strategies.

Additional research on the use of generative strategies was conducted by **Pearson**. Using subjects who were high and low reading-ability from an introductory college level biology course, Pearson compared the achievement of students in a control group who were provided teacher-made questions ($n=40$) with an experimental group ($n=37$) who were trained to generate and use their own questions, after each group read weekly science assignments. The questions used in the study (whether teacher-provided or student-generated) reflected a taxonomic scheme having: referent, literal, interpretive, inferential, and self-critical level questions. High and low reading abilities were determined by using Part II of the Nelson-Denny Reading Test. Achievement was measured using a combination of weekly quizzes and a summative examination measuring biology content at the end of one semester. The results revealed that training students to generate and answer their own questions from text reading significantly improved performance. It was also found that teacher-provided questions at the literal level promoted the learning of intended and nonspecific discrimination material better than teacher-posed questions at any other taxonomic level. Because of the naturalistic setting and length of time during which this study was conducted, the findings add to the ecological validity of transfer of strategies to other science classes.

Chiappetta, Fillman, and Sethna developed a procedure to quantify major themes in science textbooks that would enable teachers to systematically analyze the content coverage before adoption. Through many iterations of analyzing textbooks from life science, earth science, physical science, chemistry, and biology, a 25-page training manual consisting of four major themes of scientific literacy was developed. These themes included: (1) the knowledge of science; (2) the investigative nature of science; (3) science as a way of thinking; and (4) interaction of science, technology, and society. After all modifications to the manual were completed, a random sample of the five types of science textbooks was chosen, with 5% of the content sampled from each text for analysis. This procedure resulted in an average of 36.6 pages per text being selected to undergo content analysis. Three raters were used, two having had extensive experience with the approach developed and one who was a high school teacher who had reviewed the training manual and performed the exercises contained in that manual.

The authors found an overall range of percent agreements between 80 to 97 (with kappas ranging between 0.73 and 0.96) was obtained using the thematic units described in this project. It is important to note that this approach stands in contrast to using scientific words to characterize science textbooks. For the particular books reviewed, the percentage of themes of scientific literacy revealed

that science as a body of knowledge was most prevalent ($mean=65.7$), followed by science as a way of investigating ($mean=24.2$), interaction of science, technology, and society ($mean=9.0$), and science as a way of thinking ($mean=1.1$). Although the authors suggest that the reliability of the procedure developed in the training manual should be verified by other researchers, using themes as the unit of analysis appears to be a fruitful avenue for the assessment of science textbooks with regard to their eventual adoption.

In a related study, **Chiappetta, Sethna, and Fillman** used the procedure described above to perform a quantitative analysis of high school chemistry textbooks for scientific literacy themes and expository learning aids. Five texts most commonly adopted by school systems across the nation [*Chemistry* (Wilbraham et al., 1987); *Chemistry* (Dorin, 1987); *Heath Chemistry* (Heron et al., 1987); *Modern Chemistry* (Metcalf et al., 1986); *Chemistry, A Modern Course* (Smoot et al., 1987)] and two additional nationally recognized chemistry course texts [*Chemistry-An Experimental Science* (CHEM Study) (Chemical Education Study Material, 1960); and *Chemistry in the Community* (ChemCom)(American Chemical Society, 1988)] were selected for review using a 5% sampling of material coverage and two raters. Inter-coder agreement for the seven books ranged from 82% to 92% with kappas from 0.73 to 0.89 with respect to identifying the four themes of scientific literacy described above.

Of particular interest is the fact that the knowledge of science theme had means that ranged from 68% to 87% for the original five texts, while the ChemCom *mean* was 25% and the CHEM Study *mean* was 91%. In contrast, the investigative nature of science theme had *mean* ranges from 9% to 26% for the five texts, while the ChemCom *mean* was 43% and the CHEM Study *mean* was only 6%. This result reflects the 1960s orientation of goals for CHEM Study and the 1980s orientation of goals for ChemCom. The theme of science as a way of thinking was very poorly represented (less than 5%) for all texts, and the STS theme was highest for the ChemCom text. The authors also found the quantity of expository learning aids varied greatly among the texts with the *mean* number of pictures ranging from 9 to 25, the *mean* number of questions per chapter ranging from 3 to 60, and the *mean* number of questions at the end of chapter ranging from 11 to 120.

Shepardson and Pizzini extended the examination of expository learning aids in science textbooks by considering what differences exist in the cognitive level of questions among eight junior high school texts that represent approximately 50% of the market. An analysis scheme that classifies the cognitive level of questions raised by texts as input (recall of information), processing (form relationships among information that has been recalled), and output (information used in new ways that extend concepts) was selected, using two coders who achieved inter-coder reliabilities ranging from 0.83 to 0.96. The publishers of the texts were Merrill and Scott-Foresman. Using a stratified cluster sampling approach, the chapters analyzed accounted for approximately 17% of all textbook chapters. A total of 3,140 questions were analyzed: 79% were at the input level; 15% were at the processing level; and only 7% were at the output level. It was

also found that the proportion of input, processing, and output questions among the texts representing life science, physical science earth science, and general science was equivalent, suggesting that students are uniformly exposed to low-level questions among science disciplines during junior high school. The authors suggested that the over reliance on low-level cognitive questions appears to hinder text comprehension by limiting the extent to which the student's prior knowledge is utilized, and by fostering a low-level purpose for reading, thereby reducing the integration of textual information into the existing knowledge base of the reader.

The level of inquiry contained within the activities of science textbooks and supplemental activity guides was examined by **Pizzini, Shepardson, and Abell**. The Merrill Focus and Principles series and the Scott Foresman series were reviewed, with random chapters sampled for inquiry level analysis. Inquiry levels were coded by level of openness: confirmation, structured-inquiry, guided-inquiry, and open-inquiry. Two trained coders achieved reliability of $r = 0.99$ on six randomly selected chapters. A total of 32 chapters from eight textbook series and their supplemental guides were reviewed.

The results indicated that no guided or open-inquiry activities were found in the chapters sampled from the textbooks or the supplemental activity guides. There were significant differences among the levels of inquiry among all the series, with more confirmation level activities than all others together. Significant differences were also found between the Merrill series and the Scott, Foresman series, the latter having very low numbers of structured-level inquiry activities. The authors concluded that the level of inquiry in these textbook series is very restrictive, confining students to confirmation and structured-inquiry level activities. They suggest that science teachers take the responsibility to include more guided and open-inquiry activities in their classes.

Selden examined the selective traditions of biology textbooks covering the period between 1914 and 1949. Specifically, 40 high school texts available to the author were reviewed (1) to determine whether eugenics was presented as legitimate science, (2) to examine the nature of the evidence provided, and (3) to explore what eugenic social policies may have been recommended during that time. The author found that over 90% of the texts reviewed included eugenics as legitimate science and noted that evidence in support of the theory was furnished in the form of pedigree charts containing personality traits (e.g., "character," "intelligence," "wandering") that ran in certain families, and discussions of "superior" families. Analysis of photographs from these books revealed that some photos were retouched to depict offspring with certain socially undesirable anomalies to appear even more threatening and degenerative, by lowering hairlines and emphasizing scowling visages, particularly when discussing traits such as "feeble-mindedness," which threatened traditional values. This fascinating historical study raises serious implications with respect to how contemporary science may also be presented in a way that exemplifies the desire to use it for socialization rather than for education.

Others in the literature related to reading and science, have raised issues of concern involving pedagogical decisions about how to best utilize reading material. Some, like **Yore and Shymansky**, outline critical references related to comprehension of science text material and present several general teaching strategies to promote student comprehension. Others, like **Memory and Uhlhorn** argue the case for using a multiple-textbook approach with different readability levels in the science classroom. These authors also included a list of "easy-reading" textbooks of secondary students for earth, life, physical, and general sciences.

Only one article presents a strategy for stimulating students' thinking through writing. **Butler** describes a traditional lesson in biology presented using a writing process approach. Research in this latter area would seem appropriate.

Finally, **Kinnear** discusses the benefits of using a historical perspective (hence, historical readings) to enrich science teaching in the area of genetics. Such an approach, it is argued, can convey to students the development of explanatory models over time, can show how prior knowledge affects model development, and can aid in understanding the scope of underlying assumptions in the construction of a model. These points would tend to illuminate an instrumental conceptualization of the nature of scientific knowledge.

Critical Thinking and Problem Solving

Harty, Kloosterman, and Matkin investigated the extent to which problem solving/critical thinking have been incorporated into the elementary school science curriculum, and whether it was taught more often in the upper or lower elementary grade levels. Problem solving was operationalized as the ability to draw reasonable conclusions about data given no clear procedures for making conclusions. A Likert-type questionnaire containing four items was constructed and validated by an expert panel for content. Reliability was determined by test-retest (0.95) Spearman-Brown coefficient. The questionnaire was mailed to 414 elementary principals representing 37% of the principals in one state with a response rate of 76% ($n=317$). The authors found that the upper elementary school science program placed a significantly greater emphasis on problem solving than programs at lower grade levels, and that 58% of the schools in the sample used such approaches very often. In contrast, 64% of lower grade level schools rarely utilized this approach. It should be noted that the authors used the terms critical thinking and problem solving analogously and that possible demand characteristics of the questionnaire itself may have contributed to the responses.

McMurray, Beisenherz, and Thompson noted that efforts to teach critical thinking in science classrooms needs to be accompanied by ways to measure the success of intervention strategies and that the instrument used to evaluate the method of teaching employed must clearly operationalize the construct being measured. Although some measures assess general definitions of critical thinking do exist, it would be beneficial to researchers and teachers to be able to measure

critical thinking in specific science domains. The purpose of this study was to construct a Test of Critical Thinking in Biology (TCTB) appropriate for general courses in biology. The authors conceptualized critical thinking as being able to reason dialectically or logically in synthesizing multiple frames of reference applied to new problems.

An initial pool of 75 items was pilot tested on 72 introductory college biology students. Based on item difficulty and discrimination coefficients, the pool was reduced to 52 items that examined the following biological areas: protein synthesis and enzymes, diffusion and osmosis, respiration, photosynthesis, cells and cell division, general biological information, and ecological interactions. An alpha reliability coefficient for this data was 0.83. Subjects were selected ($n=47$) from a larger new group of students ($n=290$) enrolled in an introductory college level biology course. They completed the exam at the end of the course. The sample selected was representative of that larger group.

The authors reported good internal consistency and a reliable composite score. Support for concurrent validity with other general measures of critical thinking (e.g. Watson-Glaser Critical Thinking Appraisal; Critical Thinking Appraisal) was established and additional item analysis indicated the TCTB to be consistent with additional psychometric criteria.

In related research, Johnstone and Al-Naeme pooled correlational studies that have examined the relationship between working memory space and field-dependence on science performance at the secondary and tertiary levels. The authors examine how working, holding, and thinking space may be related to performance by inferring that field-dependence/independence provides an indication of potential and usable working memory. It was hypothesized that a student's ability to critically select pertinent information related to performing some task (e.g. recording notes on a scientific lecture) would be influenced by the extent to which he or she gave attention to "noise" rather than appropriate "signals." Although only a cursory description of subjects and methodology is provided, this study provides insight into an area of problem solving that has received little attention in science education.

Strategies and Methods

Changing Misconceptions

Stavy (b) studied the effect of using analogy to correct misconceptions about the conservation of matter. Two experiments were conducted; the first one examined the spontaneous transfer of new knowledge from the learning situation to analogical ones, the second one examined an attempt to induce change in misconception by analogy. A total of 192 children from second, third, and fourth grades was pretested for understanding of the inverse function (i.e., ratio) in three different contexts. Eighty-two did not successfully complete all three tasks, and subsequently became the experimental population. One half of this group received training in the role of water with respect to concentrations of solutions.

(The procedure is not fully described in the present article). Results from the first part of the experiment showed significant improvement in the experimental group overcoming their misconceptions and suggested that analogy can be used as a natural means for correcting misconceptions.

In the second study, 74 students in grades 5 and 6 were given conservation of weight tasks; one when iodine was evaporated, and one when acetone was evaporated. Because past studies suggested that misconceptions about conservation when the acetone task was presented first, followed by the iodine, occurred because students use preexisting intuitive knowledge, Stavy reversed the order of the tasks to teach conservation of weight in the intuitively understood iodine task first, followed by the analogical (but misunderstood) acetone task. This strategy produced significant results in the performance of the acetone task, suggesting that the intuitively understood and perceptually supported iodine task could serve an analogical link for prior misconceptions about the acetone task.

Banerjee and Power developed three modules for the teaching of chemical equilibrium, an area that has been noted for the conceptual difficulties and misconceptions it presents to students. The first module examined qualitative aspects of chemical equilibrium; the second covered quantitative aspects of gaseous and ionic equilibria; and the third contained quantitative aspects of solubility, acid-base and redox equilibria. However, all the modules had the following elements in common: a statement of the content and concepts to be developed, an assumption of prior knowledge of students, process and problem-solving skills, an outline of probable conceptual difficulties and misconceptions, and an outline of teaching strategies. Further detail of the modules was provided, and it should be noted that the teaching strategies entailed small group discussions each week. The modules were used by a group of 46 college chemistry students, all of whom had studied chemistry for three years prior to this study. A pretest-posttest without a control group was employed over one semester with the dependent variable, achievement, measured by a compilation of items selected from standardized sources that stressed knowledge, understanding, application, process and problem-solving. In total, three assessments were obtained over the semester.

Percentages of increase in *mean* scores showed marked improvement of competence in concepts, processes, applications, and problem-solving areas. The data also revealed that at the beginning of the course many students held misconceptions that were greatly reduced by the end of the study. These misconceptions included: (a) large values of an equilibrium constant suggesting quick reactions and (b) an inverse relationship between the temperature of an exothermic reaction and the rate of the forward reaction. The authors noted that final achievement scores were not very high, and 30% of the students retained misconceptions in the aforementioned areas suggesting that this area of study remains a challenging one. Unfortunately, statistical tests were not provided by the authors, but inspection of the pre- to posttest *mean* scores appears promising.

Evidence that cooperative group work could provide a classroom environment that was conducive to facilitating conceptual change strategies was brought to

light by **Basili and Sanford**. The unique aspect of this approach was that small cooperative groups could discuss amongst themselves various tasks aimed at eliciting their misconceptions. The authors were interested in determining whether this approach would result in fewer misconceptions, in observing how verbal language patterns during small group interaction was related to conceptual change, and in qualitatively assessing what other factors may be related to small group dynamics during the process of conceptual change.

Four intact groups of students enrolled in a general course at a community college were used in a pretest posttest control group design, with two classes assigned to the treatment group and two assigned to a control group. Pretest scores on the dependent variable (a conception test about conservation laws) established equivalence between groups. Two instructors each taught a treatment group and control group. The treatment group received conventional instruction for five class periods, and during a sixth class, engaged in small-group discussion concerning questions designed to challenge misconceptions. An incentive of group bonus points was awarded if every member of a group could achieve a predetermined level of competency on an exam. The control group received parallel conventional instruction for five class periods and saw a demonstration related to the course content for the sixth class.

Posttests comparisons revealed that the treatment group had a significantly lower proportion of misconceptions on laws of conservation than the control group. Qualitative coding and assessments of transcripts recorded during small group discussion suggested that the group tasks facilitated group interaction, which promoted conceptual change. Additionally, three factors emerged from analysis of the transcripts that shed light on group processes as they relate to conceptual change. They included the fact that students exhibited a flawed understanding of basic science terms, which served to inhibit fruitful discussion and correct concept attainment. They were preoccupied with arriving at answers that matched the text rather than deriving personally satisfying answers. The groups that were more truly cooperative (i.e. democratically run) were more successful than groups that were more autocratically run (a group leader took control and made decision without group consent).

Central to the idea of conceptual change is the constructivist approach to teaching. Some investigators, like **Trumper**, have used the constructivist method to teach various scientific concepts. Trumper noted that in a study of teaching energy concepts with 35 ninth grade students, the most common alternative framework held by students was anthropocentric in nature (i.e., energy is only associated with humans). The author stressed the need for the teacher to act as a diagnostician in eliciting pupils' alternative frameworks, to develop strategies to confront these frameworks, and to develop evaluation techniques that examine the extent of assimilation of concepts taught. Selected instances of small group dialogue in which these strategies are invoked are provided. It was reported that 80% of the students were ultimately able to use acceptable scientific concepts in describing numerous energy concepts.

Hand and Treagust assessed the ability of a particular curriculum design to help students examine their own conceptions of subject matter. The 15-lesson curriculum on acids and bases followed a conceptual conflict format and was administered to a class of average to below average grade 10 students ($n=19$) in Queensland, Australia. An equivalent class ($n=18$) constituted the control group (non-constructivist teaching approach). Given that a conceptual conflict model was followed, students' conceptions of acids and bases was assessed via semi-structured interviews and used as the basis for the design of curriculum activities. Five misconceptions were identified: "(1) an acid is something which eats material away; (2) testing of an acid can only be done by trying to eat something away; (3) to neutralize is to break down an acid or to change from an acid; (4) a base is something which makes up an acid; (5) a strong acid can eat material away faster than a weak acid." Students' achievement was assessed with a posttest on both content and process following the administration of the unit. The students exposed to the constructivist teaching approach scored significantly higher on both content and process sections of the assessment instrument. The authors cautioned that the noted results may have been confounded by the fact that different teachers taught the two sections and that no attempt was made to establish equivalence of the two classes.

Other Studies on Pedagogical Strategies

Willerman and MacHarg examined the use of a concept map as an advance organizer. The working assumptions of advance organizer maps were that they should be expressed in terms that are familiar to students where the student is required to construct interrelationships between major concepts and subconcepts. Additionally, advance organizers are assumed to be advantageous in situations where the content is not well organized, and particularly with students of limited skills. Because concept mapping organizes knowledge into hierarchical structures, the authors hypothesized that students who are presented with a concept map as an advance organizer at the beginning of a physical science unit will outperform those who do not utilize one.

Forty students from eighth grade physical science classes made up the experimental group and 42 students were in the control group. The subjects represented a fairly wide range of racial, sex, and SES backgrounds. Although there was no difference between the groups in reading and mathematics scores, initial differences on content knowledge were not assessed. As an advance organizer, the experimental group received, prior to instruction, a blank concept map with spaces assigned for the hierarchical concepts to be presented. It also contained arrows showing the connections between the concepts. These students copied the teacher's example. The control group was given an introductory lesson that included the objectives of the lesson. The results indicated that the experimental group significantly outperformed the control group on a teacher-constructed achievement test.

Linn and Songer investigated the cognitive demands required to foster middle school student understanding of thermodynamics. The area of thermodynamics was chosen, in part, because it involves numerous observable influences and is accessible to students in lab-based settings. A heat flow model of thermodynamics was selected because it provided a generative, qualitative, concrete way to present a variety of thermodynamics problems to students. The Computer as A Lab Partner Curriculum (CLP) was created as a means to investigate problems in this area, which provided real-time data for investigation and practice in analyzing the reliability and validity of computer-presented information.

Four physical science classes (about 128 students) participated in the 20-week instructional unit of which the CLP curriculum devoted 13 weeks to heat energy and temperature activities. Student understanding of thermodynamics was measured by the Heat and Temperature Assessment (HTA), which provided a qualitative means to code student responses. Both pretests and posttests were given for each of four versions (plus a baseline) of the CLP model.

The first version demonstrated that students could readily use and interpret real-time data, but that they did not possess an integrated understanding of the distinction between heat energy and temperature. The second version used multiple representations of concepts, and students were able to use a word-processing program to produce joint-partner reports. There was only a small increase in students' integration of knowledge. Version three sought to increase the cognitive demands by emphasizing prediction and observation to foster scientific reasoning and integrated understanding. Students were much more active in this version in terms of actively recording their observations and using the results of prior experiments to make predictions about new investigations. This version was found to significantly improve students' integration of knowledge. The final version (four) more fully integrated the role of observation and prediction. Again, significant differences were found when contrasted with version three, in students' ability to differentiate heat from temperature.

Considered together, the findings suggest that the CLP curriculum can provide the motivation for students to construct their own understanding of integrated concepts, which appears to have both depth and robustness. The authors also argued that attending to fewer topics in more depth will ultimately lead to a more coherent understanding of scientific concepts.

The use of adjunct questions (in this case, questions used in conjunction with science charts) was investigated by Holliday and Benson. This research is a subset of work on the selective-attention hypothesis, which explores how students' attention can be directed toward particular relevant categories of information as they are taught various science topics. Because charts focus students' attention on compartmentalized, relevant pieces of information, the authors hypothesized that students receiving questions to be considered in conjunction with charts would significantly learn more difficult content.

In this study, 299 predominantly tenth grade biology students in 16 classrooms were randomly assigned to four conditions: (a) no orienting directions; (b) test

exposure where an achievement test was examined for 60 seconds; (c) question emphasis where adjunct questions were presented; and (d) combinational conditions (strategies b and c combined). Within each classroom the students were randomly assigned to one of four question groups: (a) no question; (b) questions focusing on easy content; (c) question on difficult content; and (d) combinational (strategies b and c) and questions on chart information). The dependent variable was students' achievement on a recognition test of vitamins and their characteristics. Space does not permit a more detailed description of the experimental treatments.

The main hypothesis of this study was supported. Questions adjunct to a science chart significantly improved students' performance by focusing their attention in a selective manner. This interaction effect was so pervasive that content labeled as difficult to learn in the control data became content that was easier to learn when focused by adjunct questions. The authors reported numerous secondary findings that have important implications for teaching that uses these strategies; researchers interested in pursuing this area of investigation are encouraged to read this article in full.

Comments

As evidenced from the cited literature, work in the area of the nature of science continues to grow. Science educators appear to recognize the importance of considering the philosophical underpinnings of science in the context of teacher preparation programs. Future research on students' and teachers' perceptions of the nature of science and how those views can impact on teaching and learning would help extend the current knowledge base in this area.

It was somewhat surprising to find only five research articles dealing with science, technology, and society themes, given that teaching science in a social context continues to be a recognized goal in science education. Alternative forms of assessment may provide a means to improve instruction in this area. Related topics of moral and ethical issues in science and classroom discourse with respect to these topics is clearly lacking. While other non-empirical articles offer pedagogical arguments for reforming science education towards an STS-based curricula (e.g. **McFadden; Wraga & Hlebowitsh**), research on various aspects of the STS movement and related issues of moral and ethical issues embedded in science teaching are clearly lacking.

Teaching science through informal settings is an area of research that is beginning to receive the attention it deserves in the science education literature. It offers an alternative approach to conveying science topics, but more systematic investigations need to be conducted to ascertain what factors can make these experiences both cognitively and affectively rewarding for students. Research is also needed to determine how to better prepare students to reap the benefits of informal settings through complementary teaching methods in the classroom. Work on how students construct and transfer knowledge from alternative settings to the classroom and vice-versa should be encouraged.

Surprisingly, only one research study in this section was found in the science education literature on the use of technology in the classroom. Although some work has been done on the use of technology in the classroom, there apparently is very little work published in the science education literature about the use of technology in science teaching. Perhaps this lack of research is not truly representative of a trend, but just the fact that not many articles found their way into the science education literature this particular year. Research on the use of a variety of forms of technology (microcomputers, telecommunications, videodiscs, etc.) and how these forms of technology can enhance curriculum design and instruction is certainly warranted.

The area of reading received a good deal of attention, while the use of writing strategies in science teaching was discussed by only one author. In the area of reading, texts were examined for the level of questioning incorporated in text, use of inquiry activities, use of major science themes, gender fairness, and selective traditions (paradigm effects). These were complemented by several pedagogical articles that address the selection and use of reading material in science teaching.

Critical thinking and problem solving received only minor attention during this year. It is not entirely clear that researchers and teachers differentiate between these terms, nor is the extent to which these issues are addressed in schools, courses, or teacher education programs clear. Again, incorporating research from other disciplines, as was done in an article by **Stewart and Hafner**, may provide the science education community with the theoretical framework necessary to assess how to best integrate such thinking strategies into the curriculum and to assess the cognitive prerequisites that may be necessary for the effective employment of critical thought.

The area of strategies and methods included a wide array of articles. There was very little information on the integration of science with other scientific disciplines (e.g., mathematics), or among other areas of study outside of science (e.g., social studies). In contrast, there were numerous studies on different approaches to treating misconceptions. Of particular interest was the variety of instructional approaches used in conjunction with standard conceptual change strategies (e.g., cooperative learning). This work may provide a basis for future studies that attempt to ascertain more "across the board" or generic teaching approaches to treating misconceptions and that deal with unifying themes in science. This latter point reinforces the importance of considering alternative epistemological models of theory development and change in the scientific community.

Finally, for researchers interested in cross-paradigm perspectives in the use of questioning in the classroom, the reader is referred to another review of the literature by **Carlsen (a)**, who examines three features of questions: context, content, and responses and reaction by speakers. Studies representing two distinct research paradigms (process-product research and sociolinguistic approaches) are contrasted, and many of the examples are science-oriented. This review is highly recommended to those who desire a robust conceptual framework in which to embed their science teaching research on questioning strategies.

Related Dissertations

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Cognition and Achievement

For the purposes of this review, teachers' cognition and achievement is defined as teachers' pedagogical understandings, their knowledge of content and of the students they teach, and the merging of these understandings into classroom practice. Information concerning teachers' understandings of their role in the classroom has been included in the section on Teacher Affect and Characteristics. Two articles in this section describe teachers' knowledge of students' knowledge. The remaining two articles are related to teachers' knowledge of content and the influence of reflection on teachers' and students' knowledge of content and pedagogy.

Teachers' Knowledge of Students' Knowledge

Twenty high school physics teachers were interviewed by **Berg and Brouwer** to determine their awareness of student alternate conceptions in the areas of force and gravity. The teachers were also asked to indicate preferred teaching strategies dealing with alternate conceptions. Teacher predictions of student responses were compared to alternate conceptions held by 315 ninth-grade students and published findings from other research studies. Edmonton students were found to possess nearly every alternate conception identified in previous research in similar proportions. A few previously undocumented alternative conceptions were also identified. At times students were observed to arrive at the currently acceptable conclusion by using alternate conceptions. The high school physics teachers, as a group, identified nearly all the alternate conceptions, used by the students. Individual teachers were generally aware of only a few alternate conceptions, however, with fully one third of them possessing alternate conceptions themselves in one or more of the tasks. The teachers were also unable to predict with any accuracy the different types of student responses or the proportion of students choosing each alternative. The teaching strategies outlined by the teachers would be considered only partially effective according to current research findings.

Altieri and Duell conducted a study that examined (1) students' preferences for wait times of 3 seconds versus 0.9 second following a higher-order cognitive question, (2) teachers' ability to accurately predict their students' preferences, and (3) the reasons both groups of participants gave for their choices. Thirty-five middle school science classes ($N=679$ students) watched two versions of a videotaped science review lesson. The versions differed only in the length of time the teacher paused after questions before she called on a student to respond. When asked which version would produce more learning and when asked which version they preferred (after being told how the two versions differed), significantly more students chose the version with the longer wait time. Significantly more teachers predicted these choices accurately than inaccurately. Students identified think time, time use, teacher helpfulness, and topic ease as reasons for their choices.

Teachers' Knowledge of Content and Pedagogy

Carlsen (b) examined the instructional plans of four beginning teachers as they prepared to teach familiar and unfamiliar topics in biology in an attempt to determine the effects of teacher subject matter knowledge on high school science teaching. Framed on the assumption that teachers use discourse strategies that vary as a function of their subject matter knowledge, 12-16 lessons were audiotaped for each teacher over the course of the school year. Lesson plans for the entire year were examined and coded according to topic and instructional strategy and within-teacher analyses were used to account for differences in lesson plan formats. Each of the teachers taught more lessons on high-knowledge topics than on low-knowledge topics. Group work, projects, and student presentations were more common activities during low-knowledge units. Lecture, recitation, quizzes and tests, and reviews were more commonly employed techniques when teaching high-knowledge topics. The use of labs and movies did not relate to topic knowledge level.

A three-year naturalistic study was conducted by **Baird, Fensham, Gunstone and White** to see whether collaborative reflection could enhance teaching and learning of science by generating desirable cognitive, metacognitive, and affective outcomes. Reflection was both individual and in groups and involved reflection on practice in the classroom and phenomenological reflection on the nature of science teaching and learning. The study had two components. The preservice component involved 13 student teachers and teacher educators. The inservice component involved 14 novice and experienced science teachers and 350 of their students. The data collected included interviews, questionnaires, and written evaluations. Findings from the study illuminate aspects of the nature of science teaching and learning, processes by which individuals improve the quality of their practice, and methods for exploring teaching and learning mechanisms and facilitating change. Central to these findings is the importance of each of the two types of reflection for fostering personal and professional development. For both teachers and students, both types of reflection acted to improve their knowledge, awareness, and control of themselves and their classroom practice.

Comments

With as many aspects of the classroom being dependent on the thoughts and actions of the teacher, it is amazing how few studies dealt with this issue in 1991, especially when compared to the wealth of studies reported in the area of student cognition and achievement. The importance of teachers having knowledge about their students' preferences and misconceptions was added to the literature base this year. Why is this information important? The simple documentation of what teachers know and do not know is hollow without further exploration of how this knowledge impacts classroom practice. For instance, do teachers with greater knowledge of the variety of student misconceptions use this knowledge to improve their teaching? If not, how can such improvements be encouraged?

Carlsen attempted to make this connection by looking at the relationship between teachers' content knowledge and the teaching strategies used in the classroom. The results support the persistent call to upgrade teachers' knowledge over the course of their careers with the potential result being the incorporation of more appropriate teaching strategies in the classroom. Simply requiring teachers to take more content courses, however, does not seem to remedy this situation. As Carlsen noted, it is difficult to expect any potential teacher to be fully versed in all the content they are expected to teach. Perhaps research should be aimed at looking at the effectiveness of systematically spaced inservice programs related to content across the course of a science teacher's career. Such a strategy might enhance content knowledge while allowing for the direct application of this knowledge directly back to the teaching context.

In many ways, the Baird, Fensham, Gunstone and White article may suggest a vehicle in which both teacher and student knowledge can be increased through the use of reflective techniques. The advantage of reflective techniques over inservice courses is that the solutions produced are personally and contextually valid. Time for reflection must be provided in a structured way, however, if significant results are to be anticipated. The noted success of reflective strategies in increasing teachers' and students' knowledge and awareness of science teaching and learning encourages its application to other documented variations in teacher and student knowledge.

Related Dissertations

Evans, K.D. (1991). An investigation into the problem-solving abilities of preservice elementary teachers. *Dissertation Abstracts International*, 52(6), 2094a.

Mosothwane, M. (1991). An assessment of Botswana preservice teachers' environmental content knowledge, attitude towards environmental education and concern for environmental quality. *Dissertation Abstracts International*, 52(6), 2095a.

Affect and Characteristics

Because of their interrelated nature, teacher characteristics and affect were combined in this literature review. Teacher characteristics and affect were defined in the broadest sense: demographic aspects of teacher populations and teachers' beliefs, perceptions, attitudes, and interests toward and about science and science teaching. In organizing these articles, four major categories of research emphases were derived: attitudes toward science teaching, attitudes toward science teaching techniques, teacher beliefs and their effect on teaching behaviors (including teachers' conceptions of their role in the classroom), and teacher characteristics and teaching contexts.

Teachers' Attitudes Toward Teaching Science

In an attempt to better understand the background characteristics, perceptions of content taught, and inservice needs of elementary teachers in the areas of mathematics and science, **Berenson, Hodgin, Ward, Andrews and Rudin** designed a 60-item *Needs Assessment of North Carolina Elementary Teachers*. Twelve hundred surveys were sent to principals across the state with 964 teachers returning completed forms. Results were reported in terms of teacher background, education, perceptions, materials use, and inservice courses. Of the four core subjects taught, teacher preferences for teaching content were (from most preferred to least) language arts, mathematics, social studies and science. Perceived levels of qualification to teach these subjects followed identical patterns. More elementary teachers requested additional inservice courses in science than in mathematics. Improvising laboratory equipment was a topic of specific need and interest. Implications for inservice programs for teachers are discussed by the authors.

Atwater, Gardner, and Kight administered two instruments in order to determine the unique needs and some of the attitudes and beliefs of urban primary school teachers (K-3) toward physical science and physical science teaching. The sample consisted of 16 elementary teachers from five urban elementary schools in the southeast who agreed to participate in a two week summer science institute and school year enrichment series. Fifteen of these female teachers were African Americans, one was White. The results of the study indicated that these elementary teachers realized the importance of hands-on activities. They felt, however, a need for a stronger knowledge of chemistry and physics to competently teach elementary physical science using that instructional strategy. There were significant positive relationships between their attitudes and beliefs about physical science.

Teachers' Attitudes Toward Science Teaching Techniques

In response to mandates by the Texas legislature that 40% of all science teaching time in grades 7-12 be allocated to laboratory instruction, **James**

surveyed 290 teachers about their concerns about the 40% lab time mandate prior to implementation and surveyed an additional 272 teachers at the end of the first year of implementation. Findings suggest that a large portion of the population felt negative about the 40% lab time rule. Few changes in personal and informational concerns occurred over the course of the year of implementation. The authors suggest that personal concerns related to innovations in classroom practice must be addressed through personal approaches if instructional changes are to be expected.

Science textbooks are dominant influences behind most secondary instruction but little is known about teachers' approach to science reading. Yore conducted a naturalistic study to develop and validate a *Science and Reading Questionnaire* (SRQ) to assess secondary science teachers' attitudes toward science reading (12 items) and their beliefs or informed opinions about science reading (13 items). The survey results of 215 British Columbia secondary science teachers indicated that teachers place a high value on reading as an important strategy to promote learning in science and that they generally accept responsibility for teaching content reading skills to science students. Most science teachers generally reject the text-driven model of reading, but they usually do not have well-formulated alternative models to guide their teaching practices. Teachers have intuitive beliefs about science reading that partially agree with many research findings, but their beliefs are fragmented and particularly sketchy in regard to the cognitive and metacognitive skills required by readers to learn from science texts. The findings for attitude, belief, and total skills were substantiated by further questions in the SRQ regarding classroom practice and by individual interviews and classroom observations of a 15-teacher subsample of the questionnaire respondents.

Teachers' Beliefs and Teaching Behaviors

Lederman and Gess-Newsome qualitatively studied the transfer of concerns, perceptions, and skills developed by 17 secondary preservice science teachers during microteaching and followed a random sample of six of these teachers into student teaching. Open-ended questionnaires designed to assess concerns, perceptions of teaching, and instructional decisions were completed periodically throughout the microteaching and student teaching experience. Analysis yielded a list of 17 concerns grouped into "Concerns for Self" and "Concerns for Students." Concerns and perceptions developed during microteaching persisted throughout student teaching. During microteaching, planning was viewed as a systematic process beginning with objectives and concluding with a mental rehearsal, while during student teaching it was reduced to a hasty search for "teaching tricks" that quickly conveyed subject matter. Comparative data analysis indicated that the much publicized developmental shift in preservice teachers' concerns from self to students is more likely an artifact of inherent differences between campus-based and field-based teaching situations than an indicator of professional development.

Research has indicated that most science classrooms are not intellectually demanding and place little emphasis on small-group discussions and laboratory activities. However, successful science programs and competent science teaching that can provide models for other science teachers do exist. **Treagust** sought to document the teaching practices of two exemplary biology teachers of grades 11 and 12 by means of an interpretive research methodology. A total of 54 classroom observations was conducted over a six-week period. Both teachers had a thorough and comprehensive knowledge of the content they were to teach and had a range of teaching strategies that could be used without a great deal of thought. Their expectations for student performance were high, consistent, and firm. Students were expected to complete a high level of academic work in discussions, problem work, and laboratory activities, and were encouraged to take responsibility for their own learning. A distinctive feature of these biology classes was the high level of managerial efficiency, where lessons were busy occasions for both teacher and students; students had little opportunity for off-task behavior. Both teachers actively monitored the behavior of both high- and low-ability students by moving around the room and speaking with individuals, while still maintaining control of the entire class. By manipulating questioning and the social environment, both teachers encouraged student input by referring to it, helped students to effectively use their time, and gave marks for completion of set work. Compared to research with less-successful teachers, these teaching behaviors contributed to exemplary practice.

Barrow states that embedded within images are beliefs, and the values associated with beliefs about teacher's roles often determine what is done in a specific context. This study looked at how one teacher conceptualized her role while implementing an elementary school science curriculum. Data collection involved teacher interviews, classroom observations, and weekly meetings. Two key assertions were made about elementary teachers: time limitations often constrain a teacher's ability to reflect on classroom teaching and practices, and the curriculum is often seen as a set of separate and discrete subjects to be taught rather than as an integrated whole. The underlying values associated with particular beliefs the teacher held about the teaching and learning of reading and how those beliefs changed when she personalized and constructed new visions of her role as teacher through critical reflection were delineated. That reflection led to a Wonderful Teaching Idea about how manipulative and observational science activities may bind traditionally discrete subject matter into a single experience, challenge traditional teaching methods, and bring old beliefs about teaching and the curriculum into question, thereby effectively integrating science and language teaching.

In a case study of **Brad**, a chemistry teacher who participated as a co-researcher in investigating the process of change, **Briscoe** describes the teacher's conceptualizations of his roles, the beliefs that supported the conceptualizations, and the constraints to change that exist in the larger social context of schools. Data collection consisted of weekly interviews over a 12-month period, field notes from bi-weekly classroom observations, and classroom documents. **Brad's**

metaphors for his role in the classroom and the role of classroom management and assessment were in contradiction to his classroom practices. The initial metaphors were supported by a set of beliefs that pertained to the expectations that students, other teachers, and administrators held regarding classroom practices. Reflection allowed Brad to see how his metaphors constrained him from changing his practice and from envisioning changes that were more consistent with a constructivist epistemology. The author concluded that metaphors are an important source of knowledge that teachers use in constructing roles for themselves and that changes in belief systems fostered through reflection are needed in order to change the metaphors held.

The influence of teacher beliefs on curriculum implementation was explored by **Cronin-Jones** in two different contexts. Two middle-level teachers implemented a 20-lesson life science curriculum package in the presence of participant observers. The teachers were selected to represent two predominant types of middle school teachers: teachers primarily educated as secondary subject area teachers and teachers primarily educated as broad-field elementary teachers. Data sources, which included field notes and interview transcripts, were analyzed in a constant comparative format. Case studies of the belief structures of each teacher were then prepared. In both cases, four major categories of beliefs appeared to influence curriculum implementation: beliefs about (1) how students learn, (2) a teacher's role in the classroom, (3) the ability levels of students in a particular age group, and (4) the relative importance of content topics. Both teachers believed that the most important student outcome is factual knowledge, that middle-grade students learn through repeated drill and practice, and that middle school students require a great deal of direction. The teachers' beliefs differed concerning a teacher's role in the classroom and beliefs regarding the curriculum and its content topics. Although certain components of both teachers' belief structures enhanced the success of curriculum implementation, their existing belief structures were incongruent with the underlying philosophy of the intended curriculum, thus hampering successful implementation.

Characteristics of Teaching and Teaching Contexts

In an attempt to further clarify the pressures on biology teachers to teach evolution from both scientific and creationist perspectives, **Zimmerman** conducted a survey of 336 school board presidents throughout the state of Ohio to elicit their views on the role of creationist versus scientific explanations of evolution in science classrooms. Fifty-two percent of the respondents felt that "creation science" should be taught in the public schools, though 67% felt that evolution should also be taught. While school board presidents had a fairly accurate view of what was being taught in their local school, the questionnaire demonstrated a prevalent misunderstanding of evolution by these leaders. Specifically, over 40% felt that "creation science" could be taught without bringing religion into the classroom. The number of school board presidents who would take an interventionist role on this issue was, however, quite small.

Orgren and Pawlewski note that though some reports have been interpreted as indicating future shortages of science teachers; others report that only 63% of the teachers seeking employment in 1987-88 were hired. To determine whether science teacher shortages are a reality, 265 Empire State Scholarship/Fellowship participants returned surveys concerning their field of science preparation, their employment experience, and their opinions relative to teaching and the scholarship program. Among the 64% of the respondents who had found full-time employment in science teaching, 33% added spontaneous comments about the difficulty they had finding jobs. Job availability was the highest for physics teachers (96%), followed by earth science (76%), biology (37%), and chemistry (29%). The authors suggest that such statistics be used to justify a decrease in the number of science teachers prepared with a concurrent increase in the quality of their preparation.

Comments

When examining teachers' beliefs and attitudes toward teaching science, several themes reoccur. First, teachers who are uncomfortable with the teaching of science or the use of specific teaching techniques often site a lack of appropriate background knowledge—either in the content, rationale behind the teaching strategy, or alternative methodologies—as the causative agent. The remedy to such a situation seems to be increased access to the necessary information and skills, though the manner in which this is handled must be personalized to both the teacher and the context. When science content knowledge is considered more carefully, teachers often realize that their understandings are fragmented and factually rather than conceptually based. Inservice methods must take such background knowledge and reticent feelings into account by utilizing strategies that recognize that teachers are also students in certain contexts and must be approached using the same constructivist teaching techniques advocated for younger learners.

Second, "good" teaching, at least in terms of how teachers practice their craft, seems to be defined by generic pedagogical practices: classroom management, beliefs in teacher role, students' ability and learning methods, and teachers' expectations of students. Although content knowledge, or the lack thereof, has been mentioned as a factor affecting teachers' preference in teaching content, the ability to handle the general aspects of the classroom seems to take precedence over content concerns. It may be that these generic concerns need to be addressed and reinforced more carefully in content-related classes in order to properly prepare and further the development of teachers at all levels of experience. In addition, the definition of the role of content knowledge and the level of content knowledge that is essential for "good" science teaching may need to be examined more carefully. What does it mean to have "adequate" content knowledge? Is factual knowledge the same as knowledge of the larger picture of science and the inherent relationships that exist? How can and should content knowledge merge with pedagogical skills to create an appropriate portrait of an exemplary science teacher?

Finally, reflection seems to be a luxury for most preservice and inservice teachers. Based upon the overwhelming complexity of the classroom, few teachers have the opportunity to reflect on their knowledge of content or pedagogy or to evaluate their teaching methods in terms of these beliefs. The lack of such opportunities seems to create teaching behaviors based primarily on outside influences (students, administrators, and textbooks), to encourage the adoption of survival strategies (the "bag of tricks" approach) rather than thoughtful practice, and to limit professional growth. When opportunities for reflection do exist, most teachers seem to recognize the dissonance between their beliefs and practices and are put in a position to positively activate change.

The three mentioned themes—knowledge, pedagogical skill and reflection—seem to provide both a challenge and a goal for programs designed for teachers. The delineation of these aspects of teacher affect provides fertile ground for the future development of preservice and inservice teacher education programs as well as provides avenues for future research. Research which evaluates specific methods for increasing teacher knowledge and skills as well as provisions for reflection should be welcome results to be utilized in the planning of teacher preparation programs.

Related Dissertations

- Briscoe, C.S. (1991). Cognitive frameworks and classroom practices: A case study of teacher learning and change. *Dissertation Abstracts International*, 52(3), 860a.
- Clemenson, J.J. (1991). A qualitative study of elementary teachers' and students' interactions with Full Option Science Systems. *Dissertation Abstracts International*, 52(5), 1621a.
- Johnson, K.L. (1991). Factors affecting curriculum decisions of San Diego seventh and eighth-grade science teachers regarding the creation-evolution issue. *Dissertation Abstracts International*, 52(4), 1152a.
- Lee, M.N.N. (1991). Structural determinants and economic consequences of science education: A cross-national study, 1950-1986. *Dissertation Abstracts International*, 52(1), 128a.
- Markovich, P.W. (1991). The perception of the goals of contemporary science education among science supervisors, directors, coordinators and chairpersons in New York state public secondary schools. *Dissertation Abstracts International*, 52(2), 492a.
- Matsumoto, C.S. (1991). Changing the way we teach: A descriptive analysis of elementary teachers attempting to make changes in their science teaching. *Dissertation Abstracts International*, 52(6), 2095a.
- Nyberg, L.M. (1991). Dynamics of excellence in science education: The state of the art. *Dissertation Abstracts International*, 52(4), 1280a.

Shore, L.S. (1991). The effect of astronomy teaching experience on the astronomy interest and conceptions of elementary school teachers. *Dissertation Abstracts International*, 52(3), 873a.

Spence, L.L. (1991). Factors that characterize teachers who plan and take field trips. *Dissertation Abstracts International*, 52(6), 2096a.

Science Teacher Education

Research that dealt with the preparation of inservice and preservice teachers is included in this section. Specifically, articles relating information concerning the status of elementary science teacher education programs, preservice science teacher preparation, and research concerning inservice and professional development were included. Despite the fact that there is a journal devoted to the topic of science teacher education, few of the articles from the year 1991 could be considered empirical research. When applicable, some of the articles that describe strategies for the preservice and inservice preparation of teachers were included. This inclusion is only to provide an indication of the types of articles that are being produced in this field, however, and is not intended to be a comprehensive listing.

The Status of Elementary Science Teacher Education

Three studies in this review looked at the requirements for elementary teacher preparation and certification in relation to science. **Tolman and Campbell** designed a survey to determine the current science preparation requirements of preservice elementary teachers in the United States in light of the standards suggested by the National Science Teachers Association in 1983. Central to these recommendations was the need for elementary science teachers to take courses in both science content and process and to have opportunities to develop positive attitudes towards science and science instruction. Results were returned from 239 public and private institutions that graduate 75 or more education majors per year at the bachelor degree level. Less than one third of the institutions surveyed reported compliance with the standards for content preparation. Only 20% claim to have science courses specifically designed for preservice elementary teachers. Nearly 75% provide science methods courses with a large majority of those courses requiring a practicum.

Recognizing the significant role and importance of science teacher preparation in small four-year colleges, **Yager and Bybee** elected to assess the status of these programs and the changes that have occurred during the last 25 years. A survey was sent out to the 301 four-year member colleges of the American Association of Colleges of Teacher Education. After extended effort, a 25% response rate was achieved, resulting in the authors' recommendation of cautious interpretation of the results. Changes in science teacher education programs in these institutions are similar to those occurring in larger institutions, though less pronounced. The authors attribute this difference to the fact that smaller institutions are more isolated from changes dictated by guidelines from professional societies, research, and funding agencies. The increase in science requirements, instruction in the history/philosophy of science, science methods, early experience in schools, student teaching, and total professional requirements in education reflect trends similar to those noted in teacher education institutions of all sizes. Changes in

elementary education with respect to science are very small except for the increased requirement of a science methods class.

Barrow compared preservice elementary science programs of two geographic regions—Big Eight States and New England. Survey data were collected from 132 teacher education institutions about the types and amount of science content and elementary science methods courses, program emphasis in science content, emphasis on science processes and methods, variety and use of science teaching techniques, effectiveness of science preparation, and the general quality of the preparation of elementary science teachers. Differences in the requirements for preparing elementary science teachers were found between the two regions. Big Eight institutions required more content science hours and greater use of laboratories in science courses. Almost all institutions failed to meet the NSTA guidelines for content preparation.

Preservice Teacher Preparation

The differences among three elementary school science preservice teacher preparation course sequences with respect to three variables, understanding the nature of science, attitudes toward science, and attitudes toward science teaching were examined by **Harty, Samuel and Andersen**. In addition, this study also sought to ascertain whether correlations were present among these variables with each of the three course sequences. The Science Process-Content/Methods-Field Sequence consisted of a physical science course on science process skills and was designed to help preservice teachers prepare for the science courses to be taken in subsequent terms. Science teaching methods were covered in three one-hour sequential, highly coordinated and structured courses that were taught concurrently with co-requisite science courses specifically designed for elementary teachers in biology, physical science and geology/astronomy. The content gained in each of these pairs of courses (content and methods) was applied to planning and teaching small groups of students during bi-weekly field experiences over the three semesters. Because of this content/methods arrangement, the methods courses taught were more content/subject matter oriented than those in the other sequences. The Science Process-Methods Sequence included a process skills course (the same as the first group) and a single three-hour science methods course consisting of a lecture and two-hour laboratory per week that focused on ways to implement a process-discovery teaching approach. The science content vehicle for this course was a combination of the contents taken by the first group. The students in this section did not participate in a concurrent field experience. The Methods Sequence consisted of a single three-hour methods course similar to that for the second group. No field component was offered to this group, and they did not receive the science process skills class provided to the other two groups. Teachers completing the Science Process-Methods Sequence and Methods Sequence groups possessed a significantly greater understanding of the nature of science than teachers in the Science Process-Content/Methods-Field Sequence group. This finding would lead one to believe that the decreased emphasis on content

contributed to a greater focus on process skills and the nature of science. No significant differences were found among the three groups with respect to either attitudes toward science or attitudes toward science teaching. No significant correlations were found between understanding the nature of science and attitudes toward science or attitudes toward science teaching within each of the two groups. Significant correlations were found between attitudes toward science and attitudes toward science teaching for all three groups.

Trumbull and Slack report the pedagogical realizations developed by preservice biology teachers after extensive work in a course that aims to increase students' abilities to reflect on their own pedagogical understandings. Based on the assumption that successful science students are not always sensitive to the perspectives held by learners who have not been "socialized by success in science," these teacher candidates designed, conducted, and analyzed Interviews about Instances in order to elicit students' ways of thinking about and making sense of a particular phenomenon. An analysis of the work (interviews, journals, and portfolios) completed by five female juniors majoring in biology was described. Several key findings were discussed: the difficulty preservice teachers have in asking authentic questions, the realization by teacher candidates of the multiple perspectives that students hold on a single concept, the recognition of the existing compartmentalization of school learning from everyday life, and the low content background of fellow teachers. The authors also present a description of what the course instructors learned and discuss some of the problems and dilemmas encountered in teaching this course.

Inservice and Professional Development

Based upon the common complaint by teachers of insufficient opportunities for professional development, **Herr** sought to determine which of the formats for advanced science instruction, Advanced Placement (AP) or "honors," is more effective at fostering communication between educators at secondary and higher education levels thereby stimulating their professional development. Nineteen teachers experienced in teaching AP biology, honors biology or both were interviewed regarding the teachers' perspectives of the influence of program format on their professional growth. Questionnaires based on these interviews were later returned by 155 biology teachers who had experience teaching both formats. Teachers experienced in both courses believed that the AP format more effectively fostered professional communication and development. Some of this difference was attributed to the offering of workshops on teaching AP biology by the College Boards. AP teachers cited the need for intellectual stimulation more often than honors teachers, read more professional journals, and dedicated more time to improving their content background and preparing for classroom presentations.

Contable and Long conducted a two-year evaluation of a two-day short course on teaching science. In particular, the relationship of the course, which presented information on constructivist teaching perspectives and practices, to

change in classroom practice was examined. An important mediating factor of teaching in line with the principles proposed by the workshop appeared to be the process of getting a critical grasp of the ideas involved in constructivism. Teachers' existing knowledge was defined as an important factor in the way that new ideas were examined. It was suggested that apparently familiar ideas do not get the attention needed for the fine-grained discrimination necessary for a critical understanding to be developed. It was suggested that fidelity to a teaching philosophy and demonstrations which translate that philosophy into action may provide a mechanism by which teachers may enhance their critical grasp of the teaching approach proposed to them.

McNay distinguishes between the "scientists' science," instruction focusing on content knowledge that is typical of the teaching traditionally advocated in the upper elementary grades and in secondary classrooms, and "children's science," instruction focused on children's experiences of natural phenomenon and the way they make sense of those experiences. Eight elementary teachers agreed to read original research on children's science conceptions, write reaction papers, and discuss the readings in a group setting eight times over the course of the school year. The focus of the project was to have teachers identify the significance, if any, of this line of research to their classroom practice. The teachers were surprised by the results of the research they read and expressed the desire to learn more and to change their teaching practice in ways that will sensitize them to their students' incoming science conceptions.

Comments

In 1991, many policy papers addressed how science education should be improved. Central to many of these arguments is the important role that science teachers play in the proposed reform of science education. **Kyle, Lynn, Bitner, Mitchener and Perry** recommended how research should increase our understandings of science teaching and learning: research should be a collaborative endeavor; teachers should be action-researchers; research must be close to the classroom; an investigative society should be created; and research should inform policy. Note that almost all activities mentioned include the direct involvement of teachers, with the logical implication being the need for teacher education programs to find ways to bridge the gap between theory and practice and to draw teachers into a more research oriented role within the profession. When one examines the research conducted, however, a very different picture emerges. Relatively few studies are conducted on the effectiveness of various programs to prepare teachers for the complex role they are to participate in or in ways to transfer research activities and findings from university contexts to those of the public schools. It seems much easier to create policy and to delineate the current status of programs than it is to actually affect change in teacher education in a systematic and research-based manner. Unfortunately, the creation of policy without concomitant action only furthers the rift between research and practice by raising expectations without offering means to accomplish them.

Several strategies that have the potential to positively affect teacher preparation and development have been conducted and reviewed in this issue. Of key importance is the potentially powerful influence of teaching teachers in a constructivist manner. Often it seems that the attention paid to student learning falls short of its natural implications for learning for teachers. The **Contable and Long** article is a reminder of the importance of fidelity to a teaching approach and its faithful demonstration to teachers if learning outcomes related to the teaching philosophy are to be expected. Such statements should remind all teacher educators of the need to carefully examine personal philosophies and the ability to put beliefs about teaching into practice for students to see. Articulation of beliefs seems to be a much less powerful strategy for changing teaching philosophies than does the observation of these beliefs in practice.

The research abstracted also outlines various strategies that allow inservice and preservice teachers to examine and change their practice. Two methods of introducing teachers to the importance of student misconceptions were offered: reading the research, and interviewing students about their misconceptions and analyzing the results they obtained. The article by **Harty, Samuel and Andersen** was particularly useful for identifying how changes in the sequence of methods/content/process classes seem to influence the types of beliefs that students have about science. The fact that students leave content/methods course combinations with a less developed sense of the discovery approach to science teaching and an understanding of the nature of science should stimulate reflection on preservice teachers' incoming beliefs and the teaching strategies and methods they are exposed to at the post-secondary level. Is the difference in their outgoing beliefs and understandings a result of a disproportionate emphasis on discovery in one course sequence, and content in the other? Is it not possible to adequately teach content and process simultaneously, or is the learning of these contents in tandem too difficult for the typical elementary major? If this is so, how can we expect elementary and secondary students to properly attend to and learn both? Are the teaching strategies used in university settings focusing on the integration of process and content? Answers to questions of this nature may help us more appropriately develop preservice and inservice programs.

Finally, the lack of empirical research on science teacher education is disturbing. However, several articles that describe personally effective teaching techniques have been published. Among these include an article by **Evans** on how to use science education journals in methods classes; **Johnson, Laughran, Tamppari and Thomas** on how to set up a resource file; **Tobin, Davis, Shaw and Jakubowski** on how to design a program that uses a constructivist epistemology; and **Johnson** on how to get students to evaluate a methods course and thus synthesize the content. All of these articles seem to provide strategies that are worthy of empirical testing in order to determine their effectiveness as alternate methods of achieving various student outcomes. The science education community often decries the under-utilization of the knowledge gained through research on science teaching and learning in the public school classroom. Is the same true for the university classroom? Maybe it is time for us to reexamine

university teaching practices and determine if we, as science educators, are following our own advice and using research to inform practice, and conduct research that will inform practice.

Related Dissertations

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RESEARCH ON LEARNING

Empirical studies within this category focus on the student as the *primary* unit of analysis. Consequently, although some of the investigations that follow may address questions related to teacher behaviors and actions, such emphases are clearly secondary to student outcome variables.

Curriculum and Instruction

The student outcomes focused upon in this grouping of research reports are primarily related to global curriculum themes (e.g., scientific literacy, process skills) and/or instructional approaches (e.g., technology integration, museum exhibits, learning in small groups). Although many of the reports relate to teaching approaches, they have been placed in the Research on Learning section as a consequence of the primary emphasis on student learning.

Process Skills and Reasoning

Flick focused on the ability of analogical comparisons and explanations to foster students' understanding of science concepts and preference for causal explanations when describing changes in states of matter. The sample consisted of 24 volunteer students (eight each from grades 3, 4, and 5) from a high ability student population. Instruction centered around the use of a sugar-cube analogy to conceptualize changes of state in water as resulting from the action of particles. Instruction lasted 30 minutes a day for two weeks. Students' preference for causal explanations was measured with a pre and posttest administration of a Concept Preference Inventory. After instruction, students were asked to complete a two part worksheet. The first part reestablished the analogical context of grinding sugar and the second part asked students to identify similarities between grinding sugar into a powder and blowing it away and ice melting to a liquid and then evaporating.

The Concept Preference Inventory indicated a shift away from the concept of transmutation and, in general, students exhibited a shift to more causally oriented expressions of state transitions in water using language that suggested concrete images and mechanisms. It was concluded that explicitly highlighting

the selection and application of analogies results in students using language that has operational connections in their own experience but is useful for exploring the concept targeted by instruction.

Gilbert developed an alternative definition of science (i.e., a process of constructing predictive conceptual models) and attempted to show its usefulness relative to definitions of science currently in use. A sample of 687 undergraduate students enrolled in their first university science course (i.e., introductory biology) were administered two sets of six statements adapted from the VOSTS and NSKS instruments. These statements were designed to assess the students' understanding of the nature of science and research, and the nature of models and model building. On the first day of class, each student was asked to agree or disagree with one of the statements and provide a reason for the response provided. A total of 42 to 67 responses were collected for each of the 12 statements with each student only responding to one statement. Students responses concerning the nature of science were compared with expressed views about model building. The results indicated that students disagreed with the idea that scientific knowledge is artificial and does not show nature as it is. On the other hand, a majority of students agreed that a model is an artificial representation. Students tended to agree that both scientific knowledge and models can and will contain error. Although most of the students believed that the laws, theories, and concepts of different disciplines interact, they did not agree with the notion that models produced by different disciplines interact. Interestingly, although a large majority of students (79%) believed that there is no single scientific method, only 37% believed that there are a variety of acceptable approaches for creating models.

In another investigation of students' thought processes, **Ingham and Gilbert** interviewed 45 chemistry students (ranging from first year undergraduate to post-graduate research level) in the United Kingdom. Using a collection of analogue model chemistry construction kits as the primary prop, participants were interviewed with respect to use of such models in their secondary schools, perceived uses of the models, and the relation of analogue models, and modeling in general, to chemical reactions and the corresponding projection of a reaction mechanism. Only six of the students had personally used models in secondary school, while 23 remembered them being used by teachers to demonstrate certain principles. Most students viewed the usefulness of models as enabling them to concretely represent abstract ideas as opposed to having internalized the concept of modeling. In general, the uses of models noted by the subjects in interviews were not related to the values typically ascribed to models by practicing chemists.

The basic ontology present in the common-sense reasoning of 38 Brazilian secondary students was explored by **Mariani and Ogborn**. The concepts of matter, energy, time, space, movement, heat, light, sound, and force served as focal points for a questionnaire that used Piaget's structuralist and constructivist view of reality construction as a theoretical framework. The ontological features assessed for the selected scientific concepts were: What it is like, What it can do, What can be done to it, You can treat it as, and You can use it to. Analysis of the

data showed that the students' responses could be interpreted as lying within a four dimensional "ontological space" consisting of: static-dynamic, place-like-localized within a place, discrete-continuous, and cause-motion (effect). The authors then analyzed the ontological location of each of the nine concepts investigated and viewed the results using Piaget's psychogenic and sociogenic perspectives. The results primarily conformed to the psychogenic perspective indicating that the world (as seen by the sampled students) is understood as constituted of objects, which are real and have some permanence, and to which one can effect changes by exercising actions, within a spacio-temporal framework.

How students approach and actually think about experiments performed in their science classes is becoming an emerging area of interest. **Schauble, Klopfer, and Raghavan** investigated the hypothesis that when children engage in science experiments that focus on causes and effects they often use the engineering model of experimentation, which is characterized by manipulation of variables to produce a desired outcome. The sample consisted of nine females and seven males, which were representative of the four 5th and 6th-grade classrooms in a middle class suburban intermediate school. Each student was asked to work on two experimentation tasks, one mirrored the engineering model and the other adhered to the science model. The two tasks were derived from hydrodynamics and hydrostatics. The contexts, however, of task presentation were varied so that half the students worked on each task in an engineering context (purposeful generation of effects) and half worked within a science context (oriented toward understanding relationships). Each subject worked approximately two hours on each task (in 40-minute sessions) on an individual basis with one of two researchers. After extensive analysis of students' approaches to the experimental tasks, it was noted that, in general, the group of students exhibited statistically significant increases in the percentages of inferences about variables that were both correct and valid. However, greater gains were noted for those students who began with the engineering problem. By carefully manipulating the engineering versus science context of the tasks, it became evident that students may perceive activities from a personally biased perspective, one oriented toward thinking the purpose of the task is to generate interesting or desirable outcomes. This particular model of experimentation may influence students to overlook the possibility that undesirable or unfavorable results can also produce useful information and impede the development of strategies of scientific reasoning that can be useful in some situations. In short, the results clearly indicated the importance of considering the students' perception of the purpose of the experiment in addition to the actual subject matter content of the experiment.

Song and Black investigated the performance of two different science process skills (i.e., interpretation and application) in different contexts (i.e., everyday and scientific). A total of 228 students were selected from two middle schools and two high schools in Seoul, Korea. Data were collected using a paper and pencil instrument consisting of questions derived from the Assessment of Performance Unit as well as questions designed by the authors. Questions related to interpretation required students to recognize/identify patterns in a given

situation and then make a prediction based on the identified pattern or regularity. Interpretation questions did not require students to use scientific concepts or knowledge. Alternatively, application questions required respondents to use their knowledge of physics concepts in making predictions and then to justify their predictions. A total of 14 questions, of equivalent cognitive demand, were asked for each process skill (i.e., seven with an everyday context and seven within a scientific context).

Although there were no differences in the overall *mean* performance for the two contexts, there were noted interactions between process skill performance and context. For interpretation, students performed significantly better within everyday contexts while application skills were performed at a higher level in scientific contexts. The researchers inferred from the results that interpretation skills may be used primarily in everyday life situations while application processes may be used primarily in school situations.

The anthropomorphic and teleological reasoning of high school students was investigated in a descriptive study by **Tamir and Zohar**. Twenty-eight randomly selected students (12 in grade 12, and 16 in grade 10), from the academic track of a comprehensive school in Jerusalem, comprised the sample. Each student participated in a semi-structured interview that focused on the following issues: (1) acceptance of teleological/anthropomorphic/causal formulations, (2) anthropomorphic reasoning in relation to plants, (3) anthropomorphic reasoning in relation to animals, (4) ability to distinguish between teleological and causal explanations, (5) teleological reasoning in relation to evolution. The data indicated that the majority of students saw nothing wrong with the anthropomorphic formulations included in science textbooks. Most of the students were able, however, to distinguish anthropomorphic formulations from factual explanations and felt that use of such language actually assisted in making concepts and processes more comprehensible. Interestingly, most students did not attribute human purposeful behavior to plants, while most attributed at least some human behaviors to animals. Furthermore, the majority of students exhibited partially teleological reasoning when presented with conflicting situations containing both teleological and causal reasons. Finally, 71% of the grade 10 students and 56% of those in grade 12 exhibited teleological reasoning with respect to evolution.

Problem Solving

Bowen and Bodner used interview and "think aloud" techniques to analyze the problem solving processes of 10 students in a graduate course in organic synthesis. A variety of tasks that focused on specific phases of problem solving (i.e., preparation, production, and evaluation) were developed. After becoming familiar with the "think aloud" technique, each participant completed a 45-90 minute interview during which they completed tasks. Textbooks and monographs were available to participants as references during task completion. Qualitative analyses of interview transcriptions allowed the researchers to construct a profile of the various behaviors used by the graduate students as they solved organic chemistry problems.

In general, the preparation phase consisted of representing the problem either verbally or pictorially followed by attempts to relate verbal or pictorial representations to a methodological representation system in which specific reactions were selected to form the desired functional groups. The production phase was characterized almost exclusively by a methodological system in which the problem solver was guided by the belief that knowing reactions was the heart of organic synthesis (e.g., similar reactions were researched in the available books).

During the evaluation phase, students typically used representations grounded in principles, literature, laboratory knowledge, and economics. Of particular note was the finding that individuals moved through the particular phases of problem solving very quickly (i.e., often a matter of seconds) and cycled through the phases several times. This approach is not consistent with the view that students spend long periods of time in each phase and that each phase is only cycled through one time during the solution to a problem. The authors also noted that one of the most important decisions made was the representational system to use, because this decision tended to affect subsequent tactical decisions as well as the success of all subsequent problem solving phases. Interestingly, this significantly important decision was made with little conscious thought.

In another investigation of the highly prized, but often elusive, educational goal of problem solving skills Gabel and Samuel attempted to enhance college freshmen chemistry students' skills through the use of problem categorization. The sample consisted of 24 female students enrolled in an introductory college chemistry course for health professionals. Students were randomly assigned to two laboratory sections at the beginning of the semester. Each group was directed (in lecture) to use a particular approach to problem solving (EMPS). In the laboratory sections, however, the experimental group was helped to see the consequences of problem categorization and was given time to practice the categorization skill while the control group simply watched the solution of problems on the overhead projector using EMPS. The Logical Mathematical Reasoning Test, categorization and achievement tests, and cumulative achievement tests were administered at various times during the semester to measure students' achievement and categorization ability.

No significant differences were noted between the control and treatment groups for the compilation of all achievement tests. The treatment groups, however, scored significantly higher on combination problems (those containing two or more concepts) and unannounced achievement tests. Twelve students (six control and six treatment) were randomly interviewed in order to assess categorization skills. There was no appreciable difference in the two groups' use of categorization during problem solving. It was concluded that explicit training in the problem solving strategies of EMPS and categorization may increase achievement, but such training by itself is not sufficient for helping students to maximize their problem solving potential.

Pizzini and Shepardson investigated the quantity and quality of students' questions within the context of a problem solving instructional model. The

sample consisted of 22 teachers (grades 5-8) who participated in a project designed to refine and evaluate the Solve, Search, Create, and Share (SSCS) problem solving instructional model. Teachers were videotaped prior to the SSCS treatment and following the treatment. Students' questions in the presence of the teacher were coded with respect to cognitive level (i.e., input, processing, output) and to whom the question was directed.

The data indicated that, during large group instruction, there was no difference in the total frequency of students' questions between the SSCS instructional model and a teacher-directed laboratory model. However, during small group instruction, significant differences, favoring the SSCS model existed with respect to number of student questions and the percentage of student-student questions. Although not statistically significant, students tended to ask higher level questions in the problem solving instructional approach. Overall, the data clearly indicated how various instructional approaches and organizational formats affect the quantity and quality of students' questions.

STS and Scientific Literacy

Students' understanding of science-technology-society interactions and the attainment of scientific literacy continues to be at the forefront of educational reform. **Baker and Piburn** assessed the effects of a scientific literacy course on the skills, cognitive ability, and attitudes of students in their first year of high school. The sample consisted of 250 ninth grade students randomly assigned to three sections of the required course. The year long course was developed around four modules (i.e., exploration, relationships, verification, and models) that emphasized the commonalities of science as opposed to discipline-specific subject matter. Students' beginning and final characteristics were measured with a variety of instruments. Logical ability was assessed with the Propositional logic test, psychological type with the Myers-Briggs Type Indicator, cognitive ability with the Developing Cognitive Abilities Test, attitude with the School Attitude measure, and process skills with a series of teacher-developed measures selected on the basis of face validity. The results showed a significant improvement in skills such as observation, inference, measurement, and seriation. Statistically significant results were also noted in each of the subtests of the Developing Cognitive Abilities Test. Students' entering levels of logical ability, self-concept, and measurement ability were also significantly related to students' posttest scores on cognitive ability. Overall, changes in cognitive ability were predicted by achievement on tests of logical reasoning, measurement ability, and academic self-concept. After completing the curriculum, academic self-concept and mastery were related to scores on cognitive measures, while motivation, mastery, and control were correlated with psychological type. Given that there was a noted decrease in positive attitude from pre-posttest, it was concluded that the scientific literacy course may be best suited for the practical student who thrives in a controlled setting and not as well matched to the more academic and autonomous student.

Ben-Chaim and Zoller constructed STS outlook profiles of 11th grade Israeli students following the science, non-science, and technological curriculum tracks. A total of 546 students (and their teachers) constituted the sample for their ex-post facto investigation. Six representative statements from the VOSTS inventory were used to assess respondents' STS outlook specifically related to STS views/positions, STS beliefs/attitudes, and STS literacy.

Statistically significant differences were found among the three curriculum tracks on STS beliefs/attitudes and literacy, but not with respect to the more cognitively based views/positions. When students and their teachers were compared, statistically significant differences were found with respect to views/positions and beliefs/attitudes, but not for STS literacy. Finally, science teachers and non-science teachers differed with respect to STS beliefs/attitudes. The results supported the contention that none of the high school tracks contain an appropriate STS education component. Prior research by these authors has demonstrated the effectiveness of STS courses in promoting desired STS views/positions. Consequently, it was recommended that a more concerted effort to include STS instruction in science courses, social studies courses, and preservice and inservice teacher education be pursued if current goals concerning STS literacy are to be achieved.

Rubba, McGuyer, and Wahlund conducted two investigations, each using a non-equivalent control group design, to assess the effects of infusing STS vignettes into the genetics unit in high school biology. The effects of vignettes, along with discussion of the vignettes, on students' awareness of current STS issues, the importance assigned to STS issues, and genetics achievement were investigated. The sample for each investigation consisted of four sections of grade 9/10 biology taught by the same teacher. Class sections were randomly assigned to experimental (infusion of STS vignettes) and control conditions. In one experiment, vignettes were used twice per week and a discussion of the vignettes occurred every two weeks. In the other experiment, vignettes were used four days per week with ensuing discussion of vignettes occurring at least once per week. Each investigation lasted for six weeks. Students were administered the STS Issues Questionnaire (containing three free-response items) to assess their awareness of and importance assigned to STS issues. The teacher-made tests were used to assess students' genetics achievement.

In each investigation, no differences were found in genetics achievement between the control and experimental groups. Additionally, no differences were found between control and experimental groups with respect to either awareness of STS issues or the perceived importance assigned by students to such issues. It was concluded that teachers should not rely solely on the use of STS vignettes to achieve STS curriculum objectives. It was also noted that current academically oriented biology instruction typically found in high schools does little to influence students' awareness of STS issues.

Zoller investigated the relative effects of courses focusing on science, technology, environment, and society interactions within a science teacher education program. Specifically, three identical courses (two at the undergraduate

level and one graduate) were implemented, and relative effectiveness was assessed. In addition to the focus on current curriculum reform emphases, the course design was characterized by an integrated subject matter/methods presentation. The courses applied non-traditional, interdisciplinary, divergent, inquiry, self-study, open-ended, problem solving, and decision-making strategies. An eclectic exam and individualized eclectic exam were used as assessment instruments within the course framework. In brief, these examination formats can be characterized as open-ended and problem solving in orientation. In addition, all students completed a higher-level cognitive performance (HLCP) instrument and a 30-item Likert-type annual teaching evaluation questionnaire.

The results indicated that prospective teachers can succeed in learning at higher cognitive levels within the context of the new instructional approach. The undergraduates, however, typically perceived the course as either difficult or not in accord with their needs relative to those views expressed by the graduate students. It was concluded that the instructional approach holds much promise for science teacher education, but that much attention must be given to the implementation stage in order to ameliorate the problems experienced by undergraduate students.

Zoller, Donn, Wild, and Beckett compared the beliefs and positions of Grade 11 British Columbia students on STS oriented issues with those of their respective teachers. The sample consisted of 302 students enrolled in 49 STS courses and 255 students from 134 non-STS courses as well the students' respective teachers. Six statements from Aikenhead's VOSTS inventory were used to assess students' and teachers' beliefs.

The data revealed statistically significant differences between the beliefs of students and the beliefs of their teachers within both the STS and non-STS groups. Although no differences were found between the beliefs of STS and non-STS teachers, there were significant differences between STS and non-STS students. Because the student groups differed from each other and the STS students possessed views different from their teachers, it was concluded that STS students were educated with respect to STS issues as opposed to being indoctrinated with teachers' views.

Group Learning

The nature of student interaction within small-group learning situations is considered to be critical to the success of the group. **Kempa and Ayob** analyzed the verbal interactions of students engaged in problem-solving tasks (i.e., the planning of an experiment). The sample consisted of 93 high school students drawn from six schools (one intact class from each school) in Malaysia. Students were allowed to form their own working groups with the only limitation being that the number of students could not exceed four. Each group was then asked to discuss the possible solution to four separate problem-solving tasks. All group discussions were audiotaped, and all students were asked to write individual solutions to the problems following the group discussions. A categorization

system for the analysis of discourse was developed which included task-related talk (interpersonal-interactive and cognitive information), and task-unrelated talk.

Although there was much variation among the discourse of the 27 student groups involved in the investigation, several patterns were evident. Groups were found to vary significantly with respect to the total amount of verbal information exchanged and the extent to which individual people contributed to group discussions. Most interactions tended to take the form of dialogues between two group members at a time with the role of other group members uncertain during such interactions. With respect to the nature of interactions, most discourse tended to be task-related but heavily weighted in favor of interpersonal interactions as opposed to the exchange of cognitive information. In short, students tended to seek/express approval and/or express disapproval rather than participate in higher level discussions that are typically associated with true problem solving. The authors concluded that problem solving does not readily occur in group work situations and that whatever problem solving does occur is more the result of individual activity as opposed to the sharing of ideas among group members.

Watson used a 2 X 2 factorial design to investigate the relative effects of cooperative learning and Group Educational Modules (GEM) on the achievement of high school biology students. GEM is a team-learning approach that is a variation on the jigsaw instructional approach. The sample for the investigation consisted of 11 biology teachers with 36 classes and 715 students. Class sizes ranged from 16-31 with large and small class sizes represented in each of the treatment groups. Instruction took place over a three week period. In all, four treatments were included: GEM program with cooperative learning, GEM program with no cooperative learning, traditional materials with cooperative learning, traditional materials and no cooperative learning. A 50 item multiple choice test was developed and validated for use as a pre and posttest of students' biology achievement.

Overall, both the GEM approach and the cooperative learning approach were superior to the traditional approach in fostering student learning. However, no interaction effect of using both the cooperative and GEM approach together was noted.

Textbooks and Written Text

The importance of written text in relation to students' learning of science concepts has generated much interest recently. Boyle and Maloney investigated the relative effectiveness of two different written statements designed to facilitate students' completion of Newton's third law problems. A sample of undergraduate students were asked to complete five paper and pencil task sets related to the interactions of two blocks or a block and water. One third of the subjects ($n=48$) worked the task sets without any outside aid, one third was provided with a written description of forces as interactions which always come in pairs, and the final third was provided with an expanded version of the "pairs" statement which

stressed that the paired forces were equal in strength. Following the completion of each written task set, each subject was interviewed.

The results indicated that the vast majority of subjects used rules that involved more than one of the possible factors the problem situations contained. In short, the subjects tended to make the presented problems more complex than necessary. The students also seemed to conceive a force as either a "thing in itself, a property of an object, or an event." Finally, most of the subjects did not use Newton's third law to work the problems. When comparisons were made between the three groups, it appeared that the individuals who were in the best position to use the handouts with written texts were those who already understood and could have used such information without the handout. Overall, the data strongly indicated that students' "natural ideas" affect what they can learn and use from written text.

Physics texts have often been criticized for their level of reading comprehension. Koch and Eckstein developed a strategy to ameliorate this perennial problem. A random sample of 20 college students enrolled in an introductory physics course was used in a preliminary investigation designed to identify the difficulties students have in comprehending physics texts. Following the reading of a portion of a physics text, the students were interviewed about what they had read. In general, students were found to misjudge their comprehension level in either an overly optimistic or overly pessimistic manner. A follow-up paper and pencil test (following the reading of an additional portion of text) was used to investigate students' difficulties in a more in-depth manner.

The most common difficulties exhibited by the sample of students were: agreeing with statements that contradict the text, skipping statements in the text, believing there are statements in the text that are actually not present, not distinguishing between words that are only related and substituting related words for those in the text, inattention to textual inconsistencies, and using inappropriate meanings for words that have multiple meanings.

Based on their findings, the authors developed a question formulation strategy that consisted of an answer/questioning (A/Q) component and a peer feedback (PF) component. The A/Q component required students to read a portion of text and then summarize it through the development (and attempted answers) of a series of questions about the text. The PF is actually an interactive peer teaching game in which students read their homework questions concerning a portion of text and the other students attempt to answer the questions. This approach helps students to clarify their questions as well as provide substantive answers to questions.

Three intact classes (83 students) were randomly assigned to three groups: one using A/Q, one using A/Q and adding PF after the initial eight weeks, and a control group. A pretest and two posttests (one after eight weeks and one after 16 weeks) designed to assess students' reading comprehension of physics text material were administered to each of the groups. The control group reading comprehension scores were found to remain constant during the first eight weeks of the experiment and then decrease significantly during the final eight weeks.

The group using only A/Q improved significantly during the first eight weeks and then showed no gains during the final eight weeks. The group using A/Q with PF added during the second eight weeks exhibited significant gains during both segments of the experiment. The authors concluded that it is possible to improve students' independent reading comprehension of physics texts by using the question formulation technique involving only the A/Q method or a combination of the A/Q and PF methods.

Museum Exhibits

Science is learned in many settings outside of the classroom. One such setting is the science exhibit at the local museum or science center. How much visitor interest is created relative to a museum exhibit's potential investigative and potential interactive characteristics was investigated by **Busque** at the Ottawa Museum of Science and science centers in Sudbury and Toronto. A sample of 1089 (age 10 and above) visitors to 15 exhibits, located in three different museums, completed a 30-item interest test immediately following their departure from a particular exhibit.

In general, there were no differences in interest relative to the gender of the museum visitor. Additionally, there was no significant difference in interest scores for exhibits of strong interaction potential and those of weak interaction potential. The same results were found for exhibits with strong investigative potential and those of weak investigative potential. In fact, there was an indication that a strong investigative orientation for an exhibit was related to a disinterest by visitors. Given that significant differences in level of interest were generated by various museum exhibits, it was concluded that characteristics other than investigative and interactive potential (e.g., familiarity with exhibit, presence of a guide, etc.) are responsible for visitor interest.

Kubota and Olstad assessed the effects of novelty reduction on exploratory behavior and cognitive learning in a science museum setting. The subjects for the investigation consisted of 64 sixth grade students from a Seattle magnet school. Students were studied as they visited the Pacific Science Center's Playground, a collection of interactive, hands-on, physics exhibits. The investigation followed a posttest-only control group design with students randomly assigned to a treatment group and control group. The treatment group received a slide/tape program designed to reduce the novelty of the Science Playground. The control group received a slide/tape presentation about another area of the Science Center. Following the presentation of these programs, students were videotaped as they visited the Science Center. Students' cognitive learning was assessed with a paper and pencil test while on-task exploratory behavior was measured by counting the number of seconds students' spent in meaningful interaction with an exhibit. California Achievement Test scores were used as a measure of prior academic achievement.

The treatment group exhibited significantly more exploratory behavior than the control group with a significant gender interaction favoring the males. There

was no difference in the cognitive learning of the two groups. There again was, however, a significant interaction with gender favoring males. The authors concluded that the novelty reducing treatment served to increase the treatment group's on-task exploration. The authors raised the issue of sex-role socialization as a possible explanation for the differential effects of the treatment on males and females. In particular, it was noted that the exhibits were specifically physics oriented and science oriented in general.

Stevenson assessed the long-term impact of an interactive museum exhibit on adults and children. Initially, the behaviors of 20 visitors (ranging in age from six to adult) were unobtrusively observed as they visited the Launch Pad exhibit at the London Science Museum. Information gathered during this initial phase was used to guide the development of interview questions with the larger, primary sample. A total of 383 visitors (109 groups) were interviewed with a set of nine questions immediately after they visited the Launch Pad exhibit. A few weeks later, a follow-up questionnaire was sent to each member of each group. Approximately six months after the museum visit, each group (who participated in both the first interview and had returned the mailed questionnaire) participated in a follow-up interview that was transcribed for analysis.

Results of the direct observation portion of the investigation showed that visitors tended to remain in the Launch Pad exhibit for 40-90 minutes. Consequently, it was concluded that the exhibit was effectively holding visitors' attention. Data gathered via the first interview and follow-up questionnaire indicated that the museum visitors were favorably impressed with the Launch Pad and could recall specifics about various aspects of the exhibit. Analysis of the follow-up interview yielded 857 exhibit memories containing 1436 separate comments. Sixty percent of the comments were descriptions, 26% thoughts, and 14% feelings. The data related to thoughts and feelings contradict the general perception that visitors to interactive exhibits tend to enjoy the exhibit, but reflection or thought related to learning is infrequently noted. Of particular note was the observation that 81% of the reported interactions with the exhibit were in association with familiar members or other museum visitors and 99% of those interviewed reported having spoken about the exhibit with others after leaving the museum. The authors concluded that interactive exhibits like Launch Pad appear to have provided an interactive experience that generates interest and enthusiasm.

In another investigation of an interactive museum exhibit, **Tulley and Lucas** addressed the issue of what constitutes true understanding of an exhibit. The exhibit providing focus for their investigation was a kit of parts from which visitors could assemble a large two-lever mortise lock. Visitors to the exhibit were videotaped as they interacted with the exhibit and then a randomly selected sample was interviewed. Following the interview, individuals were asked to reassemble the lock.

Males as well as individuals who had observed another visitor assemble the lock were faster at initial lock assembly. However, the males' advantage disappeared during the reassembly task. Seventy percent of the visitors could provide a full description of the workings of the lock, but their descriptions of the

lock, self-assessment of understanding, and prior experiences were unrelated to the amount of time it took to reassemble the lock. The discrepancy between one's ability to explain the workings of the lock and ability to assemble the lock correctly clearly showed the differences that may exist between verbal and performance assessments of understanding. Additionally, the authors also noted the primary importance of watching another individual assemble the lock before attempting to do so oneself. The data appeared to indicate that vicarious experiences are of equal or more importance than actual experience interacting with the exhibit.

Technology Integration

Jegede, Okebukola, and Ajewole, recognizing that many developing countries do not possess adequate computer technology environments, investigated the effects of computer use on the attitudes and biology achievement. Sixty-four students enrolled in a preparatory course for the Nigerian Joint Matriculation Examination in biology comprised the sample. Students were administered an attitude instrument (which measured attitudes toward the usefulness of computers in learning biological concepts) and a biology achievement test prior to and following instructional treatments. Following the pretest, students were randomly assigned to one of three groups: individual use of computer ($n=10$), cooperative teams of three ($n=30$), and no computer use ($n=24$). The "no computer" group was presented material in a whole-group lecture-recitation format, while the computer groups did not receive any support from the teacher.

A main effect by group was noted for attitude with the cooperative computer use groups showing the most positive attitudes, followed by the individual computer use and then "no computer use" groups. No difference were found with respect to students' biology achievement. Although it was recognized that follow-up research was needed, the authors concluded that the use of computer technology appears to have the capability of exciting students in a developing Third World country.

Rural Science

The nature of science instruction in rural settings is beginning to be recognized as very different from either urban or suburban science instruction. **Sunal** surveyed 105 science teachers, representing 67 schools serving a total of 37,997 students, in 46 county school districts in Alabama. The purpose of his investigation was to characterize rural 7-12 science programs and ascertain which characteristics are related to science achievement. Data was collected using four separate sources. The Rural School Itemized Survey gathered information about school characteristics and teacher's background and the Rural School Science Questionnaire sought information concerning the teacher's perception and evaluation of the science program. Twenty teachers were randomly visited and interviewed in an effort to further discuss and verify responses to the two

questionnaires. A final source of data was students' scores on the science portion of the Comprehensive Test of Basic Skills.

Overall, students enrolled in rural schools exhibited lower science achievement than students enrolled in schools in the same region in less rural settings. Rural teachers tended to be males who were originally from rural or small communities. These teachers typically had numerous different class preparations with a significant portion teaching out of their content specialty. The rural teachers' perceptions reflected realistic and practical ideas with "understanding the natural world" identified as the primary purpose of science. Overall, teachers did not feel that efforts were being made, through inservice, to improve science program adequacy. Teacher and school variables were found to correlate with variations in students' achievement. Such variables as teacher characteristics, student and teacher attendance, teacher inservice, and instructional approaches were significantly related to student achievement.

Of primary significance was the finding that the number of certified science teachers correlates with higher science achievement scores. In and of itself this finding is rather intuitive, but it is of critical importance because rural schools are often unable to attract certified personnel to staff all of their science courses.

Comments

The overwhelming number of research reports in this section mirror the current emphasis on higher-level thinking in science education reform efforts. In particular, numerous investigations focused on students' reasoning patterns, problem solving abilities, or understanding of STS issues. The investigation of students' anthropomorphic and teleological reasoning represents the continuation of a perennial concern.

Several new and intriguing lines of research were, however, also noted. Of particular interest is the research pursued by **Schauble, Klopfer, and Raghavan** because of its varied implications (e.g., understanding the nature of science, laboratory instruction, STS, problem solving in science). Clearly if a student views the purpose of an experiment is to "produce a desired effect," the student's subsequent learning with respect to the content of the laboratory activity is affected as well as the student's view of the role of experimentation in science. Further research is needed concerning the sources of students' perceptions of the purpose of experiments and how these perceptions affect subsequent learning of subject matter and conceptions of science.

The research concerning STS and the achievement of scientific literacy was both encouraging and disconcerting. It was encouraging to see that students' achievement of these contemporary curriculum foci remains an active line of research, but it was disconcerting to see that we are still struggling with the integration of STS into current curricula as well as effective ways to communicate such critical understandings to students.

Zoller, Donn, Wild, and Beckett's findings that students were not indoctrinated with teachers' views is of particular importance. Many of the extant

instructional approaches and curricula that attempt to focus on STS interactions appear to disregard the danger of indoctrinating students with a particular view. A case in point are the environmentally oriented STS programs and approaches. Future curriculum development needs to place more emphasis on the possibility of indoctrination and future research should focus on students' perceptions of STS oriented curricula/activities and how these perceptions affect subsequent learning, especially when students' views on a controversial topic appear to be at odds with the supposedly "hidden views" of the curriculum/teacher.

The research concerning museum exhibits raises some intriguing questions for classroom instruction. If actual interaction with an exhibit is not necessarily instructive or even more instructive than vicarious experience, are our continuous efforts to promote "hands-on" activities and laboratory experiences as opposed to demonstrations misguided? Or, do we need to more carefully analyze the nature of the "hands-on" experience?

Overall, researchers appear to be relying more on interviews, tasks (or activity-oriented data collection methods) as opposed to, or in addition to, traditional paper and pencil techniques. This trend is consistent with the increasing acceptance of qualitative research approaches and appears to be yielding more in-depth and informed assessments of students' thinking. This is no more evident than in the research related to problem solving, where it is becoming clear that students do not necessarily approach problems in a manner that is at all consistent with our theoretical models.

Related Dissertations

- Anderson, A.V. (1991). The effect of pre-activity instruction to parents on their questioning behavior and the learning outcomes of their children. *Dissertation Abstracts International*, 52(5), 1702a.
- Brown, T.H. (1991). The relation between form and learning in physics education. *Masters Abstracts International*, 29(4), 542a.
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- Krishnan, S.R. (1991). Conceptual change in chemistry through cooperative problem-solving. *Dissertation Abstracts International*, 52(3), 870a.
- Lorson, M.V. (1991). A comparison of microcomputer-based laboratories and traditional laboratory methods in the high school chemistry laboratory. *Dissertation Abstracts International*, 52(3), 870a.
- McWhirter, M.E. (1991). The effect of level one videodisc technology on sixth-grade student achievement in science. *Dissertation Abstracts International*, 52(5), 1719a.
- Meyers, A.K. (1991). The effects of two science-based instructional approaches on the creative thinking of second-grade students. *Dissertation Abstracts International*, 52(4), 1205a.
- Moody, D.E. (1991). Student cognition and the structure of instruction in the theory of evolution. *Dissertation Abstracts International*, 52(3), 794a.
- Wagner, S.P. (1991). Robotics and children: Their relationship to science achievement, problem-solving, ADHD rating scale scores, and learning styles. *Dissertation Abstracts International*, 52(4), 1280a.

Cognition and Achievement

The primary focus of research reports included in this section is on specific student understandings, conceptions, reasoning patterns, achievement, and cognitive styles. Again, although data on teachers and instructional approaches has been included in many of the cited studies, the primary emphasis is on student learning as opposed to teaching.

Conceptions and Alternative Conceptions

Recognition that students come to their science classes with conceptions of the world and the phenomena that they experience everyday, and that these conceptions influence subsequent learning, has significantly piqued the interest of researchers. Research on students' conceptions, alternative conceptions/frameworks, and conceptual change has become one of the primary research areas in science education.

Elementary school level

It is well known that students possess conceptions of natural phenomena that may differ drastically from those held by scientists. This variation occurs even with respect to common everyday experiences. In particular, **Bar and Travis** investigated students' (grades 1-9) ideas concerning phase changes from liquid to gas and gas to liquid. An initial sample of 83 students was selected from an elementary school in Jerusalem. The sample specifically consisted of students with the following *mean* ages: 6 years ($n=23$), 7 years ($n=20$), 9 years ($n=20$), and 11 years ($n=20$). All students were administered an open-ended oral test that focused on the concepts of boiling and evaporation. A second sample of students was selected from one elementary and one junior high school with the following *mean* ages: 10.5 years ($n=37$), 11.5 years ($n=28$), 12.5 years ($n=50$), and 13.5 years ($n=37$). These students were asked to complete a nine item multiple choice test containing distractors derived from the responses given by students during the oral test. Finally, three open-ended written questions were administered to two groups ($n=134$, $n=132$) of junior high school students ranging in ages from 11 to 15.

Overall, the data analysis indicated that with respect to evaporation, students' views changed from water that penetrates solid objects to water that evaporates, while the identification of matter in a bubble changed from water to air. The understanding of boiling was found to precede understanding of evaporation. Importantly, the results also indicated that the format of testing affected the findings, with items offering alternative answers (e.g., multiple choice) frequently misleading students. The authors concluded that science teachers should carefully explain everyday experiences and the use of concrete experiments and theoretical models should be emphasized, within an atmosphere allowing open discussion and evaluation of alternative conceptions. It was further recommended that

formal models of physical phenomena should be withheld until most of the students have attained a qualitative understanding.

The specialized vocabulary used as part of science instruction is often a focus of discussions concerning the level of students' learning and the development of students' alternative conceptions. **Meyerson, Ford, Jones, and Ward** examined how elementary school students think about science vocabulary by examining the organizational schemes employed with science words. The sample consisted of 144 third grade and 123 fifth grade students from all classes in a particular elementary school. Students identified by their teachers as special education students were not included in the sample. Examination of publishers' and school district vocabulary lists led to the development of a common sense core vocabulary list of 155 words: 44 words from the third grade level and 111 from the fifth grade level. Comparisons between grades resulted in a listing of 15 words common to both grade levels, with 11 additional words considered to be unique to fifth grade. Using worksheets containing the identified vocabulary words for each grade level, students were asked to group the words in a "meaningful way." Follow-up interviews were conducted with each student in order to clarify any confusion and elicit explanations for the students' categorization scheme. The data were analyzed with respect to whether a student's response did (or did not) provide a concept for the word and whether the response did (or did not) provide a science concept.

The results indicated that, in general, third and fifth grade students provide appropriate conceptual groupings for science vocabulary, but the conceptual groupings are not always science related. Fifth grade students provided more science conceptual groupings. In addition, third grade students were less likely to assign a multiple meaning word to a science conceptual grouping than fifth graders.

The results demonstrated a developmental trend in student ability to correctly associate a particular science vocabulary item with an appropriate science concept. It was recommended that teachers encourage students' schematic development for vocabulary specific to science concepts and help students recognize the multiplicity of word meanings.

As with many concepts in science, the meaning of "neutralization" has been revised over the years. Consequently, chemistry teachers and their students must confront the difficulties created by historically varied meanings. **Schmidt** used a sample of 7500 elementary level students in Germany to assess students' understanding of the concept of "neutralization." A series of nine test items related to neutralization were developed and six of these items were randomly inserted into a test containing 154 items, which was administered to each student. Consequently, each student was asked to complete six items related to neutralization, but the specific items varied among students.

Analysis of students' responses indicated that most students assumed that a neutral solution resulted from any neutralization reaction, an understanding consistent with the original meaning of the term. Whenever a test item addressed a reaction between an acid and base, students immediately thought of

“neutralization,” and many students believed neutralization necessarily involved only strong acids and bases. The author concluded, overall, that the terms “neutral” and “neutralization” significantly influenced students’ thinking and often led to wrong conclusions and understandings. It is often the case in science that appropriately descriptive terminology can become misleading when scientists revise meanings and conceptualizations without altering the term/label used for the concept.

Much research has indicated that upper elementary and junior high school students possess alternative ideas about matter. **Stavy (a)** investigated conceptions of matter possessed by students in grades 1, 3, 5, and 7. Twenty students from each grade level were chosen from an upper middle class population near Tel-Aviv, Israel. The seventh grade students had just completed a course specifically related to matter. Each student participated in a task-oriented interview that focused on explanations of the concept of matter and the classification of items as matter or non-matter. Most of the students, regardless of grade level, were able to correctly explain the concept of matter. Students explanations were either in the form of examples, function, structure, or properties. In general, younger students tended to explain matter by giving typical examples or by describing functions. Students in third grade and beyond described matter in terms of structure and properties, but only 10% of the seventh graders referred to the properties of weight and volume.

With respect to the classification of matter, the ability improves with age and by the seventh grade the majority of students regard solids, liquids, and biological materials as matter. The data suggested that younger children’s concept of matter is in some cases under extended so as to exclude some solids, most liquids and biological materials, and all gases. Alternatively, it is overextended to include some physical phenomena associated with matter and non-matter items. The author concluded that there is “no point in teaching the particulate nature of matter when students don’t know what we mean by matter.” It was recommended that instruction should focus on clarifying the concept of matter (beginning with objects recognized as matter and then proceeding to objects not usually regarded as matter by students) prior to any introduction of particulate theory.

Middle school level

BouJaoude identified and characterized eighth grade students’ ($n=20$) conceptions of burning. The class of students was of mixed ability, ethnic background, and socioeconomic status. Students were presented with various demonstrations (e.g., burning candle, lighting an alcohol burner, heating sugar in a spoon, etc.) and interviewed about their conceptions of the presented phenomena. Prior to these interviews, the researcher made classroom observations for weeks so he could become familiar with the students, teacher, and school setting. Using analytic induction, the transcribed interviews were analyzed.

The results indicated that students based their understandings on concrete and observable changes, used memorized information to explain observations,

held fragmented, inconsistent, situation-specific understandings of burning, and possessed conceptions at odds with current scientific explanations. Given the significant impact of visible environmental cues on students' understandings, it was recommended that teachers present students with numerous diverse and observable examples to reduce the possibility of over generalization from a limited set of salient examples.

Working with two groups of middle school students (ages 11-12 and 13-14), **Longden, Black, and Solomon** investigated the students' representations of dissolving in terms of the observable process and the more theoretical particle-based description. Students were asked to respond to two pictorial situations related to the dissolving of a substance. One picture was specific to everyday observations while the other was specific to a particle representation of matter. Students were asked, on a separate sheet of paper to draw and explain what each diagram would look like if the crystal pictured dissolved. A total of 246 students from three schools comprised the younger (ages 11-12) sample and 196, from three schools, comprised the older (13-14) sample.

Interestingly, analyses of students' diagrams and explanations indicated that fewer pupils (in each age level) held a correct view of dissolving in everyday terms as opposed to the more theoretically based particle interpretation. Furthermore, there appeared to be an improvement of understanding with respect to the particle interpretation with age while no improvement was noted for the everyday conception with age.

The authors concluded that although school teaching of new theoretical models is effective, it is of less value for the development of everyday notions. In short, the students in this investigation clearly adhered to two domains of knowledge and explanation; in school science and out of school science.

In another study related to students' conceptions and learning, **Rhoneck and Grob** investigated students' psychological background with respect to their ability to learn basic electricity. In actuality, three separate studies were carried out in different schools to investigate why some students learn successfully while others do not. For this reason, in addition to data on learning outcomes, data were collected on students' interest, achievement motivation, IQ, and cognitive development. A total of seven classes were involved in the three investigations (grade levels were not reported, but the subject matter focus suggests a middle school level), and these schools were representative of urban and rural locations.

In urban classes, achievement was significantly lower than in rural classes. Factor analysis revealed that in urban classes the learning of electricity is primarily related to interest and motivation and only peripherally related to cognitive development. In rural classes, however, there was a close association between learning electricity concepts and students' cognitive abilities with interest and achievement motivation of markedly less importance. The authors explained the differences between urban and rural learning in terms of the construct of "mindfulness" (a combination of motivational states and cognitive actions, a mixture of will and skill). Ultimately, they concluded, the real reasons for differential learning are still "hidden behind the variables which can be measured today" (p 95).

recently completed an advanced or introductory mechanics course and 201 high school students from both urban and rural schools throughout Israel (112 advanced physics students, 8 of whom were interviewed; 32 introductory physics students, 4 of whom were interviewed; 57 students who had not taken physics, 5 of whom were interviewed). All students were administered a 10 item test to elicit their beliefs about the forces acting on a pendulum bob, book, and cannonball at rest and in motion. Students interviewed were probed for explanations of their answers.

With respect to systems involving objects at rest, the vast majority of students were able to identify the correct Newtonian forces involved. Contrary to prior research, very few of the students not having taken physics possessed the belief that no forces were involved. The data also indicated that students possessed no general law for describing objects at rest. Students used specific rules for each situation. Additionally, the data did not support the view that most students possess the "motion implies a net force" notion. Finally, although students appeared to possess frameworks for physical phenomena, such frameworks did not provide a perspective from which students' beliefs could have been predicted. The authors concluded that their results reinforced the perennial problem of students being unable to identify particular instances of general rules or laws and that the problem is only further aggravated in physics instruction by students' prior knowledge.

In another study of undergraduate students' conceptions of physical phenomena, Saxena investigated 181 Indian undergraduate students' conceptions of light. Students were administered an eight-item questionnaire, with each item based on at least one of six identified major concepts associated with light (e.g., reflection, refraction, shadow). The questions were multiple choice, but students were also required to explain the reason for their selected response. A sample of 5% of the students were interviewed to clarify written responses.

Analysis of the questionnaire responses and interviews indicated that students had difficulty understanding the process of visibility of an object, shadow formation by an opaque object, action of a filter, and action of a lens in image formation. Students generally understood the basic properties of light at a knowledge level as evidenced in their ability to represent these properties using a line diagram. Difficulties were noted, however, when students were asked to apply these properties in novel situations. The author also noted that many of the students who arrived at correct responses were not able to support their responses with acceptable logical reasoning.

Longitudinal studies

Assessment of the long-term effects of various learning interventions is much needed. Novak and Musonda conducted a longitudinal investigation that followed two groups of students from grades 1 to 12. The treatment group for their investigation included 191 first and second grade students from 11 classes. The comparison/control group consisted of 48 students from the same schools as the

were measured using the Test of Logical Thinking (TOLT) and their conceptions of subject matter (e.g., dissolution, diffusion, etc.) was assessed with the Physical Changes Concepts Test (PCCT). The PCCT consists of one form that presents concepts in everyday situations using everyday language (A form) and a theoretical form (T form) that presents information in scientific language. The two forms of the PCCT were administered two weeks apart with the A form being administered first.

The sample scored a *mean* of 4.54 on the TOLT indicating, on average, early formal reasoning had been achieved. Over 40% of the sample possessed alternative conceptions for those concepts covered by the PCCT. Dissolution presented the most difficulty while states of matter appeared to be the easiest. A statistically significant correlation was found to exist between students' reasoning ability and preexisting knowledge with their conceptions and use of particulate theory. Analysis of specific student conceptions indicated two possible sources for alternative conceptions: macroscopic reasoning (translation of observable behavior of matter to the scale of atoms and molecules) and instruction (misinterpretation of instructional analogies and devices).

There was an overall difference in students' scores on the applied and theoretical forms of the PCCT. In general, students used macroscopic explanations when they were asked questions using everyday language and theoretical knowledge (obtained from school) when questions used formal classroom language. It was concluded that students should be given the opportunity to evaluate their preexisting knowledge with respect to the scientific conceptions so that compartmentalization of knowledge into applied and theoretical can be avoided.

Protein synthesis is a topic included in virtually every high school biology curriculum. The abstract nature of the process, however, presents numerous instructional problems. Mensch and Rubha assessed the effects of a set of hands-on models on students' content achievement and attitudes. Twenty-eight ninth grade academic biology students were randomly assigned to two sections of biology. As a consequence of absences, the actual size of the experimental group was ten and the control group, 11. The experimental group received four class periods of instruction on protein synthesis. These included a one-period lecture on structure and function of DNA and RNA, a one-period lab during which DNA and mRNA were constructed with hands-on models, a one-period lecture on protein synthesis, and a one-period lab on protein synthesis using the hands-on models. The control group received the lectures on days one and two and then received an environmental science activity on days three and four. Both groups were pre and posttested with paper and pencil tests assessing subject matter knowledge, attitudes toward biology, and attitudes toward biochemistry. Follow-up administrations of the three tests were administered six weeks after the experiment.

An overall repeated measures ANOVA showed no differences with respect to any of the outcome measures. However, Tukey comparisons indicated that students who manipulated the hands-on models showed more positive attitudes

toward biology and biochemistry on the posttest and/or follow-up test. The authors concluded that the attitude gains justified the use of large hands-on models during instruction on protein synthesis.

Concept mapping has been commonly used as both an assessment and instructional technique. **Ross and Munby** analyzed 34 high school physics students' conceptions of acids and bases. These students had completed an advanced, grade 11, chemistry course the previous semester. All students were administered a 25-item multiple-choice test primarily selected from a validated item pool developed by the Ontario Ministry of Education. Students' scores on this examination, teachers' recommendations, and previous chemistry achievement were used to select eight students to participate in two 40-minute clinical interviews. Each interview consisted of four tasks related to acids and bases presented in the form of a diagram, drawing, or picture. A Model Concept Map was developed from the curriculum guidelines and students' concept maps were derived by examining students' multiple-choice responses and interview protocols for missing concepts. Removal of missing concepts from the Model Concept Map resulted in a map for each participant.

Analysis of the multiple-choice test revealed that students performed best on pH and everyday-phenomena items but experienced difficulty writing and balancing chemical equations. There was a consistency among the data revealed via the multiple-choice test, interviews, and concept map constructions. The authors strongly emphasized the utility of concept mapping and the use of a Model Concept Map as reference point in both instruction and future research.

Postsecondary level

Students' and teachers' understanding of chemical equilibrium was assessed by **Banerjee**. The sample consisted of 120 college chemistry students enrolled in the third semester of a four year teacher education course, 42 students in a content methodology course within a one year teacher education program, 40 secondary level chemistry teachers (possessing a B.S.), and 29 secondary level teachers with at least a M.S. in chemistry. A 21 item test on chemical equilibrium (containing closed and open response items) was developed and administered to all participants. The data indicated widespread misconceptions among both teachers and students relating to Le Chatlier's principle, rate and equilibrium, application of equilibrium principles to problem solving situations, and application of equilibrium principles to acid-base and ionic solutions. Group comparisons showed misconceptions to be equally high in both teachers and students. It was speculated that the teachers may have developed their misconceptions during their educational experiences and retained the misconceptions despite their teaching and professional experiences.

Finegold and Gorsky reported on an analytical technique by which they were able to identify meaningful conceptual categories of students' understanding of force. Data were collected with a written test and interviews. The sample consisted of 333 university students (18 of whom were interviewed) who had

Middle/high school levels

Pereira and Pestana investigated conceptions of water possessed by Portuguese students in grades 8 to 12. A total of 227 students were asked to "represent water in its three states—solid, liquid, and gas—using a model." Qualitative analyses of students' models were used to discern the nature of students' representations and the presence of any misconceptions. The dominant microscopic models, across all grades, were of the particle type (e.g., space-filling, ball type, and structural formula). Students in grades 8 and 9 were more likely to provide models that included the dynamic aspects of water, especially in the gas models. For all grade levels, the increase of intermolecular distance in liquid and gaseous states compared with the solid was often associated with an increase in the size of the model used. The authors cautioned that the sample of students was selected from participants at a chemistry olympiad and the results are most likely not representative of the "average" student population.

How students develop their understanding of the concept of diffusion was the focus of a cross-age study conducted by **Westbrook and Marek**. The sample consisted of 100 randomly selected students from each of three grade levels: 7th, 10th, and college students enrolled in freshman zoology. The final sample of 300 was randomly reduced from an original sample of 410 students. All subjects completed a biographical questionnaire, two Piagetian tasks assessing combinatorial logic and proportional reasoning, and a concept evaluation statement. Understanding diffusion at the concrete, observable level was considered to be a "sound" understanding and an understanding at the molecular, abstract level was considered to be a "complete" understanding.

None of the 300 students were found to possess a "complete" or "sound" understanding, and there was no apparent relationship between understanding and Piagetian developmental level. Interestingly, 55% of the 7th graders possessed misconceptions while over 60% of both 10th graders and college students exhibited misconceptions. Furthermore, only one student in the total sample of 300 mentioned random molecular motion, four mentioned concentration gradient, and six recognized molecular motion as important to the process. One college student defined and named Brownian motion.

The authors concluded that certain misconceptions about diffusion prevail across grade levels, a molecular perspective of diffusion increased with grade level, additional exposure to diffusion as one proceeds through school does not lead to greater understanding, and students frequently use errant vocabulary when describing diffusion.

High school level

Students' everyday understandings often differ from their scientific understandings of the same phenomenon. **Haidar and Abraham** compared 11th and 12th grade chemistry students' ($n=183$) applied and theoretical knowledge of dissolution, diffusion, effusion, and states of matter. Students' reasoning abilities

treatment group. It is important to note that the authors chose to refer to the comparison/control group as the "uninstructed" group because virtually no science is taught in the primary grades of the Ithaca public school system. The treatment group received an audio-tutorial program consisting of 28 lessons forming a coherent conceptual sequence developing ideas of matter and energy and the interrelationships in both living and non-living things. The format of the science lessons attempted to capitalize on the use of advance organizers and was consistent with Ausubelian learning theory.

The specific purpose of the investigation was to assess the effect of early instruction in basic science concepts on subsequent learning. Clinical interviews (following a Piagetian format) and concept maps derived from interview transcripts constituted the data set. Students were interviewed approximately seven separate times spanning the 12 years of the investigation. Although the audio-tutorial lessons covered a broad range of topics, the authors chose to focus their analysis (in later grades) on the topic of particulate nature and the behavior of solids, liquids, and gases.

The specific findings with respect to students' understandings, misconceptions, and changes in conceptual understandings are too numerous to elaborate here. However, the results clearly indicated that those students who had completed the audio-tutorial program exhibited many more valid conceptions and fewer invalid conceptions in grades 2, 7, 10, and 12. The authors concluded that provision of high-quality science instruction can significantly enhance students' understanding of science in grades 1-12. In particular, it was surmised that "only a relatively few hours of quality science instruction in grades one and two can have a discernible influence on science learning throughout the school years" (p 149).

Reasoning and Problem Solving

At a more global level than specific conceptions, it is also well recognized that students possess developmental or learned patterns of reasoning that they use when approaching problems or tasks in science.

Elementary school level

Marek and Methven investigated the relationships among teachers' attitudes and implementation of in-service developed science materials and elementary students' conservation reasoning and language use. The sample consisted of 16 teachers (experimental group) from grades K-5 who participated in a summer workshop. The workshop was designed to promote understanding that science is as much a search for knowledge as it is the knowledge, a constructivist teaching approach is necessary to teach students that science is a search for knowledge, and teachers' must create curriculum (learning cycles) that allow students to experience science. Eleven teachers were identified by the experimental teachers, to serve as a comparison group, based on the criteria of similar years of experience, grade

level taught, and expository teaching approach. Ten students were randomly selected from each of the experimental and comparison teacher's classrooms and were interviewed (pre and post instruction) with respect to conservation reasoning and descriptive language for the concept of property. The Piagetian clinical interview format was used. Additional data was collected with a 26 item workshop evaluation questionnaire (teachers' characteristics, attitudes, and degree of learning cycle implementation) which was administered prior to the workshop, immediately after the workshop, and 10 months after the workshop.

The collected data indicated that teachers involved in the workshop did implement the materials developed during the workshop. Students in the classes of workshop participants exhibited greater gains in conservation reasoning. Experimental students exhibited a 44% gain in conservation reasoning while comparison students showed gains of only 17%. The authors concluded that these differences may be attributed to the numerous direct experiences or learning cycles provided by the experimental teachers. It was further inferred that these experiences allowed students to manipulate objects, make observations, record data, interact with other students and the teacher, invent concepts, and apply the concept to other situations. The learning of students in the comparison (expository) group was compromised by the lack of such experiences.

Metz argued that examination of children's' explanations provides a more powerful perspective on their developing understanding of causality. Consequently, changes in students' explanations formed the focus of her investigation. The sample consisted of students of ages three, five, seven, and nine. Eight students from each age level were selected with the three year olds randomly selected from a university laboratory school and the other students randomly selected from a public school of middle socioeconomic status. Data was collected through clinical interviews in which students made predictions about 14 task situations involving movement and jamming of gears. The author and assistant qualitatively analyzed protocols of the subjects' interviews.

The data indicated increasing understanding of causality with age with three phases of development distinguished: function of object as explanation, connections (among gear elements) as explanation, and finally a mechanistic explanation. Two forms of fundamental change were noted by analysis of explanation development from one phase to the next: radical substitution (where one explanation is supplanted by the next) and transforming incorporation (where one explanation forms the basis for the next and is also transformed within the new conceptualization of causality). Within individual phases, incremental changes were primarily in the form of differentiation and decomposition.

Elementary/high school level

Whitelock tested a formal causal model of thinking with a sample of students ranging in age from 7 to 16. The model was derived from a systemic network that was based on a common analysis of causation that suggests that for any type of motion to take place there must be a cause that can be circumstantial or specific

to the object. A matching-pairs paper and pencil task was developed in which subjects were asked to distinguish between examples of nine common motions (e.g., walk, push, jump), comparing the differences between the causes of these motions. A total of 49 comparison pairs were included. A separate task was designed to test the notion of animacy for each of the nine motion types. A total of 215 students from four separate schools were administered the matching-pairs test. A sample of 30 seven year olds and 27 sixteen year olds were administered the animacy task.

Theoretical predictions derived from the formal model of causation were more accurate for older students than younger students. In addition, there were differences between students' responses with respect to age with the smallest differences existing between the 10-14 and 12-14 age groups. Whether the motion involved an animate or inanimate object affected students' responses. When an "animacy allowance" was included, the accuracy of the causal model's predictions were improved for each age level. The author concluded that notions about animacy are important considerations in the understanding of movement for students of all ages and should not be omitted from any models of students' common sense thinking about motion.

Middle/high school level

The influence of students' social-cultural background on the development of spatial conceptual structures was the focus of Cohen and Akarsu's investigation of sixth and tenth grade students in Turkey and Arizona. Specifically, 34 sixth grade students and 34 tenth grade students were selected for participation in the study. All sixth graders were presently studying mathematics and science, while for tenth graders, only the Arizona students were currently studying both mathematics and science. A set of 10 Piagetian tasks designed to assess students' projective and Euclidean spatial thinking abilities were individually administered to each of the students in his/her native language. Statistical comparisons between the performance of sixth grade students and tenth grade students, from Arizona and Turkey, were made for each of the 10 tasks.

In 14 of the 20 tasks, statistically significant differences were found, with 11 favoring the Arizona students. Although the authors strongly emphasized that absolute cause and effect conclusions could not be reached, they did speculate about the possible influence of painting and sculpturing being historically forbidden within Turkish society. The lack of practice with three dimensional representations of reality may have been one factor contributing to the apparent lag of spatial ability development in Turkish students. Regardless of the actual causal factors, the results clearly indicated that teachers need to be sensitive to potential cultural-specific patterns in reasoning when designing mathematics/science curricula and instruction.

High school level

The role of formal operational reasoning in students' critical thinking abilities and grades received in science and mathematics was investigated by **Bittner**. A sample of 101 students in grades 9-12, from a small rural school, was administered the abbreviated Group Assessment of Logical Thinking (GALT) and the Watson-Glaser Critical Thinking Appraisal (WGCTA). At the end of the school year, teacher-assigned grades in mathematics and science were also recorded.

Using a 95% confidence interval, all five formal operational reasoning modes (as measured by the GALT) were found to be significant predictors of critical thinking abilities (as measured by the WGCTA) and of grades assigned in science and mathematics. The overwhelming majority (63%) of the sample was categorized at the concrete operational level, and probabilistic reasoning, in general, contributed the largest proportion of the variance in critical thinking. Formal operational reasoning explained 62% of the variance in science grades, but only 29% in mathematics. The author concluded that instructional approaches should emphasize procedural knowledge as well as declarative knowledge.

Johsua and Dupin attempted to discern the differences between students who can successfully complete a physics problem and those who can not. In particular, they focused their attention on the students' cognitive mechanisms and procedures. Four classes of French physics students ($n=156$) were observed during instruction (approximately 38 hours) on electric circuits. A series of five tests (each containing 2-3 problems) was taken by students during the observation period and comprised the data for the investigation. A model answer was prepared by teachers for each of the test problems and used as a reference point for comparison with students' problem solutions.

Overall, there were no differences noted among the four classes of students. On the standard type problems (problems similar in content and form to those done in class) there existed a close correspondence between teacher and student approaches. In addition, such problems provided little discrimination among students performing at different levels of achievement. As expected, the "good" students were more successful at handling problems considered to be "innovative" or different in type and content to those previously completed in class. Those problems considered to be "implicitly difficult" discriminated most clearly between "good" and "average" students. Such problems appeared, on the surface, to be similar in form and content to those discussed in class but contained subtle differences that often led students to incorrect solutions.

The authors concluded that a "problem for the student" exists whenever the standard solving procedure previously provided by the teacher is not available or appropriate. This effect was particularly noted for the "average" students, the ones on whom an improvement in physics teaching would presumably have the greatest impact.

The constructivist hypothesis that the acquisition of domain-specific conceptual knowledge (declarative knowledge) requires use of general procedural

knowledge was tested by **Lawson, McElrath, Burton, James, Doyle, Woodward, Kellerman, and Snyder**. The sample consisted of students ($n=314$) enrolled in ten sections of high school general biology and ten sections of high school general chemistry at two high schools. Skill in hypothetico-deductive reasoning was assessed with 12 paper and pencil items. Ability to acquire novel domain-specific concepts was assessed with a series of four concept-acquisition puzzles. Several students were asked to respond to some of the items in taped individual interviews.

Sixty-one students (19.4%) were classified as intuitive thinkers, 184 (58%) as transitional thinkers, and 69 (22%) as reflective thinkers based on their hypothetico-deductive reasoning skill scores. Assessing the relationship between developmental level and concept acquisition indicated that the majority of intuitive thinkers performed relatively poorly on the concept acquisition tasks, with only 3.3% correctly completing all four tasks. Alternatively, 43.5% of the reflective thinkers correctly completed all four tasks. Partial correlation coefficients indicated that hypothetico-deductive reasoning skill as opposed to age/experience is the primary factor in successful concept acquisition.

The authors concluded the constructivist hypothesis that acquisition of novel domain-specific concepts depends upon the use of more general knowledge was supported. It was recommended that instruction be designed and implemented so that students' acquisition of necessary reasoning is facilitated. As science is presently taught, it was concluded, reflective students have a decided advantage over intuitive students in acquiring virtually all concepts presented.

Students' reasoning in science has historically been assessed in a variety of ways. **Lopez-Ruperez, Palacios, and Sanchez** investigated the relationship between the field-dependence/independence (FDI) dimension of the Group Embedded Figures Test (GEFT) and the Longeot test of Piagetian level of development. The sample for the investigation consisted of 94 students enrolled in the third year of Spanish secondary education (*mean* age=16.9 years). The sample was selected such that only individuals with extremes along the field dependence/independence continuum were included. All subjects were administered the Longeot test and GEFT.

The results indicated that the FDI dimension and GEFT correlate significantly on only those items on the Longeot test that require formal reasoning. The effect of open or closed item format was found to be specific to formal reasoning items with only the open format items discriminating between field-dependent and field-independent students. The authors recommended that a mixed-model evaluation plan could be employed by teachers with closed formats reserved for questions that require formal reasoning and open formats for those that do not. They also reiterated the idea that curriculum adequacy should consider individual differences among students within the same Piagetian level.

Postsecondary level

Dee-Lucas and Larkin investigated the effects of equation-based proofs on undergraduate level college students' proof comprehension. The sample was 40

Carnegie Mellon undergraduates who had not completed more than one semester of college physics. Subjects participated individually, with each being asked to read two passages related to Pascal's principle and the equation of continuity. One passage was equation-based while the other was in verbal format. The sequence of passage reading was counterbalanced to remove sequence as a variable. The participants were required to read both passages before attempting to complete the problem solving tasks associated with each. Completion of problems was performed in the same sequence as the passages were read. Logistic regression analyses were used to analyze the resulting data.

Of most interest was the finding that passage format (equation-based or verbal) influenced performance on problem solutions. In particular, performance on proof questions was significantly better for the verbal format while a trend was evident indicating performance on direct application problems to be better for the equation-based format. After analyzing the data to explain why the verbal proof format improved performance on proof questions, the authors concluded that the verbal presentation improved subjects' understanding of the quantitative relations, and it also encouraged attention to nonquantitative information in the text of the passage. It was also clear that learners had more difficulty processing equations than verbal statements containing the same content. The authors further elaborated that novices tend to give special status/importance to equations when they are presented in science texts and may ignore other types of information. Alternatively, when a proof does not include equations, the novice is more likely to spread his/her attention more evenly across all of the information presented in the proof. Consequently, it was suggested that the traditional equation-based format for presenting proofs is not optimal for enhancing proof learning by novices.

The ability of novice students to solve problems in electrostatics was investigated by **McMillan and Swadener**. In particular, six students enrolled in the second semester of introductory calculus-based college physics comprised the sample for the investigation. Five of the students were physics majors and one was an engineering major. Based on self-report and substantiated by instructor, grade point average, and final course grade, five of the subjects were classified as "A" or "B" students and one as a "D" student. Immediately following course instruction on electrostatics, each of the subjects was asked to verbalize all thoughts while completing an electrostatics problem. After completing the problem, subjects were asked to comment about any assumptions made, conceptions of various aspects of the problem, and the qualitative aspects of the problem. During problem solution, subjects were allowed to use any aids (e.g., text, notes) and as much time as needed. All interview sessions were videotaped and analyzed for problem-solving procedures and the presence of qualitative and non-quantitative problem-solving methods.

Qualitative data analysis indicated that, in general, students possessed major misconceptions and did not use qualitative thinking nor did they conceptualize a problem situation when solving problems. The primary characteristic distinguishing "A" and "B" students from the "D" student is facility with equation manipulation, not conceptual understanding of physics. The "A" and "B"

students were successful in identifying, either from memory or written notes, relevant equations while the "D" student could not. It was concluded that current instructional techniques in college physics focus on acquisition of correct quantitative solutions at the expense of qualitative understanding. The authors recommended that consistent emphasis be placed on the quantitative and qualitative aspects of all problem situations.

Niaz (a) investigated the reasons why students can succeed and fail at the accomplishment of different tasks that apparently have the same logical structure (i.e., formal operational). The sample for the investigation consisted of 72 college freshmen enrolled in two sections of an introductory chemistry course in Venezuela. All students were administered paper and pencil tests designed to assess formal operational reasoning, functional M-capacity (Figural Intersection Test), structural M-capacity, cognitive styles (Group Embedded Figures Test), and a general intelligence factor (Raven test). The resulting data clearly indicated that Pascual-Leone's structural M-capacity was the most consistent predictor of success in the different formal reasoning tasks used in the investigation, followed by the Group Embedded Figures Test, and to a much lesser degree Raven's progressive matrices, and Pascual-Leone's functional M-capacity. It was concluded that the results emphasize the importance of individual difference variables and that, in formal reasoning tasks, we should expect horizontal decalages as the rule and not the exception.

The reasoning evident in medical students' causal explanations for a physiological problem were assessed by **Patel, Kaufman, and Magder**. The sample for this investigation consisted of 40 first year medical students at McGill University who were attending a series of regular lectures on cardiopulmonary physiology. An essay question related to a hypothetical clinical situation was added to the regular examination taken by all enrolled students. Two phases of data analysis were pursued. Initial analysis simply identified the "facts" and information used by respondents in describing the problem. The second phase compared students' causal networks evident in the problem solution (as created by the researchers) with a causal network used as a reference model. This comparison enabled the researchers to identify students' reasoning patterns and misconceptions evident in their approach to the problem.

The results indicated that the first year medical students possessed several significant misconceptions in reasoning related to ventilation/perfusion matching. In particular, the students exhibited difficulty in conceptualizing the cardiopulmonary system as a closed mechanistic system. In addition, subjects were unable to accurately relate clinical findings to pathophysiological manifestations. The authors concluded by raising the obvious question concerning medical schools' ability (in a limited time frame) to provide the basic science knowledge background necessary to support their goal of clinical problem solver.

The performance of chemistry students in solving stoichiometry problems, having been exposed to a lecture or interactive techniques, and the effect of certain cognitive variables on their performance, was investigated by **Robinson and Niaz**. Eighty-two students were selected from two sections of a remedial

college chemistry course. Assessments of students' formal operation reasoning (Group Assessment of Logical Thinking), M-capacity (Figural Intersection Test), and Disembedding ability (Group Embedded Figures Test) were conducted. Assessments of stoichiometry understanding were made from standard type problems with varying levels of M-demand. The control group received traditional instruction over 10 weeks with weekly quizzes. The treatment group was provided with opportunities to actively engage in concept development and problem solving, during which there was emphasis on introducing operational schemes that stress verbal rather than numeric relationships prior to performing calculations.

Results indicated there were significant differences between treatment and control groups favoring the treatment group, even though the treatment group had fewer examples on which to practice. In both sections, those with higher formal reasoning skills tended to perform better than those with lower formal reasoning development. Interestingly, those with lower information-processing capabilities (FIT) in the interactive group outperformed those with higher scores. The opposite was observed in the lecture section. The authors concluded that interactive instruction does not challenge better students to increase the effectiveness of their information-processing capacity.

Pascual-Leone's and Case's neo-Piagetian theories were tested by **Roth and Milkent**. Specifically, the relationships between the development of proportional reasoning strategies and three cognitive variables were examined. The sample consisted of 34 non-science majors enrolled in an introductory physical science course. An eight-item test containing the recipe problem, Mr. Tall and Mr. Small, and six juice-mixing problems was used to categorize the subjects as formal or concrete operational reasoners (less than two correct responses).

Twenty-three of the subjects were categorized as concrete operational. All of the subjects took four tests: Figural Intersection Test (FIT), Backward-Digit Span Test, Group Embedded Figures Test (GEFT), and the Ratio Span Test. A posttest, consisting of five juice-mixing and five probability problems, were used to assess the effect of treatment and transfer. The posttest was administered two weeks after each individual's last treatment. The treatment for the investigation consisted of proportion problems at five levels, presented by computer, for which the subjects were asked to "think aloud" as they attempted a solution. Only the 23 students classified as concrete operational were exposed to the treatment.

After a maximum of six hours, 17 of the 23 subjects had induced ratio schemata at the upper formal level with the remaining subjects operating at the lower formal level. Data analysis showed that neither M-space and degree of field-independence nor short term storage predicted the number of problems students need to do until they induce an appropriate problem solving strategy. Significant differences in short-term storage space existed between those students solving ratio problems at the highest level and those that did not. Finally, field-independence was not found to be a predictor of either ability to transfer problem solving strategies or the reuse of inappropriate strategies.

The authors concluded that a training program derived from a developmental analysis in terms of the short-term storage space demand of the task could help

students develop complex problem solving skills. It was also inferred that the construct of short-term storage space could enhance science and mathematics teaching and learning. In short, educational programs could use a developmental analysis to create a match between the demands of the task and the storage space of the learner.

Roth, using the same sample as **Roth and Milkent**, studied the factors involved in the development of reasoning with respect to balance beam problems. As previously described, the 34 subjects were classified as concrete or formal operational (23 concrete, 11 formal). All subjects completed the Test of Numerical Reasoning Ability (TNIRA) and the Ratio Span Test (RATIO). The 23 concrete reasoners were asked to "think aloud" as they completed balance beam problems at five levels. The results indicated that there does not exist an invariant sequence of behaviors in which subjects must engage in order to induce the product-moment rule, strong correlations exist between the number of problems needed to induce the product-moment rule and the cognitive variates measured by TNIRA and RATIO, the frequency of behaviors avoiding unsuccessful strategies and the monitoring of one's search for a solution were significantly related to inducing the rule, and RATIO was significantly related to behaviors that facilitated the inducing of the rule. As with the **Roth and Milkent** investigation, it was concluded that short-term storage space should be given considerable attention in the design of curriculum and instruction.

Rozier and Viennot investigated students' and teachers' reasoning as they completed problems in thermodynamics. The sample consisted of 2,000 students spanning all four years of undergraduate studies and two years beyond baccalaureate studies at the University of Paris and 29 teachers enrolled in an inservice program. A series of 11 questionnaires containing various thermodynamics problems were completed by participants. Qualitative analyses of responses from four of the questionnaires comprised the reported results.

Students' and teachers' reasoning patterns were found to be quite consistent with the following patterns noted. Both groups tended to simplify the problem at hand by omitting discussion/inclusion of certain variables in a process termed by the authors as "functional reduction." This reduction in variables considered was often accomplished through the combining of variables (e.g., *mean* distance between two particles and *mean* kinetic energy). A linear causal reasoning based on an artificial chronology of events was also used to simplify and solve problems. The authors concluded that such reasoning will most likely result from classroom instruction, and that although less popular than content-specific objectives, more direct attention to the types of general reasoning patterns we expect our students to learn must be included within science instruction.

Conceptions of Science

How students view science as a way of knowing and the development of scientific knowledge has been a perennial concern of science educators. **Grosslight, Unger, Jay, and Smith** focused on individuals' understanding of models and

their use in science. Their primary purpose was to characterize the nature of these conceptions, examine the criteria used to define models, and relate conceptions of models to epistemological viewpoints. The subjects included 33 mixed-ability seventh grade students, 22 eleventh grade students enrolled in an honors science class, and four adult experts (i.e., museum director, high school physics teacher, professor of engineering and education, and cognitive science researcher). Clinical interviews were used to elicit subjects' conceptions of the term "model" as well as how models are used in science. A scoring scheme for interviews was derived from qualitative analysis of data as opposed to being imposed a priori.

Virtually all of the students in both grades referred to models as concrete objects as opposed to representations of ideas, while the experts viewed models as falling into two categories: physical and abstract. Seventh graders believed models were used to show or demonstrate what something is or does while 11th grade students thought the purpose was to help someone understand and teach. The experts unanimously said models existed as aids to understanding phenomena. With respect to the design of models, both groups of students felt that one would have to "think about the real thing" while the experts focused on the purpose the model was supposed to achieve. It was concluded that students' conceptions of models were consistent with a naive realist epistemology, with experts' views being more consistent with a constructivist framework. Furthermore, only about half (58% of the 7th graders and 50% of the 11th graders) of the students used consistent criteria when asked to describe whether an item was a model, while all of the experts applied at least one criterion consistently across all four items presented in the interview.

The authors concluded that students need more experiences using models as intellectual tools, more experience with models that provide contrasting conceptual views of phenomena, and more discussions of the roles models play in scientific inquiry.

How high school students conceptualize science and the production of scientific knowledge was the focus of **Larochelle and Desautels'** research. A sample of 25 students (ages 15-18), who had completed an average of six courses in science, were interviewed concerning the nature of science, sources of scientific knowledge, and "rules" for the development of scientific knowledge. Following the semi-structured interviews, comparative and constant analysis techniques were used to analyze the collected data. In general, the students held the view that science "feeds itself on evidence" and is a matter of numbers, formulas, and compulsive experiments. More simply put, students felt that the production/development of scientific knowledge is only a matter of putting empirical evidence into numbers or words. The authors concluded that the "didactic contract," which typifies science instruction masks the fabrication of scientific knowledge and places the student in the position of simply trying to arrive at problem solutions that resemble the accepted solutions. The authors were careful to note how difficult it is to distinguish between students' personal conceptions of science and their representations of school-based learning activities in science.

How students view the scientific enterprise is considered to be a critical aspect of students' ability to develop a conceptual understanding of scientific concepts. **Songer and Linn** specifically assessed the influence of students' views of science on the ability to develop an integrated understanding of thermodynamics. The subjects were 153 eighth grade students enrolled in a one-semester physical science course. Students were assigned to one of six classes, which were all taught by the same teacher. Instruction followed the Computer as Lab Partner (CLP) curriculum which emphasizes hands-on experiments using computers that are on line to real-time data collection devices. Students completed activities in groups of 3-4. Prior to instruction all students were administered the 21-item Views of Science Evaluation and the Heat and Temperature Evaluation. Following instruction, students completed the Heat and Temperature Evaluation and Prototype Integration Evaluation.

Scores on the Views of Science instrument indicated that 15% of the students possessed a dynamic view of science, 21% a static view, and 63% a mixed view. It was concluded that most of the students had not integrated their views of science with their ideas about learning science. As anticipated, there was a relationship between students' beliefs about the nature of science and their tendency to integrate the knowledge presented in the CLP curriculum. Students with dynamic views about science were more likely to develop integrated understandings of heat energy and temperature than students with static viewpoints. With respect to principles or prototypes serving as loci for integration of knowledge, students generally preferred principles. However, students with more practice using prototypes preferred prototypes over principles. The authors concluded that students' beliefs about science are important and complement the development of thermodynamics knowledge. They also emphasized the importance of explicitly focusing on knowledge integration in helping students understand science phenomena, because students typically do not automatically integrate knowledge presented in isolation.

Cognitive Style and Study Strategies

Research on students' general preferences and styles when learning new subject matter has had a long and rich history. Interestingly, only a two studies were noted with this specific focus. There has, however, been a recent focus on student learning characteristics related to the development of conceptual understanding as opposed to the simple description of students' conceptual understandings. The former comprised the focus of **Hegarty-Hazel and Prosser's** (a & b) two studies of students enrolled in a first-year college level physics course for life science majors ($n=72$) and an introductory biology course ($n=36$). The topics of "electricity" and "photosynthesis" were of particular interest to the researchers. Students' achievement was measured by multiple-choice questions related to the topics of interest. Students' study strategies were assessed using the Biggs' Study Processes Questionnaire, and their knowledge structures of electricity and photosynthesis were assessed with concept-mapping tasks. Concept maps were completed prior to and following instruction.

Pre and post concept map comparisons indicated significant increases in correct propositions and internal integration, but not with respect to internal differentiation. Deep study strategies (relating new material to previously learned material) were positively related to pre and post concept map structures as well as achievement. Further statistical analysis indicated that the deep study strategy was related to internal correctness of the concept maps while external correctness was related to both low scores on the surface study strategy (memorization) and high scores on the deep study strategy scale.

The combined results of the two investigations led the researchers to conclude that the study strategies adopted by students do affect what they learn. Deeper and more meaningful strategies are associated with better developed post instructional knowledge and more surface strategies with less developed post knowledge. The significant impact of prior knowledge on what and how students learn is consistent with Ausubelian theory and implies that even in that which do not formally require certain levels of prior knowledge, such knowledge has an effect on the adoption of study strategies, and subsequently and indirectly on achievement.

McRobbie investigated the influence of students' educational set and cognitive preference on knowledge and cognitive organization outcome variables. The sample consisted of 160 high school chemistry students selected from intact classes in five randomly selected schools. Classes within each school were randomly assigned to alternative instructional treatments. One instructional approach was designed to reflect the information-processing style of the factually set and the other the conceptually set learner. The topic presented in each of the 14 class period units was the electrochemical series. Prior to implementation of the instructional treatments, all students completed measures of cognitive organization, cognitive preference and educational set, and subject-matter knowledge. Following instructional treatment, each group was again administered the measures of subject-matter knowledge and cognitive organization.

Analysis of the two treatment groups' pretest scores showed no significant differences on any of the variables of interest. Regression analysis indicated that educational set and cognitive preference (in combination) were significantly (accounting for 34% of the variance) related to subject matter knowledge (for both factual and conceptual knowledge). The two cognitive style variables were also significantly related (accounting for 17% of the variance) to students' cognitive organization. The author concluded that students' cognitive style is clearly important as an independent variable contributing uniquely to achievement and cognitive organization in the context of general ability, prior cognitive organization, and knowledge variables. It was further suggested that development of students' cognitive preferences should be considered an important objective for science education.

Comments

Research on students' conceptions and alternative conceptions along with investigations focusing on students' reasoning and problem solving clearly

dominated the volume of research in the Cognition and Achievement category. This trend was not unexpected and simply serves to reinforce the current emphasis on constructivism, conceptual change, and higher level thinking.

Over 90% of the research reports focusing on students' conceptions/alternative conceptions related specifically to physical science concepts and processes with little attention given to the life sciences. Given the apparent trend of investigating students' conceptions of every possible concept and process, it is intriguing that such disproportionate attention has been given to the physical sciences. There did not appear to be any relation between the grade level of students and the type (life versus physical) of concept studied. The seemingly natural recommendation would be to have the researchers with a life science background step up their production. However, there is a bigger issue concerning where this line of research will end. In particular, one hopes that we do not have to investigate students' conceptions for every concept or process included in science curricula, across all grade levels, before practical directions can be provided to classroom teachers. Think of the implications if this is actually the case. In the name of parsimony, it seems that more research needs to be pursued which investigates similarities in the types of conceptions/alternative conceptions students possess. For example, are there specific similarities between concepts such as electricity and force that lead to alternative conceptions which are also similar in nature?

The varied meanings of scientific and colloquial vocabulary has previously been identified as a critical source of students' conceptions. With the exception of only two studies, however, this line of research appears to be receiving less attention.

The assessment of students' conceptions and alternative conceptions is appropriately becoming more qualitative, but it remains troublesome, specifically with respect to representation of conceptual structures. Techniques such as card sorts, concept maps, mind maps, semantic nets, etc. still communicate relatively static representations with imposed structural limitations. Researchers would be well advised to investigate techniques that afford students more flexibility in how they represent their conceptualizations. Given the dynamic nature of students' conceptualizations, we should be using the "motion picture" as a model as opposed to a "still photograph." Although Novak and Musonda used concept maps extensively, their longitudinal investigation was a step in the right direction, as it vividly showed the dynamic (although sporadically across long time periods) nature of students' conceptual representations. The reader is referred to an excellent conceptual article (Reif and Larkin) for an in-depth discussion of students' cognition in scientific and everyday domains.

The research related to reasoning and problem solving remained focused on a Piagetian perspective. With few exceptions, this research was well conceived. Given the lag time that permeates science education publications and the current trends noted at professional meetings, one would expect the Piagetian dominance to gradually give way (if it has not already done so) to a more Ausubelian perspective. For an excellent discussion of some difficulties currently perceived within Piagetian theory, the reader is referred to a pair of conceptual articles in the

same issue of JRST (Lawson; Niaz,b). Taken together the investigations of DeLucas and Larkin and McMillan and Swadener indicate that facility with equations may allow students to achieve, but such achievement may not be an indication of conceptual understanding. Of particular interest was the finding that equations somehow possess a higher status than verbally presented information causing students to often overlook important qualitative aspects of a problem. Clearly, more research is needed concerning the effects of problem format and presentation on students' problem solving success and level of understanding.

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Affect and Characteristics

As was the case in the Research on Teaching section of this review, student characteristics and affect were combined because of their interrelated nature. Student characteristics and affect were defined in the broadest sense: demographic aspects of student populations and students' beliefs, perceptions, and attitudes and interests toward and about science and science programs. In organizing these articles, four major categories of research emphases were derived: affect toward and about the various aspects of science and science programs, including instruments used to measure these constructs; gender issues in science participation; variables that influence students' choice to participate in science-related activities; and the influence of cultural beliefs on the acquisition of scientific beliefs. This last category of articles includes studies from around the world.

Science Related Affect

The relationship between affect and achievement in science was examined by **Rennie and Punch** in two stages. First, a model was developed and tested for science-related affect, comprehensively defined as the complex of students' attitudes toward, interests in, and perceptions about science at school. The model conceptualizes science-related affect as a global variance with causally related components: Students' enjoyment in and enthusiasm for science are determined by their perceptions of their past performances in science, their expected future performance in science, and the perceived usefulness of science in school. The LISREL approach to path analysis was used to demonstrate the fit of the model to data collected for eighth-grade students ($N=342$) in two different schools on two different occasions six months apart. In the second stage of the research, multiple linear regression was used to examine the direction of the relationship between science-related affect and achievement and to apportion variance common between previous and subsequent achievement and the components of science-related affect. It was found that affect is related more strongly to previous than subsequent achievement and that much of the common variance can be attributed to students' perceptions of their competence in science.

In another attempt to understand why students act as they do in science classrooms, **Ray** collected data from students in grades three through eight ($N=377$) in order to identify the determinants of their intentions to perform laboratory and non-laboratory science activities. Fishbein and Ajzen's theory of reasoned action, which states that the immediate determinant of behavior is intention, was used as the basis for the study. Intention was determined by the weighted attitude toward the behavior (personal feelings about performing the behavior) and the weighted subjective norm (perceptions of the social pressures to perform). Attitude toward behavior and subjective norm were determined by combinations of beliefs, evaluations, and motivations to comply. Definable cores of salient beliefs related to attitude toward laboratory and non-laboratory behaviors were elicited and were significantly correlated with students' attitude toward

behavior (whether or not to participate) and subjective norm (sources of pressures to participate). The behavioral intentions of the students were predictable based upon their attitude toward behavior and subjective norm. Attitude toward behavior had a greater relative weight than subjective norm for both laboratory and non-laboratory. The correlations between adjacent constructs in the theoretical model were significant in all cases. The author notes that these findings can be used to understand and predict children's intentions to engage in science activities.

Three studies in this section examined the role of teaching strategies on students' attitudes toward science, or examined the factors that contributed to students' positive attitudes toward science and science instruction. In the first of these articles, **Ajewole** investigated the effects of discovery and expository instructional methods on the attitude of students in biology. Six intact classes of 40 Form IV (tenth grade) biology students, randomly drawn from six selected secondary schools in the Oyo state of Nigeria, were assigned to experimental and control groups. The experimental group was taught ecology concepts using the discovery method while the control group was taught the same content through expository methods. A non-randomized pretest-posttest control group design was employed using the 40-item Scientific Attitude Questionnaire. Analysis of the results showed that the experimental group scored significantly more favorable attitudes toward biology than their counterparts in the control group. Further analysis revealed that this trend held true when scores were compared with the high-, average-, and low-ability groups. No significant difference in the attitude of male and female students exposed to the discovery and expository methods existed, however. The article concludes with the recommendation that science learning using discovery methods may enable the learner to develop a more favorable attitude toward problem recognition and problem solving than when learning is done by expository methods.

Spector and Gibson explored middle school students' perceptions of what factors facilitated their learning of science. The subjects were 572 middle school students who participated in the World of Water (WOW) residential transdisciplinary summer program. Participation in this program is highly competitive; thus the students were all highly successful within their own school situations. The investigation was characterized as a discursive approach to emergent design to generate grounded theory. Primary data were collected via essays in which students were asked to reflect on their experiences and compare learning in the WOW program to learning in their own schools. Additional data were collected through participant observation field notes, open-ended interviews with individuals, and open-ended group interviews. The latter sources of data were used to corroborate or refute patterns identified from analysis of student essays. In general, students identified experiential learning, presentations by experts, transdisciplinary problem solving, hands-on activities, inductive activities, adult mentors, networks, trusting of individuals in the learning environment, and experiencing self-reliance as being helpful to learning science. The authors concluded that middle school science teacher education could be enhanced by helping teachers develop and implement strategies that build trust, provide immersion in learning, and use inductive reasoning.

In the last of these studies, **Martinez and Haertel** investigated the features of science experiments that middle school students find interesting. A sample of 59 seventh-grade students was asked to list characteristics of enjoyable science experiments. Trained raters coded these statements into a three category model derived from prior research on motivation: cognitive appeal, mastery appeal, and social appeal. A second group of 66 seventh-grade students was given 12 cards, each having one written characteristic of enjoyable science experiments that was derived from the first coding scheme; they were asked to sort the cards to form their own typologies. These typologies were subject to latent partial analysis to derive an empirical model that was matched against the former *a priori* model. The results produced a statistically significant model that fit 11 of the original 12 categories. Examples of features of interesting science experiments included discovering new things (cognitive), getting to make things (mastery), and working with friends (social).

All of the studies described thus far deal with fairly broad and general attitudes of students toward science instruction. **Dreyfus and Roth** are a noted exception to this statement in that they looked very specifically at the attitudes of students while dealing with controversial issues in science. Specifically, this study assessed the degree of ambivalence in the attitudes of students toward interventions of man in nature. A questionnaire, utilizing student input, was designed in which pupils were confronted with eight "interventions of man in natural processes" (i.e., family planning, genetic engineering, nature reserves). Each intervention was followed by three arguments against and three in favor of the intervention. Specific arguments were categorized as personal, global, or philosophical, with each intervention including a positive and negative argument of each type. Two hundred and eighty twelfth-grade pupils in Israel who had selected biology as a major were requested to rate each argument independently and to "vote," as if in a public committee, for or against each technology. The degree of ambivalence was the degree to which the pupils agreed to *both* positive and negative arguments concerning the same intervention, an apparently contradictory attitude. The authors felt that such responses indicate an appreciation for the contributions of the technology while fearing its dangers. Although a clear majority of the pupils voted in favor of all the interventions, three main patterns of responses were found: general agreement, indifference, and ambivalence. When provided with the necessary knowledge, pupils were able to appreciate arguments against a certain technology even in cases of strong personal feelings in favor of the technology (high ambivalence). The authors concluded that the development of such an ability may be one of the main objectives of science education in a STS context.

The instruments used to measure student attitude related to science continue to be a source of concern. Two studies involving attitude-instrument development were conducted. **Misiti, Shrigley and Hanson** set out to revise and validate a Likert science attitude scale for fifth through eighth grade students that was first used more than two decades ago. The target attitude was defined as learning classroom science in the middle school and was carefully differentiated from

attitudes towards science inquiry, science careers, the nature of science, or scientists. The final instrument consists of 23 statements categorized into five subcomponents: investigations, comfort/discomfort, learning science content, reading and talking about science, viewing films on TV. Coefficient alphas from two sets of data were 0.96 and 0.92 with evidence of validity offered. The final instrument seems to measure a single construct with several related subcomponents. There seems to be some degree of cross-cultural validity when the instrument is translated into Spanish.

Orion and Hofstein developed an attitude-toward-field-trip questionnaire in order to provide formative and summative evaluation of geological field trips in Israel and to investigate the factors that influence the educational effectiveness of field trips. Five dimensions of attitudes toward field trips were identified: instructional learning tool, individualized learning, social event, adventure event, and environmental aspect. The instrument was found to be reliable and valid and was sensitive to differences in age and gender. The inventory's usefulness as a measure for pre- and post-test research involving students' perceptions and attitudes about field trips was established.

Gender Issues in Science

Attribution theory states that in educational situations people tend to attribute success or failure to one or more types of cause: ability, luck, effort, or difficulty of task. Based on the premise that students attribute success or failure by the type and frequency of teacher interaction, **Barba and Cardinale** sought to identify the quality and quantity of science classroom interactions in relationship to gender. Classroom variables were investigated by randomly observing 14 secondary science teachers and tallying classroom interaction behaviors.

Results showed that male students were asked a greater percentage of the high-level questions and were more often target students. Female students were asked a greater percentage of low-level questions, used teacher approved methods of gaining attention, and were target students less frequently. Male teachers interacted with target students more often than female students. Teachers, regardless of gender, tended to interact more, however, with male students than with female students. Overall, this study suggests that female students have fewer interactions with science teachers and receive less attention by conforming to teacher expectations for classroom conduct. By asking female students low-level questions, the observed science teachers provided cues to those students that they were low ability. In contrast, male students were provided with cues that would allow them to attribute their perceived successes to high ability and their failure to lack of effort.

In a study with results that strongly contrast with those of the previous study, 144 lessons taught by 12 teachers were recorded and analyzed by **Hacker** in terms of the interactions of girls and boys in secondary school science lessons. All teachers were male and were teaching the same physics topic from the an integrated science curriculum. Analysis of classroom tapes consisted of recording

the verbal and non-verbal interactions of the teacher with 12 randomly selected students from each class, six boys and six girls. A few differences in frequencies of behaviors in favor of girls were reported, with girls more likely to initiate verbal interactions in the classroom. Effect size for these differences was small. This study did not support the hypothesis that gender differences in science achievement in favor of boys result from differential treatment of boys and girls during science lessons.

Classrooms, and the activities conducted in them, are obvious locations to search for influences that potentially gender stereotype science and science activities. In an attempt to determine the effectiveness of classroom environment interventions in attitudes concerning sex stereotyping of science, **Mason, Kahle and Gardner** randomly selected 14 biology teachers and their students from a pool of volunteers. Seven of the teachers were selected to participate in an intervention program designed to help teachers promote a stimulating, gender-free learning environment. The intervention included a preschool workshop and weekly support for teacher change throughout the school year. The content of the intervention focused on career information, role models, equitable materials, innovative practices, and the results of the Draw-a-Scientist Test (DAST) which was given as a pretest to a group of students prior to the intervention in order to obtain baseline data. Posttest-only control group comparisons revealed that changes in teachers' perceptions, as measured by the Perceptions of Science and Scientists Scale, Science Attitudes Questionnaire, Career Interest Survey and Science Experiences Survey, were significantly higher than those of the control group. All 14 teachers (control and experimental) administered the DAST to their students ($N=549$). Students in the classes of the teachers who underwent the intervention drew a significantly higher number of female scientists than the students of the control group teachers. This shift in perceptions was most apparent for female students. When pictures were analyzed for standard indicators of stereotyping (i.e., attributes, surroundings, and clothing of scientists) significant differences in *mean* score were not noted by treatment group or student sex. Interviews of randomly selected students revealed that impressions of scientists are derived through movies and cartoons that depicted scientists as mad, antisocial men. Using this information, a second analysis of pictures was conducted to determine if the scientists drawn could be described as eccentric, sinister, or neutral. Students in the experimental group drew significantly more neutral pictures than those in the control group. The combined results of this study point to the effectiveness of teacher interventions on sex stereotyping, which seem to translate in a positive manner to their students.

The differential achievement of males versus females in science has long intrigued science education researchers. In an attempt to better understand this differential achievement, **Levin, Sabar and Libman** used data from the 1983-84 Israeli IEA (International Association for the Evaluation of Education Achievement) science study to explore gender-related differences and their determinants in the learning of science. Specifically, the types of errors made by students when performing problem-solving tasks were analyzed. The sample was

composed of 1,934 ninth-grade students. The study involved several measures of science learning, ten attitudinal measures, and item and error classification. Differences between boys and girls were observed in some measures of science performance—particularly in the physical sciences, in items with lower estimates of “opportunity to learn,” and in specific kinds of errors. Gender-related differences were also observed in the predictive model of achievement, using science-specific affective measures. The discussion raises issues surrounding the cognitive and affective readiness of boys and girls for learning science.

Science Competitions, Course Enrollment, and Career Selection

Participation in science competitions, course enrollment patterns, and career choice seem to be interrelated choices, determined, at least to some extent, by variations in student affect. The studies in this section explore these various relationships and propose factors of potential influence in this area.

With increased participation in extracurricular science competitions, **Jones** explored patterns in gender participation and gender differences in subject areas selected (biological versus physical science). Participation data for grades 6 to 12 were examined for science fairs, Junior Science and Humanities Symposia, the North Carolina Student Academy of Science, the Westinghouse Science Talent Search, and the Science Olympiad during 1987-1988. All competitions are individual except for the Science Olympiad. Student data (1113 males and 972 females) were examined by gender, grade level and subject category (physical science, earth science, biological science). Results showed that gender differences in science competitions mirror those seen in course enrollment and career selection. Males have a higher interest and participation in the physical sciences, and females have higher interest and participation in biological sciences. The author suggests that the lack of female physical science research is a symptom of the differences observed in attitudes towards science. Implications include providing more female role models in the physical sciences, and increasing cooperative grouping and goal structures in science classes and competitions.

Few longitudinal studies follow a high school science student through college and into his/her research career. **Redman, Glass, and Eltinge** contacted students recognized for outstanding scientific research by the Iowa Junior Academy of Science over a period of 13 years. From the original target population of 46 students, 21 males and 15 females responded to a survey regarding the students' post secondary education and career choices, the influential people or events in their lives in terms of research topic and career selection, and several demographic variables. Ninety-two percent of the respondents completed degrees in higher education with gender differences surfacing in choice of science as a career and level of degree. Teachers/advisors and parents/guardians were credited as being the most influential in the selection of areas of research. The results of this survey support the assumption that high school students recognized for their research tend to enter a science related career.

Women and minorities continue to be underrepresented in quantitatively based fields of study. Moreover, selection of such majors by all students is declining. The choice of a math/science major is of concern in light of the occupational demands created by advancing technology as well as the potential gaps in occupational and economic attainment of women and minorities. **Maple and Stage** report the analysis of a longitudinal model of math/science major choice upon entrance to college for black and white, female and male students. The model was tested using a sample drawn from the "High School and Beyond" data base. The model included background characteristics of students, ability, and an array of high school experience factors to explain choice of quantitative major. Significant predictors of major choice for the subgroups included sophomore choice of major, mathematics attitudes, math and science completed by senior year, and various parental factors. There were, however, differences across groups, and the model explained nearly twice as much variance for the black male, black female, and white male subgroups as for the white female subgroup. Recommendations include broadening ways of researching migration into and out of the mathematics/science pipeline. An argument was made for a focus on the success of students enrolled in low-level college mathematics classes as a way of augmenting the mathematics/science pipeline.

Ndunda and Munby studied gender differences via how female high school students construct their "science futures"—their view of their future in science courses and in science or science-related careers. Kenya was selected as the context for this study because the modern education system, derived from the system introduced by European settlers, has exploited traditional Kenyan gender roles and has widened the rift between the opportunities afforded men and women. Additionally, the colonial system introduced the concept of privilege that has become institutionalized in the schools. Two schools within Kenyan society, one of mixed gender, the other an all-female school, were selected. Data included three months of observations both inside and outside the science classrooms. Twenty students (16 females and 4 males) were interviewed once or twice during the period of the study. All participants were selected from those studying pure sciences at the third year of secondary education. The concepts of resistance, challenge, and barrier emerged from the data set as useful ways to explain and contrast the students' conceptions of "science futures." These constructions were influenced by the students' perceptions of the culture of their schools and of the society in which they live. Relationships among concepts of privilege and class are complex and interactive.

Acknowledging the common concern about the dearth of female and minority scientists, **Campbell** compared the academic self-concepts, attributions and achievement of male and female Asian American and Caucasian students who won Westinghouse Awards in 1984 and 1985. Asian American students have received 25% of these awards (in comparison to population composition of 1%), contributing to the belief that Asian families socialize their children differently than Caucasian families. A total sample of 191 males and 110 females responded to a questionnaire related to the focus of this study. The results of the

study showed that fewer Caucasian female recipients anticipated college majors in the technical areas. Furthermore, this group of females scored lower on both attribution scales. In contrast, the Asian females optimized courses for the gifted and specialized research courses to distance themselves from the American females in almost all areas. The author linked these ethnic, gender differences to underlying psychological and sociological forces that are responsible for self-concept and attribution differences. It is these forces that must be altered for Caucasian females to rectify the gender inequalities that exist in the technical areas.

Mertens examined the instructional variables that are specific to hearing-impaired students' attitudes toward and interest in science. Thirty-two students and 25 staff members attended a four-week summer program in marine science with the goals of enhancing students' knowledge of and exposure to science as a career over the course of two summers. Data were collected by means of participant observation, semi-structured interviews, document review, and questionnaires completed by staff and students. The focus of the data collection was the background characteristics of the participants, their interest and preparation in science, experiences with deafness, and career awareness and aspirations. Data were reported for the following topics: student characteristics, instructional methods, project management and staffing, and affective objectives. Students were found to be heterogeneous in terms of their preferred mode of communication, skill in manual communication, lip-reading ability, degree of hearing loss, reading ability, and knowledge of an interest in science. Instructional techniques that worked well included short lectures, active involvement, and frequent feedback to the instructor as to student understanding. The students viewed the program in a positive light though changes in career orientation as a result of the program were not evident. The authors hope that the results of the research will be useful to teachers with hearing-impaired students mainstreamed into their classrooms.

The Relationship Between Cultural Beliefs and Scientific Beliefs

Five studies dealt with the relationship between cultural beliefs and the learning of scientific beliefs. In the first of these, Mohapatra argues that societal perspectives on science are influenced by the degree of knowledge that the average student acquires in school. Furthermore, pupils' alternative conceptions, which affect their degree of learning, will eventually affect the scientific view of society when these pupils become adults. Based on such arguments, the socio-cultural experience in India was investigated as a possible generative cause of alternative conceptions of the phenomenon of solar eclipse. Eighty-seven students ranging from 13-16 years of age were asked to complete a 20-question Likert scale instrument that measured their attribution of phenomenon related to the solar eclipse to social-cultural concepts and rituals. Students' alternative conceptions across the different age groups seemed resistant to extinction. The overwhelming acceptance of socio-cultural views over scientific views were

explained in terms of the differential time spent in exposure to each view. Potential strategies to take socio-cultural views into account when teaching science are provided.

The conceptual frameworks of Thai children related to causes of health and sickness were investigated by Rice. Forty-eight children from grades 6 and 8 were interviewed using the Interview about Instances technique and analyzed using the Conceptual Profile Inventory. The analysis classified statements as reflecting school knowledge, cultural knowledge, or common-sense knowledge. The results indicated that Thai children hold considerable personal knowledge about the causes of health and sickness that does not derive from school knowledge or from scientific frameworks. This additional knowledge was found to encompass both Thai cultural knowledge and Thai common-sense interpretations developed from everyday experience within Thai society. Patterns of the conceptual frameworks found reveal that Thai schoolchildren perceive concepts related to causes of health and sickness within the biomedical framework as well as a number of alternative frameworks such as: nutrition, human habit, human aggression, Thai value systems, religious beliefs, environment, living conditions, socio-economic status, and family behavior and attitudes.

In the United States, Charron conducted a qualitative, descriptive study in an effort to better understand the relationship between ideas about science that pupils acquire in classrooms and those acquired in several other contexts including the school, the school system, and the local community. Data collection included participant observation and field notes, interviews, researching maps, inventories and document files over a period of seven months. Foci of the investigation included school science experiences, non-school science experiences, the nature of science, science content, methods of teaching and learning science, methods of practicing science, and the value of science. Several dimensions of student's science perceptions in grades 1-12 in a rural country school system were presented as they relate to the pupil's viewpoints of school and non-school experiences and to the views of local adults. The students' perceptions of science were also used as a basis to explore three issues that were raised by school administrators and teachers in the community of study and that have general bearing in science education. These issues are the need for articulation of school science offerings across grade levels, the need for the science program to make connections with locally held ideas and values, and the need for the science program to be comprehensive and accurate, reflecting science professionals' thinking and yet retaining sensitivity to local viewpoints.

Jegede and Okebukola (a) highlight the significance of the process skill of observation in the teaching and learning of school science. Observations have been shown to be theory dependent; thus, making an observation implies a world view in which the observation can be made and is worth making. This study investigated the supposition that observation skills can be influenced by students' belief in traditional African cosmology, beliefs and superstitions. Data were collected from 319 pre-degree (16.9 years old) science students from one of the Nigerian universities using the Traditional Cosmology Test and the Test of

Observational Skills. The results showed that students with a high level of belief in African traditional cosmology made significantly fewer correct observations in comparison with those with a low level of belief. Similar results did not exist for tasks without traditional beliefs. African traditional beliefs seemed to exert the most influence on observational tasks in comparison with gender and religious affiliations, a possibility supported by interviews with a random selection of subjects. Implications for curriculum developers and proponents of inquiry-based science programs in African classroom are discussed.

Although the recent studies, such as those reported above, have shown that the socio-cultural characteristics that children in non-western society bring into the classroom from their environment create a wedge between what they are taught and what they learn, very little has been done to solve the problem. **Jegede and Okebukola (b)** claim that a learner who is not positively disposed to, or has a socio-cultural background that is indifferent to, learning science would find it hard to learn science effectively. This study investigated whether instruction through the use of the socio-cultural mode had any significant effect on students' attitude towards the learning of science. The sample consisted of 600 senior secondary year-one (grade level 10) students from 15 secondary schools in Nigeria. The Socio-Cultural Environment Scale (SCES) and the Biology Achievement Test (BAT) were used to measure the change in attitude and achievement of subjects in a pretest-posttest situation after a six-week treatment. The students were taught a six-week unit on mammalian reproduction with half of the students being involved in discussions surrounding socio-cultural beliefs related to biological ideas and concepts, and the other half exposed only to expository methods of instruction.

Evidence was found to support the hypothesis that science instruction which deliberately involves the discussion of socio-cultural views about science concepts engenders positive attitudes towards the study of science. Gender interactions with teaching method were not found to exist. The findings also indicate that anthropomorphic and mechanistic views can be presented in such a way as to promote positive attitudes towards the study of science in traditional cultures.

Comments

There are several concerns that have plagued research efforts on student affect. First, the relationship between attitude and achievement has commonly been noted to have low correlations, making the research efforts in these areas of marginal value in terms of impact. Secondly, the definitions used in attitudinal research are often problematic, with distinctions among attitudes towards science as a discipline, science as a subject, scientists, or methods of teaching science often being unclear. Without clear operational definitions of the attitudes being examined, few conclusions across studies can be made. The research reported in this review, however, seems to have improved upon these past flaws in several ways. First, there is a much more consistent effort to operationally define the attitude being measured. Second, many researchers have attempted to tie science

attitudes more broadly to outcome behaviors, which seem to be more directly related to the attitudes in question, namely participation in science activities as opposed to strictly science achievement.

One of the key relationships implied in several of the studies is that between attitude and scientific literacy. Research that documents this relationship does not, however, seem to exist. Will positive attitudes automatically lead to increased scientific literacy as many of the articles in this review seem to suggest?

In a similar vein, efforts in attitudinal research seem to be concentrated on students at the eighth grade and above with relationships drawn to preferences for teaching strategies and ultimately course and career selection. This choice of grade level is interesting in light of the research, which reveals that many students select themselves out of the science pipeline as early as grade five and form many of their perceptions of themselves as science learners by third grade. Consequently, it seems that the populations selected for this research are misplaced. It is measuring the attitudes and preferences of students in a target group for which there is a reduced likelihood for significant impact in terms of course and career choices. Perhaps research of this nature should be aimed at students in the lower elementary grades despite the logistical problems of working with students in this age group.

Regardless of the sub-category in which articles were placed in this review, one result seems to be consistently demonstrated: Students leave science classes with more positive attitudes about science (and their concepts of themselves as science participants) when they learn science through inductive, hands-on techniques in classrooms where they are encouraged by a caring adult and allowed to process the information they have learned with their peers. In addition, teaching techniques of this sort seem to be gender neutral. This information is not surprising since such teaching techniques have been at the core of calls for science education reform for the last 30 years. What is surprising is that teaching in the public schools has not changed to keep pace with this information. Why isn't practice changing? Are there more effective methods of passing this information on to practicing teachers so that the results can effect practice? The **Mason, Kahle and Gardner** article is particularly encouraging in this respect.

Access to science participation by women and minorities is still an issue of active research focus. Differences in participation patterns are seen in classrooms, science competitions, course enrollment, career selection and in general attitude studies. The use of attribution theory to teacher-student interaction seems to be quite useful. Across the studies reported, critical aspects of students' conceptions of themselves as science learners seems to be inextricably tied to past science performance and social pressures (parents, teachers and peers) to participate in science. The **Hacker** article, however, calls such findings into question with opposing results. Why? As Hacker suggests, maybe the methods and incoming assumptions used in gender studies should be carefully scrutinized to decrease unintentional bias. Or perhaps the context of the Hacker study, conducted in Australia, should be examined for clues that point to cultural aspects which decrease the potential of gender bias.

Finally, the last group of studies brings the cultural nature of science into full focus with the potentially unavoidable confrontation of cultural and scientific beliefs. Interestingly, results, conceptions and implications reported for non-western cultures seem to be equally applicable to western cultures. The need to make connections between science and local beliefs and ideas is supported in a number of contexts and has the potential to promote more positive student attitudes towards science instruction. Before making over-arching recommendations on how science should be taught around the world, however, a careful examination of the goals of science education in specific contexts would be warranted. Which of the broader aspects of science are most appropriate within various contexts? How can science and culture be appropriately merged while maintaining the important characteristics of both science and the native culture? Or, must a belief in science replace cultural beliefs? A critical analysis of the appropriateness of the anticipated outcomes is necessary if informed and reflective implementation of science education in all settings is to occur.

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A Brief Guide to ERIC

The Educational Resources Information Center

Office of Educational Research and Improvement
U.S. Department of Education

What is ERIC?

The Educational Resources Information Center (ERIC) is a national education information network designed to provide users with ready access to an extensive body of education-related literature. Established in 1966, ERIC is supported by the U.S. Department of Education, Office of Educational Research and Improvement.

The ERIC database, the world's largest source of education information, contains over 735,000 abstracts of documents and journal articles on education research and practice. This information is available at more than 2,800 libraries and other locations worldwide.

You can access the ERIC database by using the print indexes *Resources in Education* and *Current Index to Journals in Education*, online search services, or CD-ROM at many libraries and information centers. The database is updated monthly (quarterly on CD-ROM).

The ERIC System

The ERIC System, through its 16 subject-specific Clearinghouses, 4 Adjunct Clearinghouses, and four support components, provides a variety of services and products that can help you stay up to date on a broad range of education-related issues. Products include research summaries, publications on topics of high interest, newsletters, and bibliographies. ERIC system services include computer search services, reference and referral services, and document reproduction. ACCESS ERIC, with its toll-free number, 1-800-LET-ERIC, informs callers of the services and products offered by ERIC components and other education information service providers.

ERIC Reference and Referral Services

With the world's largest educational database as a resource, ERIC staff can help you find answers to education-related questions, refer you to appropriate information sources, and provide relevant publications. ERIC components answer more than 100,000 inquiries each year. Questions should be directed to ACCESS ERIC or a specific Clearinghouse.

Specific documents: Requests for documents in the ERIC database for which you have an accession number (EJ number) should be referred to an information provider near you. Call ACCESS ERIC to locate the nearest ERIC education information provider.

Subject-specific topics: Subject-related questions should be directed to the particular ERIC Clearinghouse whose scope is most closely associated with the subject matter involved. Or, call ACCESS ERIC for a referral.

Computer searches: Requests for a computer search should be directed to one of the search services listed in the *Directory of ERIC Information Service Providers*, available from ACCESS ERIC.

ERIC Clearinghouse publications: Requests for a publication produced by an ERIC Clearinghouse should be directed to the specific Clearinghouse.

Major ERIC Products

ERIC produces many products to help you access and use the information in the ERIC database:

Abstract Journals: ERIC produces two monthly abstract journals. *Resources in Education* (RIE), a publication announcing recent education-related documents, and the *Current Index to Journals in Education* (CIJE), a periodical announcing education-related journal articles, is available through Oryx Press (1-800-457-6799). Many libraries and information centers subscribe to both monthly journals.

All About ERIC: This guide provides detailed information on ERIC, its products and services, and how to use them. Free copies are available from ACCESS ERIC.

Catalog of ERIC Clearinghouse Publications: The *Catalog* lists publications produced by the ERIC Clearinghouses and support components, prices, and ordering information. Free copies of the *Catalog* are available from ACCESS ERIC.

The ERIC Review: This journal discusses important ERIC and education-related developments. For a copy, call ACCESS ERIC.

Information Analysis Products: ERIC Clearinghouses produce reports, interpretive summaries, syntheses, digests, and other publications, many free or for a minimal fee. Contact the Clearinghouse most closely associated with your interests for its publications list. Call ACCESS ERIC for a free copy of the *Catalog of ERIC Clearinghouse Publications*.

Microfiche: The full text of most ERIC documents is available on microfiche. Individual documents and back collections on microfiche are available. Call the ERIC Reproduction Document Service (EDRS) for more information.

Thesaurus of ERIC Descriptors - The complete list of index terms used by the ERIC System, with a complete cross-reference structure and rotated and hierarchical displays, is available from Oryx Press.

ERIC TAPES - Computer tapes of the ERIC database are available by subscription or on demand from the ERIC Facility (write for a price list).

ERIC Document Delivery

Documents: EDRS is the primary source for obtaining microfiche or paper copies of materials from the ERIC database. EDRS can provide full-text copies of most documents announced in Resources in Education (RIE), and ERIC's microfiche collection is available by monthly subscription from EDRS. EDRS also sells microfiche and paper copies of individual documents on request. For more information, call EDRS at (800) 443-ERIC.

Journal Articles: Two agencies that provide reprint services of most journal articles announced in *Current Index to Journals in Education* (CJIE) are listed below. Some journals do not permit reprints; consult your local university or local library to locate a journal issue. Or, write directly to the publisher. Addresses are listed in the front of each CJIE.

University Microfilms International (UMI)
Article Clearinghouse
300 North Zeeb Road
Ann Arbor, MI 48106
Telephone: (800) 732-0616

Institute for Scientific Information (ISI)
Genuine Article Service
3501 Market Street
Philadelphia, PA 19104
Telephone: (800) 523-1850

ERIC Information Retrieval Services

The ERIC database is one of the most widely used bibliographic databases in the world. Last year, users from 90 different countries performed nearly half a million searches of the database. The ERIC database currently can be searched via four major online and CD-ROM vendors (listed below). Anyone wishing to search ERIC online needs a computer or terminal that can link by telephone to the vendor's computer, communications software, and an account with one or more vendors.

The *Directory of ERIC Information Providers* lists the address, telephone number, and ERIC collection status for more than 900 agencies that perform searches. To order a copy, call ACCESS ERIC (1-800-LET-ERIC).

Online Vendors

BRS Information Technologies
8000 Westpark Drive
McLean, VA 22102
Telephone: (703) 442-0900
(800) 289-4277

Dialog Information Services
3460 Hillview Avenue
Palo Alto, CA 94304
Telephone: (415) 858-2700
(800) 334-2564

OCLC (Online Computer Library Center, Inc.)
6565 Frantz Road
Dublin, OH 43017-0702
Telephone (614) 764-6000
(800) 848-5878
(Ext. 6287)

CD-ROM Vendors

Dialog Information Services (same address as above)

Silver Platter Information Services
One Newton Executive Park
Newton Lower Falls, MA 02162-1449
Telephone: (617) 969-2332
(800) 343-0064

ERIC Components

Federal Sponsor

Educational Resources Information Center (ERIC)
U.S. Department of Education
Office of Educational Research and Improvement (OERI)
555 New Jersey Avenue N.W.
Washington, DC 20208-5720
Telephone: (202) 219-2289
Fax: (202) 219-1817

Clearinghouses

Adult, Career, and Vocational Education

The Ohio State University
1900 Kenny Road
Columbus, OH 43210-1090
Telephone: (614) 292-4353; (800) 848-4815
Fax (614) 292-1260

Counseling and Personnel Services

University of Michigan
School of Education, Room 2108
610 East University Street
Ann Arbor, MI 48109-1259
Telephone: (313) 764-9492
Fax: (313) 747-2425

Educational Management

University of Oregon
1787 Agate Street
Eugene, OR 97403-5207
Telephone: (503) 346-5043
Fax: (503) 346-5890

Elementary and Early Childhood Education

University of Illinois
College of Education
805 W. Pennsylvania
Urbana, IL 61801-4897
Telephone: (217) 333-1386
Fax (217) 333-5847

Handicapped and Gifted Children

Council for Exceptional Children
1920 Association Drive
Reston, VA 22091-1589
Telephone: (703) 620-3660
Fax: (703) 264-9494

Higher Education

The George Washington University
One Dupont Circle N.W., Suite 630
Washington, DC 20036-1183
Telephone: (202) 296-2597
Fax: (202) 296-8379

Information Resources

Syracuse University
Huntington Hall, Room 030
Syracuse, NY 13244-2340
Telephone: (315) 443-3640
Fax: (315) 443-5732

Junior Colleges

University of California at Los Angeles (UCLA)
Math-Sciences Building, Room 8118
405 Hilgard Avenue
Los Angeles, CA 90024-1564
Telephone: (213) 825-3931
Fax: (213) 206-8095

Languages and Linguistics*

Center for Applied Linguistics
1118 22nd Street N.W.
Washington, DC 20037-0037
Telephone: (202) 429-9551 and (202) 429-9292
Fax: (202) 429-9766 and (202) 659-5641

**Includes Adjunct ERIC Clearinghouse on Literacy Education for Limited English Proficient Adults*

Reading and Communication Skills

Indiana University
Smith Research Center, Suite 150
2805 East 10th Street
Bloomington, IN 47408-2698
Telephone: (812) 855-5847
Fax: (812) 855-7901

Rural Education and Small Schools

Appalachia Educational Laboratory
1031 Quarrier Street
P.O. Box 1348
Charleston, WV 25325-1348
Telephone: (800) 624-9120 (outside WV)
(800) 344-6646 (inside WV)
(304) 347-0400 (Charleston area)
Fax: (304) 347-0487

Science, Mathematics, and Environmental Education

The Ohio State University
1200 Chambers Road, Room 310
Columbus, OH 43212-1792
Telephone: (614) 292-6717
Fax (614) 292-0263

Social Studies/Social Studies Education**

Indiana University
Social Studies Development Center
2805 East 10th Street, Suite 120
Bloomington, IN 47408-2373
Telephone: (812) 855-3838
Fax: (812) 855-7901

***Includes Adjunct ERIC Clearinghouse on Art Education; and the National Clearinghouse for U. S.-Japan Studies*

Teacher Education

American Association of Colleges for Teacher Education (AACTE)
One Dupont Circle N.W., Suite 610
Washington, DC 20036-2412
Telephone: (202) 293-2450
Fax: (202) 457-8095

Tests, Measurement, and Evaluation

American Institutes for Research (AIR)
Washington Research Center
3333 K Street N.W.
Washington, DC 20007-3893
Telephone: (202) 342-5060
Fax: (202) 342-5033

Urban Education

Teachers College, Columbia University
Institute for Urban and Minority Education
Main Hall, Room 300, Box 40
525 West 120th Street
New York, NY 10027-9998
Telephone: (212) 678-3433; Fax (212) 678-4048

Adjunct Clearinghouses

National Clearinghouse on Literacy Education

Center for Applied Linguistics
1118 22nd Street N.W.
Washington, DC 20037
Telephone: (202) 429-9292
Fax: (202) 659-5641

Adjunct ERIC Clearinghouse for Art Education

Indiana University
Social Studies Development Center
2805 East 10th Street, Suite 120
Bloomington, IN 47405-2698
Telephone: (812) 855-3838
Fax: (812) 855-7901

National Clearinghouse for U. S.-Studies

Indiana University
Social Studies Development Center
2805 East 10th Street, Suite 120
Bloomington, IN 47408-2698
Fax: (812) 855-7901

Adjunct ERIC Clearinghouse on Chapter 1

Chapter 1 Technical Assistance Center
PRC, Inc.
2601 Fortune Circle East
One Park Fletcher Building, Suite 300-A
Indianapolis, IN 46241
Telephone: (317) 244-8160, (800) 456-2380
Fax: (317) 244-7386

Support Components

ACCESS ERIC

Aspen Systems Corporation
1600 Research Boulevard
Rockville, MD 20850-3166
Telephone: (800) LET-ERIC
Fax: (301) 251-5212

ERIC Document Reproduction Service

7420 Fullerton Road, Suite 110
Springfield, VA 22153-2852
Telephone: (301) 258-5500; (800) 443-ERIC
Fax: (301) 948-3695

Oryx Press

4041 North Central Ave., Suite 700
Phoenix, AZ 85012-3399
Telephone: (602) 265-2651; (800) 279-ORYX
Fax: (602) 265-6250; (800) 279-4663

How to Submit Documents to ERIC

ERIC collects a variety of materials on education-related topics. Examples of materials included in the database:

- Research reports
- Instructional materials
- Monographs
- Teaching Guides
- Speeches and presentations
- Manuals and handbooks
- Opinion papers

Submissions can be sent to the Acquisitions Department of the ERIC Clearinghouse most closely related to the subject of the paper submitted, or sent to the ERIC Processing Facility.

About the editors...

Norman G. Lederman is Associate Professor of Science and Mathematics Education at Oregon State University. He received his Ph.D. in Science Education from Syracuse University in 1983, M.S. in Secondary Education from Bradley University in 1977, M.S. in Biology from New York University in 1973, and B.S. in Biology from Bradley University in 1971. Dr. Lederman is known for his research on students' and teachers' conceptions of the nature of science and science teachers' knowledge structures and beliefs. Dr. Lederman serves on the following editorial boards: *Journal of Research in Science Teaching*, *Journal of Elementary Science Education*, *Journal of Science Teacher Education*, and *Science Education*.

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Dana L. Zeidler received his doctorate in Science Education from Syracuse University in 1982. He is now at the University of Massachusetts Lowell and is currently the managing editor for the *Journal of Science Teacher Education*. Dr. Zeidler is widely published in the *Journal of Research in Science Teaching and Science Education* and is an active member in various professional educational research associations.