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ABSTRACT

This volume represents a compilation and organization of more than 400 research efforts reported in 1986. Its objective was to organize the research in such a way that studies or related topics are easy to access by practitioners or researchers. It is organized around four major sections that reflect the process of teaching, learning, and schooling including: (1) "Teaching and the Teacher" (studies of teacher attitudes, perceptions, practices, repertoires and performance); (2) "Learning and the Learner" (the nature of learning and characteristics of the learner); (3) "Curriculum and Instruction" (the nature of curricula, instructional variables, and characteristics of exemplary science programs); and (4) "Instrument Development and Analysis" (efforts to develop and/or validate instruments to measure the process of teaching, learning and schooling). Each major section begins with an overview of the research summarized and a context for review, and ends with a reference list appropriate to that section. No effort to conduct an in-depth analysis of each research area was made. A discussion of the significance of the studies and implication for practice and future research is included in each major section. Three imperatives that were noted were the need for research to have a greater impact upon classroom procedures, greater teacher interaction, and teacher collaboration on research teams. (CW)

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PREFACE

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

Readers' comments and suggestions for the series are invited.

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A Summary of Research in Science Education — 1986

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INTRODUCTION

Everyone should attempt one comprehensive research summary of a broad discipline such as science education at least once in a lifetime. The task is not only challenging, it is humbling. Like many of our colleagues who have accepted the challenge to summarize the preceding year's research in science education, we grappled many long hours on the initial task of organizing the more than 400 research reports into a logical scheme. We tried to be creative - to organize the review in a way that no one before us had done. After hours of reviewing and categorizing manuscripts, and discussing various organizational schemes, we realized the wisdom of the adage, "If it's not broke, don't fix it!" In the end, we agreed upon an organizational scheme that (hopefully) reflects the best of the ideas presented in previous summaries, along with some of the creativity we hoped to share with you in our first enthusiastic thoughts about this project.

Our primary objective in preparing this summary of research was to organize the research in such a way that studies on related topics or issues would be easy to access -- both by the practitioner and the researcher. We gathered our primary organizational ideas from such sources as the Handbook of Research on Teaching (Wittrock, 1986) and Joyce & Weil's (1986) Models of Teaching. Thus, the summary is organized around four major sections that reflect the process of teaching, learning, and schooling as follows:

Section One, **Teaching and the Teacher**, synthesizes studies that investigated teacher attitudes and perceptions, practices and repertoires, preparation and classroom performance.

Section Two, **Learning and the Learner**, synthesizes studies that investigated the nature of learning and characteristics of the learner.

Section Three, **Curriculum and Instruction**, focuses upon developments in research on the nature of curricula, instructional variables, and characteristics of exemplary science programs.

Section Four, **Instrument Development and Analysis,** includes research efforts to develop and/or validate instruments to measure the process of teaching, learning, and schooling.

Each major section begins with an introduction that provides an overview of the research summarized and a context for the review. Similarly, each section ends with a discussion of the significance of the studies and implications for practice and future research. We have chosen to provide the reader with a complete citation at the end of each major section, rather than at the end of the summary. Hopefully, this will make it easier for you to find studies that pertain to a specific section. We have cross-referenced between major sections in instances where a study focused on multiple constructs or contexts. In such instances, the study is summarized in detail in the section of primary focus. Finally, you will note that we have boldfaced the author's names in text for the research articles that are the subject of this summary. All supporting references use the traditional APA referencing style.

The research efforts that are summarized within each of the above sections reflect the research that was actually reported in 1986. Our efforts to review the research should be viewed as a point of departure in a literature search, as we have not made any effort to conduct an in-depth analysis of each research area. To the extent possible we have tried to provide a context for research reported in 1986 with previous trends and efforts. We have also tried to explore the implications of the research endeavors. We caution the reader, however, that our efforts in these regards are minimal in comparison to expectations established for critical reviews and analyses of research with a narrower focus across many years of research.

A review of the research reported in 1986 reveals some interesting trends. For example, research on the nature of the learner, exemplary teaching, and the use of new technologies appear to be emerging as areas of emphasis; research in some traditional areas such as intellectual development appears to be waning; while research related to student attitudes, to curriculum implementation, and to instructional strategies are sustaining in what could be regarded as an evolving social context for research in science education. Many of the above observations should be expected since, as White & Tisher (1986) note, "Current research is based on the general conception that the outcomes of schooling are determined by interaction of teachers, students, and the curriculum within bounds set by a social context" (p. 897).

The rapidly changing social context of the 1980s has brought to light three imperatives in 1986:

1. the need for science education research to have a greater impact upon classroom practices (Hurd [1985, 1986]; White and Tisher, 1986);

2. the need for greater interaction among science education researchers (Linn, 1986); and,

3. the need for teachers to become collaborative members of research teams (Hurd [1985, 1986]; White & Tisher, 1986).

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In essence, Hurd (1985, 1986) echoes the sentiments of Lawson et al. (1985) who stated in their introduction to A Summary of Research in Science Education - 1984 that "... the current problems in science education do not stem from our inability to discover what should be taking place in the classroom. Rather, our problems stem from our inability to put our knowledge into practice" (p. 193).

Hurd (1986) explored ways in which research in science education could serve teachers better and improve student learning. He suggested that a new vision of science education must be developed, implemented, and validated in ways that would be in harmony with the current status of society. The purpose of such a reform would be to make it less possible to distinguish between school learning and life experiences. For research to be meaningful, it would therefore relate to the problems associated with teaching, learning, and curriculum development in accordance with the criteria identified by such educational reform. Hurd (1986) also cited the need for pre- and in-service teacher education programs to assist teachers in implementing research findings in their classrooms. Additionally, he stressed the imperative that teachers be made partners in research efforts aimed at improving science teaching.

Linn (1986) synthesized the recommendations of participants at a national planning conference on research and science education in a report entitled, Establishing a Research Base for Science Education: Challenges, Trends, and Recommendations. The report identifies the need for a new thrust in science education research correlated to a new view of the curriculum. The goals of the science curriculum need to be redefined and broadened to reflect new knowledge, technological advances, and societal needs. In order to accomplish such ends, the report cites a critical need for greater interaction among professionals in science education and recommends establishing Centers for Collaboration in Science Education. The report stresses that, for needed innovation in science education, we must understand better the nature of science learning. Further, research in science education should reflect and respond to real instructional needs. Thus, science educators, cognitive scientists, subject matter experts, and pre-college teachers should contribute to such endeavors.

Historically, science education research could be viewed as too narrow in concept and flawed in method to deal realistically with human behavior. Thus, research was too far removed from the reality of the classroom. What was perceived as a lack of interest in research findings on the part of science teachers by science education researchers, may actually only have been teachers failing to find any practical applicability of such research.

Recent inquiries by **Gabel et al.** and **Butzow & Gabel** indicate that teachers do indeed have interests in research. The research areas of most interest to elementary teachers include: research related to hands-on science; science content of the curriculum; cognitive development and learning styles; problem solving; and instructional strategies (Gabel et al.). Secondary teachers were most interested in research in the following areas: improving laboratory effectiveness; motivational techniques related to learning and science participation; the influence of high school science upon success in college science; ways to enhance problem solving skills; and how to make science instruction more meaningful to students (Butzow & Gabel).

As evidenced by many of the studies reported in 1986, research in science education in the 1980s has become more complex. An increasing percentage of the research is being conducted by teams of researchers looking at multiple variables and utilizing a greater range of investigative methods. It is also worth noting that the increasing complexity of the inquiries and the methodological protocols has ironically shifted the focus of the researcher closer to the school based environment. The following events are attributable to these trends: more research is being conducted by and with teachers, rather than on teachers; and, more attention is being given to the influence the social context has on the process of schooling.

Thus, it appears as though the social context of schooling in the 1980s is contributing to a research agenda in which collaboration and relevancy are being stressed. Our understanding of science teaching and learning has advanced tremendously in the last decade. We have learned much about what is effective. The research efforts summarized herein contribute to our understanding. Unfortunately, the vast amount of energy and time that has been invested in research has not affected practice. We feel that the next steps should be comprehensive studies, in the context of curricular development and reform advocated by Hurd (1986) and Linn (1986), that are designed to improve science teaching through research. Our existing knowledge must serve as a basis for practical improvements in science education, as well as the foundation for needed innovations in science education. In spite of all of our progress, more needs to be accomplished.

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1.0 TEACHING AND THE TEACHER

This section deals with research on the teacher and the process of teaching. In discussing these topics we will use an idea established by Fenstermacher (1986), that is ". . . a central task of teaching is to enable the student to perform the tasks of learning (p. 39)." The emphasis in this view is on the teacher as coach not necessarily content expert and learning as the student's improved ". . . abilities and capacities to be a student (p.39)." The teacher's task, then, is to help students acquire "studenting" skills, select material to be studied, adapt material to the level of the student, create conditions conducive to studenting, monitor student progress, and serve as a source of knowledge and skill.

Studies regarding **Te[illegible]g and the Teacher** have been categorized as follows:

1.1 Teacher Per[illegible] and Attitudes
1.2 Teacher Prac[illegible] and Patterns
1.3 Teacher Prepa[illegible]ion and Performance

Included in section 1.1 are studies designed to find out how teachers view different issues--the role of science in the curriculum, the use of computers and hands-on laboratories, and what research is needed about teaching and learning. Section 1.2 focuses on studies regarding teacher practices--the factors that influence their decisions and in what ways instructional materials are used. Studies in Section 1.3 deal with teacher characteristics--what is the teachers' level of understanding of teaching and science, how teachers can be more effective, and what characterizes exemplary teaching.

Research on teaching and the teacher continues to take on added importance in reviews as more attention is being focused on what makes teachers exemplary and as more teachers take an interest in professional growth and development. Recent funding of workshops to enhance teacher understanding of science and teaching and to improve teaching skills is placing greater emphasis on teacher effectiveness research. It is likely that research in this area will continue to flourish as still more funds become available for inservice workshops.

1.1 Teacher Perceptions and Attitudes

How teachers view their role in the classroom, the place of science in the curriculum, and the use of various instructional materials and strategies is critical. If the "golden age" of science curriculum reform in the post-Sputnik era held any lesson, it was that there is no such thing as a teacher-proof program. The teacher is key to what happens in the science classroom and the teacher's attitudes and perceptions and/or abilities and skills greatly influence decisions made. The papers reviewed in this section focus on teacher views of selected issues and practices.

1.11 How do teachers view the nature of science and the role of science in the curriculum?

Teacher perceptions of science and its role in the curriculum have been studied regularly for about the last ten years. The question is whether or not teacher perceptions are changing. **Schoeneberger and Russell** conducted two case studies of science teaching at the elementary school level in Canada to learn more about the beliefs teachers held and decisions they made with regard to science. Investigators visited the two schools twice a week from September through January where they observed classes and interviewed students and teachers. Their results echo those of Weiss (1978) and others who have conducted similar investigations--teachers reported feeling unprepared to teach science, felt they had inadequate time and facilities to do the job, but viewed the situation as tolerable considering the greater importance of such curricular areas as reading, language arts, and mathematics.

In a study of prospective teachers' understanding of the nature of science, **Anderson, Harty & Samuel** compared the responses of a group of 1969 preservice secondary science teachers (N=24) on the "Nature of Science Scale" (NOSS) to a similar group in 1984 (N=21). The 1984 group responded more in agreement with the "Model Response" pattern described by Kimball (1967) than did the 1969 group suggesting that science teaching programs may be attracting students with a better understanding of the nature of science than was the case in 1969. The authors suggested that preparation of preservice science teachers in the philosophy of science is also advised to ensure greater understanding of the nature of science.

Lederman and **Lederman & Zeidler** studied 18 high school biology teachers to assess exactly what students and teachers understand about the nature of science and to compare their "understanding" to the notion of an "adequate conception." The 18 teachers and their 409 students were randomly selected from nine New York schools and given the "Nature of Scientific Knowledge Scale" (NSKS) at the beginning and at the end of a school year. They found that teachers scored higher than students on every scale and that students scored higher than "neutral" on each scale, although there was no significant change in the scores over the school year. They concluded that both teachers and students possessed "adequate conceptions" of the nature of science--a conclusion which contradicts much of what has been written about teachers' and students' ideas about science. But they do point out that simply possessing adequate conceptions of the nature of science does not ensure that teachers will exhibit teaching behaviors which will increase students' understanding.

This gap between perception (what teachers think they understand in theory) and practice (what teachers do in the classroom) appears in another context in a study by **Karnphanit**. In this study, science teachers in the Udornthani Province of Thailand involved in the implementation of an "inquiry-based" program were tested on their understanding of inquiry teaching and were observed in the classroom. While teachers seemed knowledgeable about the elements of inquiry teaching on the test, observations showed that little or no inquiry teaching was actually taking place. Cultural factors similar to those observed by Gremli (1985) may have been at play in the case of the implementation project in Thailand or the incongruence may be just one more instance of the theory-to-practice gap discussed by Lederman in connection with the teachers' apparent understanding of the nature of science and the inconsistent behaviors they exhibit.

Research by **Koballa** (a) on teacher attitude and hands-on teaching provides support for Lederman's observation. In a study related to prospective elementary teachers' attitudes, subjective norms, and intentions to teach hands-on activities at least twice a week during their first year of teaching, Koballa found that simply measuring attitudes toward science cannot adequately predict nor provide a satisfactory explanation of the teaching behaviors teachers are likely to use in the classroom. Building on the work of Fishbein & Ajzen (1975) and Ajzen & Fishbein (1977, 1980), he argues for incorporating the "degree of correspondence between elements comprising the attitudinal and behavioral variables" (making sure that the predictor and the outcome are specified at the same level) in predicting what teachers might do in the classroom.

Related to this notion of "correspondence" is what **Koballa** (b) refers to as "cognitive response" in his study of teacher attitudes toward energy conservation. In a study to test the effect of self-generated arguments on the salience of a two-sided persuasive communication, he found that maintaining favorable arguments presented in a communication in memory by subvocally rehearsing them is no more likely to enhance the effectiveness of the communication than listing thoughts generated as a result of listening to the communication even though the persuasive techniques did improve participants' attitudes. He suggests that the critical element in the persuasive situation is the participant's acceptance of the content (cognitive response) not simply the maintenance of the communication's content in memory.

The implementation and evaluation efforts described by **Kyle, Bonnstetter, Gadsden, McCloskey, Fults & Shymansky** appear to lend support for Koballa's suggestion. **Bonnstetter & Kyle** conducted a two year longitudinal study to assess and analyze the attitudes of first- and second-year SCIIS teachers who had received extensive inservice education as compared to teachers in non-SCIIS classes who had received no district supported science inservice education. They discovered that SCIIS and non-SCIIS teachers possessed similar entering behaviors and perceptions of science. The perceptions of teachers who received inservice education were not significantly enhanced over the two year implementation process. However, the attitudes of students in the first- and second-year SCIIS classes were enhanced significantly when compared to non-SCIIS students. Thus, the data appear to suggest that the nature of process-approach science, in conjunction with a well articulated inservice education program, enables teachers to portray a much more positive and exciting image of science and scientists. The teachers may have cognitively accepted the content of the curriculum and their role as process science teachers. This is apparently far more important than merely enhancing the attitudes toward science of elementary teachers.

Kyle & Shymansky reported on classroom observations that were conducted as part of the implementation and evaluation process. The SCIIS teachers spent a greater percentage of their time working with individual students and groups of students engaged with manipulatives as compared to non-SCIIS teachers who spent over half of their instructional time presenting information to the entire class. It is also interesting to note that non-SCIIS teachers devoted a significantly greater percentage of time to administrative and procedural tasks--an important finding since the initial reluctance of many teachers to teaching process science is the amount of classroom time that it takes to do the job. With appropriate inservice addressing teachers' concerns, such issues can be resolved. The report by **Kyle et al.** addresses the need for administrative support and provides the model used in Richardson, Texas.

1.12 What do teachers perceive as the role of the laboratory and the computer in science curriculum?

In the first edition of NSTA's **What Research Says to the Science Teacher**, Bates (1978) review of research on the effectiveness of laboratory activity on student performance suggested that increased hands-on activity does not promote increased student achievement. In contrast, the meta-analysis by Shymansky, Kyle, & Alport (1983) suggested just the opposite. The question of how effective laboratories and other special experiences really are continues to interest the science education community.

Hounshell questioned 358 science teachers in North Carolina about their use of laboratory activities. Of the 196 teachers who replied to the questionnaire, 80% felt labs were effective in increasing student process skills, enhancing knowledge, and positively influencing attitudes. But about half the teachers reported that discipline problems increased during lab time and most mentioned problems with obtaining adequate funding for the labs.

Underwood surveyed 234 Tennessee biology teachers to determine their views of the purpose of laboratory activities and to check their practice against their perceptions. Teachers were asked to rank the instructional functions of the lab and give an estimate of the time allocated to various lab activities in the survey. The analysis of rankings revealed a disparity between what the teachers said was important in labs and how they allocated time. While most teachers said process skill development was the most important function of the lab, the majority of teachers devoted more time to knowledge acquisition. Underwood's results suggest that teachers may see what should be done but may not possess the teaching skills necessary to create the desired effect.

Tobin investigated the nature of secondary science laboratory activities in the classrooms of 15 teachers in two Western Australia schools. The majority of the teachers indicated that laboratory activities are an effective means of learning science. However, laboratory activities were not presented on a regular basis in most classes and they appeared to have low status compared to activities that emphasized science content. The laboratory activities were of a cookbook type with most emphasis being directed to data collecting. Few opportunities were provided for students to plan investigations or to interpret data. He noted that the amount of time scheduled for laboratory activities was dependent upon the topic being taught, the ability of the students, the presence of disruptive students, the use of non-science classrooms, the size of the class, and a perception of insufficient time because of the amount of content to cover. Thus, the results of this study indicate that although teachers appeared to value laboratory activities, they did not implement them in a manner that facilitated the type of learning that was planned. He recommended that teacher education programs focus on designing and implementing laboratory investigations in order to facilitate specified learning outcomes.

Just as the laboratory has been consistently viewed as important but not always utilized effectively, there is concern about the perceptions and practices of teachers regarding the use of computers in the science classroom. **Gaglia** surveyed 212 teachers from 18 Southern California secondary schools regarding their perceptions of the role of computers in the science classroom. He found that non-users were not convinced that computers could save time or enhance student learning even though they did not see computers as dehumanizing the classroom. Not surprisingly, he also found that non-users tended to be intimidated by the "black box."

Overcoming the fears and anxiety of using computers in the classroom was the focus of a study by **Chapline and Turkel.** Working with 73 female preservice elementary teachers, they found that as few as 15 hours work with computers in a low-structure ("try it and see"), high-reinforcement setting resulted in reduced levels of "micro phobia" and in an increased tendency to use computers in the classroom. Interviews with participants six months later indicated that the positive attitudes persisted.

1.13 What research questions do teachers want answered?

There has been an increased emphasis on translating research into classroom practice in recent years. Teachers are hungry for things that have been shown to "work" in the classroom. But as much as there have been calls for translations of research, teachers have expressed a desire to get involved in setting the research agenda and actually doing classroom research. **Gabel, Samuel, Helgeson, Novak, & Butzow** and **Butzow & Gabel** surveyed 370 high school science teachers to determine their research interests. Results revealed that teachers seem to be more interested in research on "symptoms" of science teaching problems than on "causes" of the problems. For example, teachers rated highly research on <u>how</u> to motivate students, enhance problem solving, increase laboratory effectiveness, and ensure success in college science courses but saw research on <u>why</u> students have difficulty acquiring science as unimportant. The authors suggest that teachers may not be acquiring a theoretical foundation in learning theory and teaching methodology that would permit them to understand why students perform the way they do. The authors further contend that science educators must either modify their own research agenda toward applied research or change the preservice and inservice science education curriculum to stress the theoretical if there is any hope of having teachers use research in their teaching.

It is difficult to draw generalizations about the studies of teacher attitudes and perceptions reviewed in this section; each study has special strengths and features which merit closer examination. However, it is apparent from several studies reviewed that teacher practices are often not consistent with teacher beliefs. This suggests that studies of teacher attitudes and perceptions without accompanying studies of what teachers do in the classroom may result in serious misconceptions about the state of science teaching. It may be expedient to "survey" teachers regarding teaching practices, but it is probably necessary to "see first-hand" what is actually going on in the classroom if research is to yield any meaningful changes in practice.

1.2 Teacher Practices and Patterns

In the previous section we reviewed studies that focused on how teachers view science, the role of science in the curriculum, and special elements of the science curriculum. In this section we will review studies that address teacher practices--what they actually do in the classroom. Specifically, studies reported in 1986 have been grouped into two categories: general factors that influence science teaching; and the use and influence of microcomputers in the science classroom.

1.21 What are the factors and conditions that influence science teaching practices?

Crocker and Banfield surveyed 2052 fifth, ninth, and twelfth grade teachers in Canada to study the sources of influence on teacher judgments about school characteristics, features of the classroom and properties of a science curriculum. The instrument used in the survey consisted of "policy capturing scenarios" followed by a series of questions dealing with instructional practices, teacher characteristics, and levels of decision making. Teachers were presented with a three-part scenario based on a hypothetical move to a new school (as a result of the closing of their present school). Systematic variations in components of the scenario were created to permit investigation of the impact of different sources of influence on the teacher. Results of the study suggest that the functional paradigms of science teachers are grounded in concerns for students, for strong school spirit and morale, and for teaching methods. While teachers see themselves as desiring more of a role in curriculum development and related areas, the investigators found no strong desire in the teachers individually to define their jobs to include greater responsibility for the curriculum.

There is the opinion among science educators that teachers often act intuitively and are resistant to methods that call for ongoing, systematic assessment of conditions and factors which may affect instructional outcomes. **Hodson** surveyed 105 science department heads in schools in northwest England to test this supposition and to see if the work of the "Schools Council" and "Nuffield Foundation" had led to more systematic and sophisticated procedures in schools. He found that 82% of the heads surveyed rarely (if at all) utilized any systematic means for judging the effectiveness of their teaching materials or methods. Moreover, two-thirds of those surveyed regarded as unimportant the identification through systematic means of inadequate methods and materials. Hodson suggested that a major inservice effort will be required to re-educate teachers on the need for systematic assessment procedures.

Teachers frequently cite lack of funds and facilities as reasons for teaching as they do and not as they'd like. Whether this explains the tendencies for teachers to act impulsively and intuitively as Hodson observed is questionable. However, surveys seem to show consistently that teachers cite inadequate supplies and facilities as well as lack of time to prepare as reasons for not approaching teaching and curriculum planning more systematically. For example, in a survey of public and private schools in New Jersey, **Hull & Sousa** found increases in student enrollments in science courses but frustration among supervisors regarding curriculum development. Apparently increases in state science requirements have not led to increased funding of new programs to meet the demands. **Petrella** observed similar problems of inadequate time and funds to develop high quality programs when she surveyed teachers in Massachusetts.

Studies of teacher decision-making seem doomed to inconclusive results as long as teachers perceive there is inadequate support to do an effective job. If we want to find out the extent to which teachers are capable of and actually practice purposeful teaching, research time might be better spent studying instances where the support issue is not a limiting factor. Some of the work on "exemplary" programs discussed in a later section of this review has the potential to reveal some useful data along these lines.

1.22 How are microcomputers used in the science classroom?

It is generally acknowledged that advances in microcomputer technologies have outpaced software development and teacher education regarding their use in the classroom. It seems that the microcomputer and the science laboratory were made for each other. As **Bross** points out, "...the microcomputer as a measuring instrument [is] an extremely accurate, fast, and relentless tool [and] in addition to collecting data, it can be used to process data, in almost any form, in practically no time" (p. 16). Yet, research on the use of microcomputers in science has only recently begun to flourish in the science education community.

Recognizing that the number of teachers using microcomputers for instructional purposes is small to date, **Shavelson, Winkler, Stasz, Feibel, Robin, & Shama** set out to identify the patterns of microcomputer use among "successful" science teachers in California. The teachers studied were selected by their peers and interviewed and observed by the research team. Perhaps the most significant finding of the study was that the successful teachers were difficult to find in the classroom--most have left the classroom to assume positions as computer coordinators for a school district or to work with a software development company. Of those "successful" teachers who could be found in the classroom, most seemed to use drill and practice programs almost exclusively with minority and/or low ability students but were likely to expand the number of options when high ability students or a low percentage of minority students was involved.

The Shavelson, et. al. results are probably not surprising when the profile of available software is examined. **Caprio & Brown** reviewed 779 catalog software entries and found 73% related to the physical sciences and only about 23% were suitable for the non-college bound science student. Fifty-two percent of the programs cataloged were of the drill and practice type, 28% were considered problem solving, and 15% were classified as simulations.

The drill and practice function of microcomputers is tho role that has been explored most extensively in the science classroom despite its simulation, programming, data analysis, and data display potential. But as **Tamir** cautions in his analysis of uses of the microcomputer in science classrooms, in the rush to create new simulations and complex programs which tap the power of the computer, there is the risk that the programs may end up relieving students of the very decision-making responsibilities that are most critically made by them.

How do students react toward the computer? **Enochs** surveyed 512 middle school students from a school district bordering a large metropolitan area to determine their attitude toward computers. The general attitude of the students was moderately high, with no differences between boys and girls or between grade levels. But he did find that students from homes with microcomputers were significantly more positive towards them. **Chamberlin**, however, found that students in a community college biology course using the Keller "personalized system of instruction" preferred human proctoring over computerized proctoring even though achievement was not found to be adversely affected by the computerized proctoring.

Not only do students seem favorably disposed toward computers, student performance is sometimes positively affected in unpredictable ways. For example, **O'Brien & Pizzini** found that when students attending a summer science training program used a word-processing system in preparing reports of their projects, their reports were rated higher on scientific merit than reports prepared by conventional methods. They attributed the higher quality to the ease with which students could organize and revise reports; students are more likely to strive for quality in the science when the mechanics of preparing the report are reduced.

In a different application of the organization capability of micro-systems, **Callman, Faletti, & Fisher** developed and analyzed a computer-based semantic network of biology knowledge in which the user is able to generate concept maps and see where bridges can be built between biological concepts. The system uses a Macintosh and a newly developed set of software called "Filevision."

Good observed a small group of fifth and ninth grade students using a set of programs dealing with the "intelligence" of small creatures generated with attractive graphics by a software package. In the programs students were challenged to figure out the movements of the various creatures in an attempt to study the learning habits (intelligence) of the creatures. From

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his observations of students working on controlling parameters, keeping records, and dealing with elements of randomness and chance, he concluded that such programs could be used as sources of data for student experimentation and as supplements to first-hand laboratory activities.

Software dealing in specific concept development and acquisition continued to be explored and reported in the literature in 1986. **Venugopalan** (a,b) and **Touvelle & Venugopalan**, for example, described the development of several pieces of software related to experiments on enthalpy of vaporization, partial molal volume, and activation energy.

Although software targeting specific concepts and laboratory activities will no doubt continue to be developed (there are currently about 600 software vendors), **Klopfer** contends that "intelligent tutoring systems" are on the horizon and will revolutionize computer applications in the science classroom. In his article he discusses data obtained through an NSTA task force survey of 1479 teachers from 193 schools. The survey showed that only 6% of the respondents used microcomputers regularly (at least one hour per class per week) and that low quality software was cited most often as the reason for not using computers more. Klopfer expressed optimism, however, that intelligent tutoring systems such as "Electricity Tutor" and "Eureka World Tutor" under development would provide the individualized, complete tutoring that current programs fail to do.

In each of the papers reviewed, authors consistently mentioned the need for programs for preservice and inservice education on the selection and use of computer hardware and software. The problem is especially critical at the inservice level since half the practicing teachers were prepared about 20 years ago--long before the advent of microcomputers--and these same teachers will be around for another 20 years making decisions affecting science curricula. Research on computer utilization, software development, and teacher computer education is sorely needed if we hope to be in a position to benefit from the advances in technology which are sure to continue.

1.3 Teacher Preparation and Performance.

Who are the science teachers? How are they prepared? What characterizes the best teachers and their programs? These are some of the questions addressed in this section. Specifically, we found research which deals with what skills science teachers possess, how they come to acquire those skills, and how they use those skills in the classroom. This research focuses on both the knowledge science teachers possess (about science and teaching) and the strategies they use to <u>enable</u> students to take hold of new knowledge and skills.

1.31 What factors explain science teaching competence?

Progress in preservice and inservice teacher education depends upon identification of factors which contribute to effective teaching. Controversy continues regarding the proper balance of content and method in teacher education. Researchers in 1986 studied various teacher characteristics (e.g., knowledge about teaching methods and teacher misconceptions), from different points of view (i.e., teachers, supervisors, and educators) using various strategies (including case studies and survey techniques).

Tulloch surveyed 250 science supervisors, 250 science educators, and 500 secondary science teachers regarding the repertoires of competencies within which the growth of a novice teacher was perceived as important to effective science teaching. Factor analysis of data of the 300 who responded to the survey showed "attending to the mechanics of teacher-centered instruction," "showing sensitivity to pupils' feelings and values," "showing enthusiasm and spontaneity when working with pupils," and "planning the instructional program" accounted for the greatest percentages of the total variance. Tulloch attributes these results to the recent emphasis upon development of technical skills in planning instruction and the need to sensitize preservice interns to classroom dynamics. Interestingly, however, teachers and supervisors did not perceive scientific reasoning and the multidisciplinary nature of science (STS) as nearly as important a contributor to effective science teaching when compared to science educators.

Helping novices plan the mechanics of instruction, however, may be more attractive in theory than in practice. In the case study of a student teacher, **Russell** observed a cooperating teacher who refused to use techniques to provide systematic feedback on the student teacher's use of "active teaching behaviors" or on levels of student "academic learning time" even though the student teacher found both very relevant and instructive. Russell was at a loss to explain the cooperating teacher's resistance since the person agreed to participate in the study and did learn the techniques.

While Tulloch's study of science educators in the United States clearly shows an emphasis on the importance of teaching methods, **Mittal** and **Matar** in studies of teachers, supervisors, and teacher trainers in India and Bahrain, respectively, found teacher knowledge of subject matter placed as the highest priority in the science teacher's repertoire.

When attention is focused on the competencies of persons who serve as science specialists, a slightly different picture emerges. For example, O'Neill found, in a study of 164 Georgia schools, that high school principals and science department heads believed that human relations skills were most important while specialists themselves believed that technical competencies were most important and content knowledge was least important. This study did not include classroom science teachers, but in another study, **Hollis-Melton** found that teachers preferred a coordinator's "stimulation and assistance" rather than his/her evaluation; need for content knowledge from the specialist was not mentioned as critical by teachers, specialists, or administrators in the Hollis-Melton study.

Teacher content knowledge may not be perceived as the critical determinant of effective teaching by teachers, supervisors, administrators, or selected science educators, but it has attracted significant attention among researchers. For example, **Lawrenz** uncovered serious misconceptions in

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selected physical science topics among 333 Arizona elementary teachers and **Ameh & Gunstone** observed similar deficiencies among secondary science teacher trainees in Australia. In a study of preservice elementary science students, **Stepans & McCormack** further observed that additional work in traditional science courses and better understanding of basic science concepts were not correlated among the sample studied.

The relationship between teacher subject matter and knowledge and teaching strategy was studied independently by **Hashweh** and **Okafor,** using different approaches. Using a planning activity in which teachers had to transform a written curriculum into an enacted strategy and simulated interactive teaching episodes, **Hashweh** found that both teacher concept knowledge and views of learning were related to strategy with the teachers holding a conceptual change view of teaching and adequate conceptions of target science topics exhibiting a greater variety of teaching strategies for inducing conceptual change in students. **Okafor** studied preservice biology teachers' knowledge of subject matter, ability to organize information in memory, and their classroom communication structure (called "kinetic structure"). She found that the teachers' serial information processing ability was significantly positively correlated to one of the measured classroom communication structure variables. She suggested that a teacher's sequential teaching structure may be enhanced by improving that teacher's ability to process information serially.

It is clear from the research reviewed that much work remains to be done regarding the factors describing teacher competence and predicting teacher effectiveness. Recent work on conceptual schemes and alternative frameworks (misconceptions) may be the perspective needed to bring researchers from the content and method schools of thought to a productive union of interests.

1.32 How do preservice and inservice programs impact science teachers and teaching?

Numerous strategies have been employed in teacher preservice and inservice programs over the years to affect teacher education--the study of and/or practice of methods related to instruction. **Yeany & Padilla,** in their meta-analysis of teacher training research, provide a set of labels describing various approaches for training preservice and inservice teachers in the use of specific strategies. They identified five types of training programs in the research literature: "study of an analysis system" involving study of an observation system; "observing models" where candidates view exemplars of effective teaching strategies; "analyzing models" with the emphasis on analyzing what happens in various classroom settings; "self analysis" in which candidates review tapes of their own teaching; and "peer or instructor feedback" where second party observations are shared with the candidate. To rate the various training programs, Yeany and Padilla created an "index of effectiveness" in which the aggregate effect of studies using candidate self analysis was set at 1. Using this approach they found that programs incorporating a combination of "practice-analysis-feedback" was more than three times as effective as "self analysis" in effecting change in teaching behavior.

The Yeany-Padilla results are noteworthy in that their emphasis was on systematic study and analysis of teaching in various settings, not on traditional "field experiences" versus "methods courses" per se. The importance of systematic study is in contrast to the widespread notion that field experiences of any kind are more effective than methods courses. The study by **Strawitz & Malone** provides further support that field experiences without attention to systematic analysis may not be effective. They were interested in finding out if a field experience component of an undergraduate science methods course could effect a shift in student concerns about teaching science from "concerns about self" to "concerns about management and the impact of inquiry-oriented science." Results from the "Teacher Concerns Questionnaire" indicated that no significant shift occurred.

The impact of specified feedback was studied by **Barlow** as part of a larger investigation to determine what changes in students' perceptions of teaching occur in the course of a semester. In a study of teaching assistants in college biology, he found that assistants' overall perceptions of their teaching improved during a semester in which personal feedback was given.

Several studies dealing with the impact of specific training program components were reported in 1986. **Samuel** investigated the effect of a three semester field-oriented science methods course compared to a conventional one semester, three hour campus-based course on preservice teachers' pupil control ideology and locus of control. The results revealed that the field-based teachers exhibited a more humanistic pupil control ideology and a greater internal locus of control than did the campus-based group.

Scharmann studied the effectiveness of three instructional strategies differing in their respective emphasis on science content, teaching methods, and process science to predict an understanding of the nature of science. One hundred thirty-five preservice elementary teachers were tested at the end of three different sequences of science and methods coursework reflecting the different emphases. A sample of 29 preservice teachers, assessed prior to entry in the instructional sequences, provided a cross-section for examining developmental changes in locus of control, logical thinking, understanding of the nature of science, and understanding of process science instruction. Results revealed that the understanding of the nature of science was most predictable for students with high internal locus of control who participated in the separate process, content and methods courses.

Mason studied the impact of a workshop designed to encourage inservice teachers to create gender-free learning environments in high school biology classes. The workshop's efficacy was determined by comparing the performance of students in the classrooms of workshop participants to that of students in a sample of control classrooms. Results indicated that students in the workshop teachers' classrooms scored significantly higher on tests of attitudes, perceptions, extracurricular activities, and interest in a science-related career. Similar positive results with workshops designed to

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help teachers create gender-free science classroom environments were found by **Parker & Remmie.**

Using research to get teachers to change attitudes and practices or to examine new ideas about teaching has become increasingly popular among science educators. **Koballa** (c) studied the effect of anecdotal and data-summary persuasive communications on preservice teachers' attitudes toward supplementing science programs with SCIS or SAPA activities. He found there was substantial increase in the mean attitude scores of participants using both sets of communications, but that the anecdotal form, showing less dissipation across the three-week testing period, was more effective than the data-based form.

The potential of using research to influence teacher attitudes and practices is dependent upon the availability of research to preservice and inservice teachers, however. In surveying 56 teacher preparation programs in the New England states for NSTA, **Barrow** found library resources pertaining to science education and educational research severely lacking. Though K-12 schools were not included in the survey, it is likely that most of these school libraries or teacher resource centers contain far less than the post-secondary institutions. Perhaps it is in this area of access to current research that some of the newly created computer networks such as the Council of State Science Supervisors' "PSI-NET" will have the greatest impact and payoff.

What kind of impact has the computer had in effecting changes in teacher preservice and inservice science education? Two reports related to the topic were published in 1986. **Lehman** surveyed the faculty at 400 colleges and universities in the United States to determine the extent to which the computer is utilized in science teacher training. A majority (70%) of the 200 respondents indicated that microcomputer opportunities are provided for education students; however, relatively few (25%) indicated that they require computer courses for certification or had courses specifically designed for science teachers and even fewer (6%) provided any kind of experiences related to the use of computers in the classroom.

Baird (see also **Baird & Koballa**) assessed the effect of group size and mode of presentation on the acquisition of the science process skill of forming and testing hypotheses among 87 preservice elementary teachers. The study showed strong aptitude-treatment interactions between group size and mode of presentation and initial hypothesizing and reasoning skills as might be expected. But more important, individuals who participated in cooperative learning groups rated their experience as more successful and the computer programs as more useful than individuals who worked alone.

Interestingly, we found no studies in which preservice or inservice teachers used the computer as an adjunct in a program of personal growth or development, e.g., as a diagnostic aid. Nor did we find any studies of teaching simulations even though early efforts in this area began more than 10 years ago. Perhaps science educators are waiting for video-disc technology to be refined and made less expensive before more applications to teacher education are explored. Clearly the video-disc provides greater

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power for such things as simulations. But it might be more profitable to utilize the technologies that the teachers have at their disposal now rather than take the "wait-and-see" attitude. And that means building teacher enhancement activities for the microcomputer.

1.33 What are some factors in motivating and retaining science teachers?

We have seen in recent years a dramatic increase in state and federal funding of workshops designed to enhance teachers' science background and skills and to attract new talent to the ranks of teaching. Though the number of funded programs is still far short of the sixties and early seventies, reports such as the National Commission of Excellence, **A Nation at Risk** (1983) and the National Science Board Commission on Precollege Education, **Educating Americans for the 21st Century** (1983) make it clear that we cannot afford to let inservicing efforts lapse or ignore problems of teacher supply. This section describes the results of two reports published in 1986 dealing with issues of teacher retention and enhancement.

Hendrix & Mertens collected data relating to questions of teacher motivation and professional growth from teachers attending an NSF-funded workshop on human genetics and bioethical issues. In response to questions posed by the workshop staff, 32 of the 40 teachers listed higher pay among the top three ways to attract and retain qualified science teachers. Second on their lists was the opportunity for professional growth. When asked how teacher work environments could be improved, a significant percentage of the teachers suggested that school board members need to be educated regarding the goals and needs of contemporary science education programs.

Beal, Olstad, & Harder surveyed science officers in the fifty states and the District of Columbia regarding incentive programs instituted as a result of existing and predicted science teacher shortages. The survey sought information regarding the kinds of incentives offered, the amount of money involved, the number of persons participating, the eligibility requirements of the programs, the number of subject areas targeted, the future of the programs, and evaluation data. Based on a 98% return rate, the investigators found 31 states offering incentive programs in science and mathematics, with most states offering low interest or forgiveness loan programs. For the 34 states reporting actual funding data, the survey showed that 28 million dollars were spent on incentive programs between 1983 and 1986. In that same period, 7000 persons received incentive funds in 43 of the states reporting such data. Most state officers reported that the programs would likely continue in 1986-87; however, most had not completed evaluations of the programs in the first two years.

The identification of higher pay as a critical factor in the motivation and retention of science teachers is not surprising; it is a basic variable in a supply and demand equation and one with which every teacher group and school board will continue to struggle. But as states and local school districts implement improved salary scales, the identified need for professional growth may become the more critical factor in the near future if it has not already become the primary concern of teachers today. With the median age of science teachers creeping slowly toward the mid-40 range, activities to rekindle teacher interest in teaching will be needed. This thirst for professional growth and involvement is evident in recent registrations at NSTA regional and national meetings and in the response to such NSTA publications as the Focus on Excellence series and programs such as NSTA's Every Teacher a Researcher. We found no research in 1986 dealing specifically with the impact of professional growth activities on teacher performance or attitude. But, if teaching is to mature as a profession, such research will be critical.

1.4 Summary

In this section we reviewed the research on the teacher in the science classroom. Included were studies of teacher perceptions and attitudes, practices and patterns, and preparation and performance. We will not attempt to generalize across studies, since such generalizations are probably not meaningful. But some observations seem in order.

The first thing any comprehensive review of research reveals is the profile of activity--what is being emphasized at that point in time by the research community. Granted, this profile is about two to three years out of date when one considers the lag between research conception and execution and publication. But a review such as this does give a reasonable look at the lay of the land. Looking at the landscape of research focused on the science teacher, no one area jumps out as the clear leader for papers published in 1986. This may not be surprising to most nor appear to be a problem. But we feel the low number of studies dealing with science teacher preparation (preservice and inservice) and characteristics of exemplary science teachers is cause for concern.

Right now science education is again on the upswing; funds are available to develop new science curricula and to enhance teacher knowledge and skills. We must be careful not to get caught up in the flurry of teacher workshops and curriculum development at the expense of research. Budgets for research often get spread thin as funding agencies and/or school administrators try to manage both the main workshop or development activities and do the research. One solution to this problem is to negotiate local support for the unfunded research activities and to involve colleagues. The research gleaned from training and development activities is likely to have a far greater long-term impact than the activity for which the funds were actually received!

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2.0 LEARNING AND THE LEARNER

This section synthesizes research about the nature of learning and characteristics of the learner. A central purpose of education is to improve students' reasoning abilities. It is reasonable, then, that a considerable amount of researcher time and effort has been devoted to investigating how students acquire information, ideas, skills, values, ways of thinking, and means of expressing themselves. An understanding of the nature of learning is necessary in order to ensure that students are being provided with appropriate instruction. After all, the most important outcome of the process of schooling may be the students' increased ability to learn more easily and effectively in the future. It is, therefore, imperative that we understand characteristics of the learner as well. Thus, while the nature of the learning process and the characteristics that the learners bring to that process influences instruction, how teaching is conducted has a major influence on the learners' ability to function in society.

Studies regarding **The Nature of Learning** (Section 2.1) have been categorized as follows:

2.11 The Developing Intellect
2.12 Information Processing/Problem Solving
2.13 Learning from Presentations
2.14 Conceptual Frameworks and Misconceptions

Studies describing **Characteristics of the Learner** (Section 2.2) have been categorized by grade level as follows:

2.21 Elementary Students
2.22 Middle School/Junior High Students
2.23 High School Students
2.24 Post-secondary Students

Research on the nature of learning and characteristics of the learner appears to be changing focus. Many of the studies have their underpinnings with major philosophical and/or psychological orientations toward teaching and learning. However, a number of studies are correlated to the changing social context of science education in the 1980s. Thus, some research endeavors may be difficult to categorize in the years to come until the goals for science education are clearly redefined and broadened to reflect new knowledge, technological advances, and societal needs.

2.1 The Nature of Learning

In the preceding section, we cited Fenstermacher's (1986) notion that the purpose of teaching is to provide students with the necessary skills to be able to perform the tasks of learning. Joyce and Weil (1986) have described many powerful models of teaching designed to bring about particular kinds of learning and to help students become more effective learners. In essence, the models of teaching that are described by Joyce and Weil are about models of learning. The research reviewed in this section investigates models of learning as they relate to the nature of learning.

2.11 The Developing Intellect: Can schools work in harmony with this development?

Lawson (1985) notes that interest in developmental theory among science educators has arisen primarily from the conviction that schools must do more than teach collections of facts and discipline-specific concepts. This conviction should be more true today than in any time in our history. Schools must help students acquire thinking skills. Education must prepare students to be lifelong learners. Linn (1986) cites the imperative for the process of schooling to prepare citizens who can absorb and adapt to new information, reflect on the nature and quality of their own reasoning, and adjust their thinking accordingly. For these reasons, studies regarding the development of the ability to think offer important insights into how schools can be more effective in working in harmony with this development.

Frenkel & Strauss sought to determine how students at different ages understand the concept of temperature. They were particularly interested in the logico-mathematical aspects of the concept. Three developmental approaches were compared: Piaget's structuralist approach; Siegler's rule assessment approach; and, Anderson and Wilkening's functional measurement approach. The subjects for this study were 96 middle class Israeli children ages 4 to 11. The findings reveal that there are both commonalities and differences in the development of the concept of temperature across the three methodologies. In the Piaget and Siegler approach, development proceeds from focusing upon one variable, to attending to two variables without coordinating them, to attending to two variables and coordinating them. In the Anderson and Wilkening's approach, development proceeds from integrating two variables via integration rules of first addition, then subtraction, and finally division. Children who concentrate on one variable via Piaget's and Siegler's tasks integrate these variables via Anderson and Wilkening's tasks. The authors suggest that the latter two approaches may underestimate children's intellectual capacities.

Wavering, Perry, Kelsey & Birrd assessed the performance of 101 randomly selected students in grades six, nine, and twelve on five logical, spatial, and formal tasks. The authors used the following tasks: seriation matrix, tilt of the cone, location of a point in two and three dimensions, flexible rods, and projection of shadows. Each task was given in an individual interview. They were interested in assessing what the general level of performance was, whether there were any grade level differences, and whether there were any gender differences in task performance. Chi-square tests revealed grade level differences on the three concrete operational tasks (i.e., seriation matrix, tilt of the cone, and location of a point in two and three dimensions), but no grade level differences on the two formal operational tasks. Gender differences were noted for the tilt of the cone task, with males scoring higher than females at each grade level. The data indicate that a significant number of students, even at the twelfth grade, have not fully developed the concrete level mental structures for seriation. Further, few students at any grade level showed evidence of formal reasoning on either task administered. Thus, while teachers expect their students to complete activities that require complex reasoning processes, students may not possess the cognitive structures to do so. The authors indicate that the use of specific classroom tasks to develop diverse logical reasoning abilities would allow teachers to make more effective interventions in the learning process. The authors recommend the identification of reasoning sublevels coordinated with specific classroom activities to realize this goal.

Blurton hypothesized that student success or failure in science could be attributed, in part, to Piagetian development and M-level capacity. He assessed junior high students M-capacity, developmental level, field dependence-independence, and prior knowledge as they related to instruction in genetics. Classification as a formal reasoner did not enhance student performance on a genetics posttest, whereas students' prior knowledge about genetics provided them with a significant advantage. Developmental level, however, apparently contributed to the subjects' performance on the pre-test. Thus, the issue of whether student reasoning ability or prior knowledge could be used to predict student performance was not resolved. Additionally, subjects with M-capacities equal to or greater than six were not found to be advantaged in their ability to acquire formal reasoning strategies (i.e., proportional and combinatorial reasoning) when compared to subjects with M-capacities less than six. In fact, little learning was evidenced by any of the subjects. One might infer, as suggested by **Wavering et al.** above, that the students simply did not have the cognitive structures requisite for the nature of the instruction and that specific interventions would be necessary in order to ensure student acquisition of the concepts.

Yap and **Yeany, Yap & Padilla** sought to identify possible hierarchical relationships among Piagetian cognitive modes and integrated science process skills for the formal transitional and concrete reasoning levels. Ordering theoretical and probabilistic latent structure methods were used to analyze data on five process skills and six logical thinking skills collected from 741 students in grades 7 through 12. Both linear and branching hierarchical relationships were identified within and across the two sets of skills. Most of them fit the logical hierarchies that have guided curriculum development and classroom practice in the past. Conservation reasoning, combinatorial reasoning, and designing experiments form the base of the hierarchy. Students who have mastered these skills are more probable to be the ones to develop the next level skills: graphing and interpreting data, operationally defining, controlling variables, and proportional reasoning. Beyond the second level, several lines on prerequisite relationships can be traced. For example, proportional reasoning is prerequisite to probabilistic reasoning, which in turn is prerequisite to both correlational reasoning and identifying variables. Identifying variables has the most complex set of underlying prerequisite skills. In addition to having acquired probabilistic reasoning, most students who have the ability to identify variables have also acquired the skills of hypothesizing, graphing, and interpreting data, as well as operationally defining. It is apparent that the skills are inextricably entangled with the Piagetian modes of reasoning. Process skill based curricular activities need to be developed and presented with a structure that reflects the super- and sub-ordinate relationships of the skills. The assessment of students' needs to be carried out on a systematic and individual basis. The authors recommend that the entry level, as well as progress of students in relation to the skills must also be measured regularly to determine the status of the individual and to prescribe instruction responsive to task related prerequisite skills lacking in the student. Further, they suggest that researchers should use the measurement and statistical procedures that exist to establish the hierarchical relationships among the set of concepts and skills identified as those to be attained by a scientifically literate individual.

Lawson (a) hypothesized that subjects classified as formal operational, based upon use of proportional reasoning on the Pouring Water Task, have developed the ability to comprehend hypothetical-deductive arguments of the form referred to as "reasoning to a contradiction," while subjects classified as concrete operational based upon use of additive responses on the same task have not. A sample of 100 high school students, ages 14.9 to 19.1, was divided into two groups based upon their response to a water pouring task. Both groups of students were individually administered a version of the Wason Four-Card Problem with feedback when errors were made. Immediately following instruction all students were administered a logically isomorphic four-card problem within another context. A third version of the four-card problem was administered one month later. Results were generally supportive of the hypothesis. Most of the additive subjects failed the immediate and delayed posttest problems (62% and 80%, respectively); while most of the proportional subjects succeeded (80% and 71%, respectively). The results suggest that a general hypothetical-deductive reasoning competence exists in some adolescents and is applicable across a wide variety of task domains. Lawson recommends science instruction that aims to teach this competence.

Murphy assessed the formal operational thought of college preparatory chemistry students in an urban high school in northeastern Massachusetts. Her sample consisted of all students enrolled in such a course. The 63 students, 27 females and 36 males, were administered four science reasoning tasks. The study revealed that only 20.6% of the students were late formal operational for the pendulum task, 1.6% of the students were late formal operational for the equilibrium in balance task, and 3.2% of the students were late formal operational for the chemical combinations task and the flexible rods task. When task scores were averaged, none of the college preparatory students that were enrolled in college preparatory chemistry were formal operational. No significant differences were noted for gender or grade level. Since formal abilities of the type tested in this investigation are inherent in many chemistry competencies, one can infer that students encounter serious difficulties conceptualizing the formal concepts associated with college preparatory chemistry. Rumsey also confirmed that most high school chemistry students operate at the concrete level. He sought to identify the levels of difficulty encountered by 215 students on topics related to proportional thinking, as well as to discover to what extent student performance was dependent on performance on selected cognitive developmental tasks. Hierarchical analysis indicated that item difficulty was more dependent upon cognitive skills than on chemistry topic. Skills such as proportional reasoning and direct proportional reasoning with numbers other than small whole numbers, were dependent on first-order proportional reasoning as measured by subtests of the classification measures, but not on an overall formal operational classification. He concluded that chemistry teachers should integrate more concrete referents such as demonstrations and laboratory work, and that a spiral curriculum would also enhance student learning of chemistry topics that require formal skills.

Renner, Abraham & Birnie sought to determine if empirical evidence could be formed to support the existence of assimilation, disequilibrium, accommodation, and organization in learning of high school physics in the context of the last element of Piaget's model of intelligence-functioning (the Piagetian model of intelligence consists of the elements of content, mental structures, and mental functioning). While the Piagetian mental functioning model has been available for some time, empirical evidence that the model actually did or did not function was not available. In this investigation, teaching and curriculum development procedures were extracted from the mental functioning model and a twelfth grade high school physics course was so organized and taught. Naturalistic data collected from individual student interviews and in-class discussions were used to evaluate the hypothesis that mental functioning and the factors that compose it are integral parts of the learning process. The data support the Piagetian functioning model of learning. The data also demonstrate that the exploration phase of the learning cycle provides experiences leading to assimilation and disequilibrium. The conceptual invention phase leads to accommodation and the expansion-of-the-idea phase leads to organization. Thus, the learning cycle curriculum-organization plan and teaching procedure leads students to construct their own knowledge. An implication of the findings is that curricular materials and instructional strategies should be compatible with how students learn concepts.

The work of Piaget and others has had considerable impact on curricular issues such as, "When should selected topics or concepts be introduced into a student's education?" The area of classical genetics has not received much attention, however. **Smith** addressed the following questions: Is formal operational thought a sufficient condition to successful genetics problem solving? Is formal operational thought a necessary condition? Does formal operational thought augment problem solving success? Are the underlying principles of Mendelian genetics formal concepts, and if so, what specific formal reasoning skills are required? Nine undergraduate science and non-science majors who had recently completed their first college study of genetics and seven genetics graduate students and biology instructors were videotaped as they attempted to solve classical genetics problems. Data analysis revealed that formal thought does not appear to be a condition "sufficient" to determine success in solving genetics problems that require formal thought. Further, formal operational thought does not appear to be a necessary condition to success in solving genetics problems. The results of this study do, however, corroborate previous reports that suggest a positive correlation between cognitive development and genetics problem solving success.

Poduska & Phillips conducted an investigation to probe and extend Piaget's theory of the conception of speed. Specifically, the authors tested the hypothesis that there is no hierarchical relationship in performance on the following Piagetian-type tasks: conservation of distance, asymmetric series of speeds, one-to-many (circular) speeds, symmetric speeds, time, and proportional reasoning. They also investigated gender-related performance on each of the tasks. The sample was comprised of 100 freshman and sophomore community college students, enrolled in either college physics or a nonmathematical environmental science course. Fifty-four percent of the sample had completed a high school or college physics course at the time of the interviews. A scalogram analysis of the data revealed that the tasks form a unidimensional scale of increasing difficulty of the order listed above. Thus, there appears to be a certain sequence of development for thinking about speed phenomenon. Since there is no uniform program for teaching all students about the content of all tasks, it can be inferred that the ability to pass the tasks in a certain sequence is based upon intellectual development. Significant differences were noted on all speed tasks, with males performing better than females. There were no significant differences between males and females for the distance and time tasks. The results of this study provide insights into how physics concepts might be presented. That is, science courses should start with problems involving distance rather than speed, time, or proportional reasoning. This study indicates that students should be able to understand physical situations involving speed without being able to do proportional reasoning. Thus, teachers should not rely on the definition of speed as a ratio of distance/time. In light of such findings, topics should be presented in the order: distance, speed, time, and proportional reasoning. Such sequencing would correlate with the order of intellectual development and obviously requires a re-sequencing of the traditional introductory physics course.

Golbeck examined sex-related differences on Piagetian horizontality (water level) and verticality (plumb line) among 64 college undergraduate student volunteers enrolled in a course in human development. She hypothesized that females' difficulties on those Euclidean spatial problems are not due to differences in underlying spatial competence, but rather to differences in knowledge of task-specific information about the physical properties of water levels and plumb lines. Her findings support the hypothesis: when horizontality and verticality problems are presented in the traditional manner using physical content, males are more likely to succeed; however, when such problems are presented in a manner devoid of physical content, males and females are equally likely to demonstrate success. Thus, it is imperative for science educators to recognize the difference between underlying conceptual structure and specific task information. Failure to differentiate competence from performance deficiencies may lead teachers to lower their expectations for females' success.

The theories of Jean Piaget and William Perry provide two different theories of intellectual development with several similarities, but with critical differences. **Perry, Donovan, Kelsey, Paterson, Statkiewicz & Allen** compared the two theories to determine whether they describe operation of the same mental structures or two fundamentally different aspects of intellectual development. Participants in this investigation were selected from 200 undergraduate and graduate college students who responded to a written essay intended to provide a preliminary and approximate evaluation of their Perry position. From this group, 34 students were selected representing a range of Perry positions from dualistic to relativistic stages. Each of the 34 students was administered six Piagetian tasks. The low positive nature of the correlation of composite Piaget scores with Perry positions indicates that the two developmental schemes may not measure similar dimensions of development. Thus, perhaps a greater diversity of intellectual development exists than originally anticipated and previously reported. In light of these findings, one should recognize that instructional strategies that promote or foster maturation of one scheme may not be enhancing similar developmental progression in the other. That is, Piagetian based instruction alone does not address educating the "whole" individual. The authors recommend that future research designs should allow for investigation of multiple theories in order to provide a more accurate and complete profile of a student's development.

Research in developmental psychology and science education has contributed greatly to our understanding of students' nonsocial cognition and the formation of nonsocial cognitive structures. The discipline of science education is restructuring its goals from a focus on preprofessional training to a focus on educating an informed citizenry regarding the interrelationship of science, technology, and society. In addition to acquiring scientific concepts and process skills, such a curricular focus stresses the importance of decision making in science and technology related social issues. Fleming (a) notes that science curricula that focus on socio-scientific issues require as content both the knowledge of the physical world and knowledge of the social world. Thus, pedagogy in such curricula requires students to integrate knowledge from these two domains. It follows, then, that research should also be carried out to examine the nature of the interaction between these two domains.

Fleming (a) examined the nature of the interaction between knowledge of the physical world and knowledge of the social world. Rejecting Kohlberg's "necessary but not sufficient" argument that suggests that development in one domain is necessary for development in another domain, Fleming predicated his investigation on the assumption that socio-scientific issues are multidimensional and ambiguous. Thus, Turiel's theoretical model, that the development of social cognition is independent of the development of nonsocial cognitive structures, and that there are distinct domains of social knowledge, form the basis for this investigation. The subjects were 38 high school students who had successfully completed chemistry and biology (mean age 17.3 years). A semi-structured clinical interview was used with each subject. The content focus was one of two socio-scientific scenarios: nuclear power plants or genetic engineering. Social cognition dominated adolescent reasoning in these socio-scientific issues. The two domains of reasoning used by adolescents were the moral domain (70% of the subjects were classified as moral reasoners) and the personal domain (30% of the subjects were classified as personal reasoners). Since students approach socio-scientific issues primarily from the domain of social cognition, this same domain should be the starting point for instruction. Thus, teaching materials must be structured in such a way as to stimulate social cognition.

Teachers, then, should not suggest to students that they "hold back" their social judgments until they "know more," for students are already conceptualizing the issue, albeit from a cognitive domain not traditionally dealt with (or accepted) by many science teachers.

Fleming (b) also addressed an obvious question that should be raised as a result of the above findings: How do adolescents use their knowledge of the physical world, via nonsocial cognition, when analyzing socio-scientific issues. He discovered that adolescents' knowledge of the physical world appears to be restricted to a few words heard in science class. Knowledge of the physical world is rarely, if ever, used when analyzing and discussing socio-scientific issues. School science is not, from the students' perspective, a source of useful information for analyzing socio-scientific issues. Students view socio-scientific issues as problems to be faced by people, thus they focus upon the people doing the work rather than on the products of the work. Most science curricular materials have exactly the opposite focus. School science rarely deals with science: rather, it focuses on its products, factual knowledge. Thus, students see science as an accumulation of this knowledge (science pedagogy has continued to promulgate this philosophical perspective of science, as well). The major curricular implication of this investigation is that science curricula that integrate socio-scientific issues must have as one emphasis the nature of science, the strategies of science, and the limitations of science. The personal and emotional commitment to the creation of knowledge must also be presented. Fleming notes that contemporary models from the sociology of science may serve as benchmarks for developing such curricula.

The research related to The Developing Intellect that was reported in 1986 offers many recommendations regarding the nature of science instruction. It is apparent that schools must make a concerted effort to work in harmony with the development of the learner. Research related to the development of the learner has direct implications for the development and implementation of curricula.

2.12 Information Processing and Problem Solving: How do learners acquire information and solve problems?

Berger & Pintrich conducted two studies to examine developmental and task effects in estimation problems. Study One, with 95 first, third, and sixth graders, demonstrated developmental differences in speed of processing between younger students and older students. Study Two, with 14 seventh and eighth graders, demonstrated that the amount of feedback information present influences speed of processing. They suggest that future research should address simultaneously issues related to efficiency of processing, strategy use, and knowledge. They note that emphasis on the cognitive processes involved in skill or process learning is useful for research in information processing, diagnosing student learning problems, and designing curriculum materials.

Rudnitsky & Hunt examined the transition between implicit, immature problem solving strategies and explicit, mature theorizing characteristic of scientific problem solving. Their sample was comprised of 41 randomly selected students in fourth through sixth grade. The study examined and described how students solve a complex computer-based problem during a think-aloud protocol interview. Solving the problem involved identifying or discovering a set of cause-effect relationships. Almost all subjects began the problem with exploration. Without prior knowledge that is directly applicable, exploration is a requirement for knowledge acquisition. The solution to a problem requires specific and complete knowledge of the microworld. Subjects appear to quickly grasp the fact that haphazard exploration will not result in usable knowledge. Thus, the prevalence of pattern moves reflects the appreciation of the need for regularity and predictability as a necessary condition for constructing a theory of the microworld. Focusing seems to mark the critical time for model or theory building. Progressing from a pattern or hunch gained in an exploration to a theory requires systematic and, at the same time, informal manipulation of key sequences. The crucial aspect of focusing is using the data gathered to construct a problem representation. The results indicate that the study of the development of scientific reasoning or theorizing cannot be fruitfully pursued without attention to theory formation. Subjects who are able to formulate meaningful problem representations are better able to theorize. Thus, theorizing is not likely to be a set of schemata at any particular level of intellectual development that operate independent of subjects' knowledge of the problem domain.

Collins describes the strategic knowledge required for desired performance in solving realistic transmission genetics problems. A computer program simulates problems in which the solver determines an inheritance pattern by continually producing data. The three categories of solution strategies described are: data redescription, hypothesis testing, and confirmation. After solving a problem, the solver uses tests to confirm the hypothesis and eliminate other possible hypotheses. Thus, there is a cyclic interaction among the categories of strategies.

Anamuah-Mensah sought to determine the strategies used by high school chemistry students when performing volumetric analysis calculations and to identify any conceptual difficulties during the problem solving process. Students primarily used two strategies: the Formula Approach and the Proportional Reasoning Approach. There were no achievement differences among the 47 students in the sample based upon the strategy used. In the Formula Approach, a student employs a formula provided in the text or stated in class and does not make any attempt to demonstrate an understanding of the relationship among variables in the formula they use. Students who use Proportional Reasoning seem to show an explicit recognition of the presence of some relations among the individual variables in the problem. The predominant use of the Formula Approach may reflect strategies advocated in classroom instruction. Thus, teachers should emphasize alternative problem solving strategies that focus upon conceptualizing the problem.

Lee investigated the following questions: "What cognitive variables are significant in problem solving performance?" "What are the relationships between these variables in problem solving performance?" and, "In what ways do these variables relate to the problem solving performance of different types of problems?" The subjects were 214 twelfth grade chemistry students in six schools in Victoria, Australia. Lee determined that a problem solver who is successful in securing a solution will need to achieve in relation to the three tasks to which the following variables relate: the adequate translation of the problems' statement, the correct recalling of prior knowledge such as rules and facts, and making the relevant linkages between the problem's statements and rules and facts so that a solution sequence emerges. If a student is familiar with the problem, then the tasks of linkage and translation will play the important role in predicting the problem solving performance. For a problem with which the student is not familiar, the three tasks stated will contribute significantly to the problem solving performance. For an unfamiliar problem, the task of translation will be the best predictor of the problem solvers' performance.

Gorodetsky, Hoz & Vinner describe a hierarchical system of problem solving strategies that 563 students, of average ability or better, in grades 9-11 employed for the solution of a specific kind of speed problem in which distance, speed and time are manipulated via the formula S=vt. The authors state that by studying problem solving within the algebraic context, that they are able to gain access to both the algebraic manipulation of the concepts and their relationships to the underlying physical relationships between the concepts. The six solution models used for categorization of students' written and oral solutions and explanations can be hierarchically arranged according to their combined levels of physical representation and mathematical modeling. The nature of the solution model and their hierarchical organization resemble a Piagetian developmental model in general, and the model for the development of the integration of time, speed, and distance concepts in particular (see also, Poduska & Phillips in the preceding section for research related to the conception of speed). The correct models were employed by 30.0% of ninth graders, by 32.5% of tenth graders, and by 37.8% of eleventh graders. The authors are disturbed by the fact that the weak trend does not show the increase that would be expected by the developmental model and cite the need for further research to investigate the precise manner in which students solve such problems. The work of **Poduska & Phillips** appears to address this issue when they concluded that students should be able to understand physical situations involving speed without being able to do proportional reasoning, that teachers should not rely on the definition of speed as a ratio of distance/time, and that topics should be presented in the order: distance, speed, time, and proportional reasoning.

Herron & Greenbowe present the results of a case study analysis that attempted to illuminate the difference between knowledge accumulated and ability to solve problems in stoichiometry. The subject of the case study was one of 31 students who participated in a study assessing problem solving in chemistry (Greenbowe, 1983). The subject, although successful in high school and college science and mathematics, was classified as a rule learner. The subject, like many other successful problem solvers in the study, recalled rules and applied them to the context of the problem. Many successful problem solvers also check the validity of procedures and applicability of rules by comparing the conditions given in the problem with their understanding of physical reality. The subject did not. Thus, many

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successful problem solvers do not associate the symbols and numerical answers generated with real objects and events. The subject, like many other students in the study, applied rules correctly when the context of the application was clear from the problem statement; but when problems required the integration of algebra, chemistry, and reasoning, she was not successful. In light of the entering backgrounds of such students, the authors conclude that the problem is not that the amount of previous science study is too little or too weak, but that the courses did not provide students with the ability to apply knowledge and skills in other than the problem used during instruction. They urge teachers to make deliberate attempts to relate chemical problems to the physical systems they describe, and to encourage students to examine their answers in terms of physical reality. Implicit in this suggestion is that students must understand facts about physical reality before they are expected to solve related problems.

Flank investigated the use of mental models in the solving of technical science problems among 42 college students with little background in science. The subjects had been classified previously as having high or low visualization ability on the basis of a spatial visualization test. She wished to study what stimulated visualization ability and whether the chunking of information was aided by the use of visualization. The subjects viewed one of three computerized science lessons comprised of text only, text with static graphics, or text with dynamic graphics. Students with high visualization ability using the dynamic version of text were more likely to solve the problems correctly. Thus, it would appear as though the formation of mental models did occur. She recommended further efforts to evaluate the use of mental models to more fully define specific problem solving strategies so that curricula can be developed to teach s idents to effectively solve problems. **Seddon & Enialyeju** explored whether th ability to visualize the effects of performing rotations on diagrams of three-dimensional structures is dependent on the ability to respond correctly to each of four cues used to portray depth in the diagrams. Their sample was comprised of 200 Nigerian students aged 17-23. The results of their investigation confirmed the importance and necessity of students having to respond correctly to all four depth cues in order to visualize the effects of performing rotations. **Mostafa** investigated the relationships among cognitive development, spatial ability, and achievement in science among 200 sixth, ninth, and twelfth grade male and female Saudi Arabian students. Significant differences were noted in achievement in science associated with spatial visualization ability and level of cognitive development. Females' scores were significantly higher than were males'. Interaction effects between spatial visualization ability and level of cognitive development were also significant. That is, high visualizers at the formal operational level achieved significantly better than any other group.

The results of Herron & Greenbowe's, Flank's, and Seddon & Eniaiyeju's efforts demonstrate the need for a science curriculum that not only teaches students how to apply information to a problem solving context, but how to conceptualize such information. It is apparent that the process of traditional science education, with a focus on the acquisition of scientific facts, does not provide students with the necessary skills to successfully solve problems in a societal context focused on real world problems.

Bodner & McMillen examined the hypothesis that there are preliminary stages in problem solving that most chemists neglect when trying to teach their students how to solve problems in introductory chemistry courses. They maintain that it is during these early stages that relevant information is disembedded from the question and the problem is restructured; and, that unless students can successfully complete these cognitive restructuring stages, they cannot proceed to the more analytic stages in problem solving. Thus, they looked at differences between the performance of high and low spatial ability students on highly spatial concepts in chemistry and the relationship between scores on spatial ability and problem solving performance. A battery of four tests was administered to 587 students for whom a complete set of chemistry performance, spatial ability, and SAT quantitative and verbal scores were available. They found a significant correlation between students' performance on the spatial tests and their performance on highly spatial concepts in chemistry such as the structures of metallic and ionic solids. Correlations between the students' total spatial score and their performance on a multiple-choice stoichiometry test or the comprehensive final exam were comparable to the correlations between the total spatial score and the highly spatial crystal structure questions. These findings indicate that there may be an early holistic or 'gestalt stage in problem solving in which students must disembed relevant information from a question and restructure the problem. If so, much of what we now do to teach problem solving in chemistry may be misdirected because it reflects what experts do when they work an exercise, rather than what they do when they solve a true problem (see also, the summary of Andersson's work regarding an experiential gestalt of causation in Section 2.145). Such instruction neglects the early steps in problem solving that sets the stage for the analytic thought processes that eventually lead to an answer. Thus, in working with students we are reminded of the fact that our task is to help students get to the point where they can use the analytic processes that lead to an answer.

It is apparent that research is only beginning to unravel the mysteries associated with how students undergo the processes associated with problem solving. It is also apparent that such research efforts need to be more organized if the results of such efforts are intended to improve the nature of science instruction. Theoretical frameworks and models that have interdisciplinary utility must be gleaned from the individual efforts to date. For example, **Lawson** (b) introduces researchers to Grossberg's neural modeling principles of learning, perception, cognition, and motor control. He discusses their applications to sensory motor problem solving and explores possible relationships between the patterns of problem solving and aspects of higher order formal operational problem solving. In discussing the proposed model of problem solving and intellectual development, Lawson echoes the sentiments of many of the researchers summarized above--what is acquired in school lessons is insufficient. That is, students are taught strategies but they are seldom confronted with the diversity of problems needed to provoke the sort of close inspection of problem cues necessary to link cues with strategies and tentative results with implied consequences. Lawson notes that Piaget insisted that direct instruction was insufficient since it seldom, if ever, affords the possibility for equilibration. The model presented, while too simplistic to account for the details of advanced problem solving, suggests neurological mechanisms that may be involved in some aspects of the equilibration process.

In 1983, Anderson presented a neuromathematical model relating the amount of information acquired during learning to the quality of the information to be learned and the cognitive ability of the learner. This model represented information acquisition as a two-part phenomenon involving short term memory encoding capacity and long term memory assimilation capacity. In 1986, **Anderson** expanded upon the model to include coefficients representing the motivational state of the learner. The inclusion of the two coefficients permits modeling of the effects of variations in motivation on the rate and amount of information in a learning task. Anderson notes that the use of quantitative models to understand, if not predict, learning behavior has not been widely accepted in science education. Yet, the time course and rate of learning under conditions of varying motivation and effort are fundamental to informed analyses of lesson planning and curriculum sequence design. Thus, the model is aimed at understanding some of these basic rate phenomena in learning in the context of science education toward a better theoretical understanding of the underlying variables mediating learning behavior. **Anderson & Callaway** explored the relationship between the rate of information processing as presented by the neuromathematical model and higher thought processes such as critical thinking skills by assessing the relationship between science reasoning ability and information acquisition among 93 adolescents. The strong positive correlation obtained in this study between scores on the science reasoning test and the amount of knowledge acquisition predicted by the model lends support to the assumption that the model can be expanded to include quantitative relationships with higher cognitive thought processes. With the theoretical assumptions of the model as a guide, additional investigations can be conducted to analyze finer points of the cognitive mechanisms underlying the relationship between information acquisition rates and proficiency in higher cognitive thought processes.

Finally, **Good, Kromhout & Bandler** describe a line of research that could become increasingly important to science education researchers. They note that, traditionally, science education research has been done by persons within the vague boundaries of science education. They suggest a role for science education researchers that requires a cooperative, interdisciplinary approach resulting in the development of a research team. They argue that the establishment of a large database on methods of problem solving would allow for more consistency in data handling and interpretation of in-depth interviews with subjects. Additionally, the procedures students use to solve problems and their progress in this area could be tracked with resulting implications for the design of future curricula and instruction. The authors discuss the DIPS project (Diagnosis for Instruction in Problem Solving). The goal of the project is to develop an expert computer system that closely simulates a human expert in diagnosing the difficulties of a student who is trying to solve certain science problems. Thus, DIPS is intended as a unique tool for teachers and students to use in their attempts to raise levels of science problem solving through more accurate diagnosis of problem solving states. Such diagnosis may provide students the opportunity to gain a better understanding of science, as well as enhance their ability to solve problems.

2.13 Learning from Presentations: Does the way in which new material is presented to students enhance their learning?

Joyce & Weil (1986) note that David Ausubel is one of the few educational psychologists who addresses simultaneously issues related to learning, teaching, and curriculum. His theory of meaningful verbal learning focuses upon three concerns: 1. how knowledge (curriculum content) is organized; 2. how the mind works to process new information (learning); 3. how teachers can apply these ideas about curriculum and learning when they present new material to students (instruction). The following research endeavors investigate various aspects of these three concerns as they relate to how students learn in the context of instructional presentations.

Fisher (a) assessed whether biological knowledge could be practically represented in systematic ways using techniques drawn from artificial intelligence and cognitive science. She also desired to ascertain the advantages and disadvantages of such representations. The knowledge structure of introductory college level molecular and cellular biology was analyzed, and four types of relationships were identified: analytical, spatial, temporal, and process. Three different computer-based semantic network representations were developed. Two list structure nets were useful in identifying problems in net design. The most successful of the three prototypes involved spatial representations (concept maps) for each concept, with the maps being linked together to form a network. Various styles of knowledge representation were tested with students enrolled in introductory biology classes. The students were most enthusiastic about exercises in which partially completed concept maps were given to them and they had to fill in the missing concepts or relationships. The systematic analysis of relationships between concepts reveals relationships not previously perceived by experts. These representational techniques should be useful in facilitating student learning.

In a related investigation, **Garb, Fisher & Faletti** describe efforts to apply principles of concept mapping and computer based semantic networking to the domain of ecology. Many of the relationships are identical to the ones describing molecular and cellular biology. The six classes of relationships are as follows: analytical, spatial, temporal, process, connector, and modifier. A prototype version of a semantic network of ecology knowledge is described, in which the student can move through the network from concept to related concept via a relational pathway, as well as move up to a definition frame for a concept or move down to an example frame for that concept. The authors conclude that concept maps appear to provide a powerful way of representing knowledge.

Fraser & Edwards studied the effects of training in concept mapping on student achievement in traditional classroom tests. Their sample was comprised of 27 low and average achieving ninth grade science students in North Queensland, Australia. They ascertained that students who did not master concept mapping did not show any increase in their achievement performance, while over half of the students who mastered concept mapping showed significant improvement in their performance on achievement tests. They concluded that concept mapping should be incorporated into the ongoing classroom instruction in order to potentially enhance student learning of concepts.

Kinnear, Gleeson & Comerford investigated the use of concept maps in assessing the value of a computer-based activity in assisting students' conceptual understanding in biology. They were particularly interested in determining how this activity should be integrated with other components of a laboratory. The sample was comprised of 36 students in a second year genetics course at a college of advanced education in Australia. They concluded that simulations should only be used as a substitute for laboratory experiences when actual experiences are precluded by time, safety, space, ethical, or legal constraints. Students who did the computer-based activity before undertaking the data-based activity showed better conceptual understanding than students who did the activities in the reverse order. The authors urge the use of concept mapping as an aid to making decisions about the integration of appropriate computer based activities in order to ensure that intended learning outcomes are facilitated. They also suggested that concept mapping could be used to identify student misconceptions.

Cliburn compared two systems for organizing and presenting lecture material in college level anatomy and physiology classes: the traditional method of sequencing in close accord with a textbook and an Ausubelian approach using concept maps for sequencing and as advanced organizers for instruction. While the experimental group showed marginal performance gains on the immediate posttest, they scored significantly higher than the control group on the delayed posttest. Thus, this study suggested that the use of concept mapping during instructional planning, and concept maps, as advance organizers during implementation of that plan, is a valid means of improving meaningful learning and retention of conceptual material. This study also demonstrated the value of delayed posttesting in studies intended to assess long term retention of concepts and the acquisition of meaningful knowledge.

The preceding summaries related to concept map investigations are perhaps best summarized by **Taylor** when she stated that, "Meaningful learning provides the basis for the integration of thinking, feeling, and acting and the potential for changing the meaning of experience" (abstract). Taylor's research involved a case study of the teaching, learning, curriculum, and governance within two sections of a college introductory biology class. Concept maps, Vee diagrams, and questioning techniques were the tools used in this attempt to foster meaningful learning and the integration of thinking, feeling, and acting within the 30 students involved in this study. The major claim of this study is that the use of concept maps, Vee diagrams, extensive teacher questioning, and a learning-to-learn focus within a humane and supportive environment contributed to changing the meaning of the biology lab experience for the students in this study. Taylor stated that: "Changing the meaning of educational experience can develop from a reconceptualization of the goals of educating and the four commonplaces--with a restructuring of the conceptual knowledge of what it means to teach, to learn, to create curriculum, and to govern educative events. Empowering learners means providing the tools (concept maps and Vee diagrams) and the experiences from which they can develop their own responsibility for learning meaningfully" (abstract).

Joyce & Weil (1986) note that "...the ability to remember is fundamental to intellectual effectiveness" (p. 91). They state that the ability to acquire information, to integrate it meaningfully, and later retrieve it at will is the product of successful memory learning. There is no doubt that we need information in order to function as concerned citizens in our rapidly changing society. Thus, we need to be able to memorize skillfully. Recent reviews have documented both the theoretical and practical strengths of mnemonic techniques, or systematic procedures for enhancing one's memory (Levin, 1985; Pressley, Levin & Delaney, 1982). The result is a considerable advance in the knowledge about memorization as well as the development of a system that has practical implications for the design of instructional materials. There are two obvious uses of the work related to mnemonics: to arrange instruction so as to make it easier for students to make associations and to discourage rote drill and practice; and, to teach students to make their own links when they are studying new material.

Levin, Morrison, McGivern, Mastropieri & Scruggs investigated mnemonic facilitation of text-embedded science facts. Eighth grade students read passages that described three dichotomized attributes of eight North American minerals. The 53 students were randomly assigned to one of three study conditions. One-third of the students were given instruction in the use of mnemonic techniques, combined with experimenter-provided mnemonic illustrations of the passage content; another third were told about the value of organizing and summarizing to-be-remembered factual prose material, combined with experimenter-provided fact map summaries; and a final third were given motivational instructions and told to apply their normal method(s) of study while reading the passages. Mnemonic instruction generally produced greater memory for the minerals' attributes in comparison to the other two conditions. This was true whether the passage was organized by mineral name or by attribute both on an immediate identification test and on identification and recall tests administered three days later. While previous research documenting efficacy of mnemonic techniques focused upon subjects' recall of specific facts, this investigation demonstrated the powerful effects of mnemonic illustrations on students' recall of specific attributes.

Ross developed a rule-based instructional strategy for teaching the controlling variables schema. The strategy focuses on elaboration, in contrast with previous methods that have focused on organization. Elaboration involves relating the items to be remembered to other knowledge possessed by the learner. Elaboration improves memory by encouraging deeper processing which in turn increases the number of cues available to stimulate recall. This method contrasts with organization, in that the material to be remembered is merely organized by identifying a consistent relationship among members of the same set of items. Thus, the purpose of the study was to test whether providing fifth grade students with rules enhanced the acquisition and retrieval of formal operations. The results indicated that students exposed to the treatment learned how to design controlling experiments and that this learning tended to be retained during the period two months after completion of instruction. The implication for science teaching is that instruction in which carefully designed rules play a major part is likely to be fruitful, particularly if explicit attention is given to memory strategies, especially elaboration.

Fensham & Johnson investigated the use of word associations with Australian students across a wide age range (elementary and high school students in suburbs of Melbourne) to see whether evidence could be obtained relating social factors to changes in the patterns of associations. The social factors chosen for this investigation were how different social milieux may influence the meaning of the concept, environment. The first is the different interactions with the same social milieux that people have as a result of growing older. The second is the impact of an explicit presence in a school's curriculum of environmental studies. They found a consistency in the patterns of responses. The pattern of responses is stable for each age level, although there is a substantial shift in the patterns with age. The changing interaction of age with social milieux does not appear to affect associations more than the curricular differences in the secondary schools. Thus, the consistency of patterns, given the diversity of instruction among the pairs of groups at four levels of schooling, suggests that the responses to word association tasks are largely determined by extra-school influences.

Fisher (b) used word association techniques to examine the growth of biological knowledge over a period of years, from fourth grade to college students. Results were analyzed by classifying stimulus-response word pairs according to the nature of the relationship between the words in each pair. She tested three hypotheses: 1. the proportion of enactive responses will be greatest among fourth grade students and will decrease with increasing knowledge of biology and with increasing maturity of students; 2. the pattern of word association responses in early adolescents will be different from that seen in younger and older groups, and will be consistent with concrete operational thought patterns as described by Piaget; and 3. as individuals learn more biology, the hierarchical organization of their knowledge will increase, as reflected by an increase of superordinate, subordinate, and definition responses. The results of this investigation supported each of the hypotheses.

Baird conducted a study to improve students' responsibility for, and control of, learning by training for enhanced meta-cognition. Training was for three aspects of meta-cognition--knowledge, awareness, and control. A central feature of the training was for students to practice applying evaluative cognitive strategies during lessons. Students became more informed, purposeful learners, exerting greater control over their learning. This increased control allows for greater understanding of content. However, certain classroom factors can limit meta-cognitive development such as, pre-determined syllabi, long-established expectations for appropriate student participation, and lesson development and classroom management interventions. Enhancing the meta-cognitive behaviors of students requires that teachers [illegible] their behaviors as well. **Mitchell & Baird** reported on a school based multi-faculty action research project to encourage meta-cognitive behaviors. As a result of this project, the school faculty asserted that they had acquired important new perspectives and a deeper

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understanding about various aspects of teaching and learning. Teachers found that in order to realize the expected student gains that they had to change their behavioral repertoire. This study revealed that training for enhanced meta-cognition through action research can produce substantial change in teachers and students.

Finally, **Gladstone** sought to determine whether college students in science courses had acquired the ability to apply data orientation to problems similar to those used in teaching (near transfer) and on problems dissimilar to those used in teaching (far transfer). He hypothesized that scores would be highest for the empirical question that mirrored the subject matter of science classes and lowest for the most civic-social appearing question. This hypothesis was confirmed. This study showed that schools have succeeded only selectively in teaching the data orientation of scientists. The implication of this study is that: since students do not transfer data orientation skills to social-civic issues, then schools must teach data orientation to such issues by integrating suitable social-civic issues into the science curriculum. The results of this study indicate that we are a long way toward successfully achieving the goals of science education in the 1980s outlined by NSTA in 1982. It should be apparent that if we desire to prepare "scientifically literate individuals who understand how science, technology, and society influence one another and who are able to use this knowledge in their everyday decision-making" (NSTA,1982), then their science experiences must provide them with the transfer skills requisite to address such issues.

2.14 Misconceptions: Is it necessary to take into account the ideas and beliefs that learners bring to their formal study of science?

The volume of research on student conceptual reasoning has increased tremendously within the last two years. Lawson et al. (1986) summarized 16 such studies that were reported in 1984; whereas Gallagher (1987) identified 41 research studies that were in the 1985 literature, and we have synthesized 37 studies that focus on conceptual reasoning and student misconceptions herein.

Recent studies indicate that students construct informal theories that they use to interpret a wide range of natural phenomena. There appears to be a similarity in the kinds of conceptions or beliefs that people use over a wide age range. Some research appears to suggest the universality of children's conceptions of their world within age ranges. For example, **Butts** conducted interviews with children between the ages of 12 and 14 in England, New Zealand, and Australia and found similar response patterns for their understanding of electric currents. It has also been proposed that "the historical persistence of these beliefs suggests that they are a natural outcome of experience with the real world" (Caramazza, McCloskey & Green, 1981, p.122).

In light of the noted parallelism that apparently exists between the history of scientific ideas and students' cognitive development, **Wandersee** (a) assessed whether the history of science could be useful in anticipating students' scientific misconceptions. Thus, he focused upon the photosynthesis concept and searched for relationships that might exist between students' conceptual difficulties and the transformation of the photosynthesis concept through time as noted by a historian of science. He administered the Photosynthesis Concept Test to 1405 students in grades 5, 8, 11, and college sophomores. Three patterns emerged from the analysis of the student responses: 1. elementary and junior high students are more likely to hold concepts of photosynthesis that were previously accepted by scientists but have now been discarded or greatly modified; 2. societal practices tend to encourage students to hold outdated concepts of photosynthesis; and, 3. students at all grade levels studied may hold misconceptions about photosynthesis that are similar to those that are documented in the history of science. Thus, he concludes that the historical misconceptions in science in a content area can serve as a powerful heuristic device that encourages the students to discover their own conceptual disparities.

It is clear that the existence of misconceptions among students at all levels presents a challenge for science educators. Meaningful learning cannot occur if students possess entering behaviors that prevent the acquisition of the concepts. The studies summarized below have been grouped into four categories by grade level as follows: K-6, 6-9, 9-12, and post-secondary. There is grade level overlap due to the lack of agreement on the definition of elementary school, middle school/junior high, and high school. Studies that investigated more than one grade range are summarized in the earliest grade range.

2.141 Elementary School (K-6)

A major emphasis of the Learning in Science Project at the University of Waikato (Hamilton, New Zealand) has been to investigate children's ideas about science concepts. **Appleton** investigated children's notions of hot and cold. He interviewed 25 children ages 8-11. He observed that children often confuse heat and temperature and that their conceptions of heat and temperature are often influenced by the volume of the object under consideration. Children have difficulty performing tasks regarding relatively basic notions about temperature and measurement. He concluded that children's subjective knowledge may influence their observations.

Anderson & Smith focused on misconceptions by fifth grade students related to light and vision concepts. They administered diagnostic tests to 227 students over a two year period and conducted 11 clinical interviews. They noted that almost all students shared certain misconceptions about light and its role in vision. In particular, most students believed that their eyes perceived objects directly rather than detecting light reflected by those objects. Most students also viewed color as a property of objects, not of light reflected by those objects. When teachers use traditional methods of instruction, only a few students were successful in changing these misconceptions. Most students, however, successfully mastered the scientific conceptions when teachers used materials specifically designed to help students overcome their misconceptions.

Arnaudin & Mintzes investigated student conceptions and misconceptions about the human circulatory system. They asked 200 fifth and eighth grade students five questions about the circulatory system. They also discovered that many students subscribe to a set of common misconceptions about the scientific concept in question. They note that teachers who introduce cardiovascular concepts will inevitably precipitate clashes between the conceptions their students have and the accepted scientific perspectives. Therefore, they concluded that we will have to begin to develop lesson plans that allow students to test their ideas and resolve discrepancies between their initial predications and the evidence they accumulate.

Stephens, Beiswenger & Dyche interviewed 184 students in primary and intermediate elementary school, junior high school, and college level science methods courses. They wished to determine the patterns of change in students' misconceptions at the four levels, to identify some of the underlying reasons for the patterns, and to recommend ways to improve instruction to enhance student learning of the concepts. They conducted clinical interviews with the students focusing upon concepts such as mass, density, surface tension, water pressure and buoyancy. The results indicate that there is little difference in the understanding of sink/float concepts among students at the various academic levels. They indicate that teachers should familiarize themselves with some ways of instructionally promoting conceptual change on the part of students. They also recommend that teacher education programs should provide prospective teachers with instruction in concept mapping, constructing conceptual frameworks, questioning strategies, interview techniques, and knowledge regarding common scientific misconceptions.

2.142 Middle School/Junior High School (6-9)

Rogan hypothesized that three factors might change the beliefs of junior high school students about the nature of heat. The first was the manner in which the topic is presented (kinetic theory of heat vs. multi-theory approach). The second factor was concerned with the nature of the learning environment (traditional vs. cooperative learning groups). The third factor was the level of formal reasoning exhibited by the students. Thus, the sample was dichotomized into low and high reasoners. The results indicated that on average all students, regardless of instructional approach, increased their understanding of the kinetic theory of heat. All high reasoning students showed a decrease in allegiance to the caloric theory of heat, indicating that conceptual change had taken place. Low reasoning students in the multi-theory class, but not the single-theory class, exhibited the same degree of conceptual change as the high reasoners. Altering the classroom environment did not result in any significant findings.

Arzi was concerned with the long-term kinetics of cognitive learning processes and questioned whether students' preconceptions were as stable as researchers generally assume them to be. She conducted a case study in eighth grade in Israel into students' acquisition of knowledge and learning difficulties in a chemistry oriented physical science class. This study indicated that the topics associated with the concept of ions are significantly more difficult when compared to all other topics in the course.

She noted that students' prior knowledge interfered with the acquisition of new knowledge. She concluded that a necessary condition for the consolidation of desired conceptual development is persistent use of a newly taught concept or alternative meaning for a preconception--both within the course when the new concept or meaning is encountered for the first time, and in subsequent courses or related topics. This longitudinal case study appears to show the importance of curriculum design for effective conceptual change.

Graphing is a common and powerful symbol system for representing concrete data. Yet, research shows that students often have graphical misconceptions about how graphs are related to the concrete event. The Technical Education Research Center (TERC) is developing microcomputer-based laboratory (MBL) science units that use probes to gather data on such physical phenomena as motion, heat, temperature, and response time. Thus, real time graphs can be displayed as data are being collected. Barclay interviewed students to identify the graphing misconceptions commonly held. He then conducted observations of students using MBL's to see if the MBL activities contributed to their understanding of graphing concepts. Preliminary results suggest that MBL's do help in improving graphing skills due to the grounding of the graphical representation in the concrete action of the students, the inclusion of different modes of expressing the material, and the fast feedback that allows students to immediately relate the graph to the event.

Jungwirth investigated the intra-personal meaning of regulation and equilibrium by means of analyses of subjects associate fields. He notes that these concepts are basic to learning biology and biology teaching. Thus, the sample was comprised of students at 6th grade, 9th grade, 11th grade, and biology student teachers. He found that students' associative meaning of these terms did not coincide with the expected representation or embodiment of the subject matter, in particular with regard to their ecological and homeostatic aspects. He offers the word association method as a valuable instructional strategy for teachers who want to quickly gain insight into students' current ideas. He notes that when certain to-be-expected associations are conspicuously absent in young learners that this can be taken as a lack of experience, but that as the groups get older it is more likely that there is a lack of meaningful concept formation on the part of the learner.

Clough & Driver set out to document students' conceptual frameworks and to investigate the consistency with which the ideas were used by individuals in different contexts. Their sample consisted of 30 twelve year olds, 30 fourteen year olds, and 24 sixteen year olds from which a stratified random sample was drawn based upon the results of a short relational reasoning test. The subjects were administered at least two tasks designed to probe the understanding of each of six physical and biological ideas. Their results suggest evidence for common patterns of conceptual frameworks in all of the areas investigated, suggesting that it would be possible for educators to anticipate some of the common frameworks likely to occur in teaching students of a particular age group. This study indicates that students do have alternative frameworks in all areas and that the prevalence of these is relatively predictable across similar contexts, but that they are used less consistently at the individual level. They reiterated an age old adage--curriculum development should take into account the structure of a child's thought.

Johsua & Dupin proposed making explicit use of student conceptions by structuring instruction based upon hypothetical-deductive reasoning. They indicated that the traditional inductivist approach consists of exposing students to an experimental situation that is meant to lead easily to the model introduced by the teacher. They indicated that this kind of instructional strategy may lead to several contradictory hypotheses. The initial hypotheses put forth by the students result from the conceptions that they possess, or invent, about the given situation. They suggest making these conceptions the basis of a first modeling. Thus, when studying a new phenomenon, an initial discussion between students in the class should result in various, often contradictory, explanatory models being proposed. Experiments are then used to make a choice between these models. Using such an instructional model, they investigated the teaching of basic notions about electric circuits in grades 6, 8, and 10 in France. The results of their investigation indicated that students in classes stressing hypothetical-deductive reasoning achieved better and certain of their misconceptions regressed. Some misconceptions remained, and some misconceptions reappeared when the context of the problem situation was changed. The authors concluded that, under certain conditions, a move toward hypothetical-deductive reasoning would enhance students' cognitive acquisitions and lead to an improved way of dealing with students' misconceptions.

2.143 High School

Adeniyi designed his investigation to identify some common misconceptions held by junior secondary school students who have studied an ecology unit from the Nigerian Science Study Project. He analyzed the unit to determine the instructional outcomes as construed by the curriculum developers. He also observed classes to determine the actual coverage of the concepts. He concluded that the two main sources of student misconceptions after instruction are: misconceptions already held by students prior to instruction and misconceptions introduced during instruction. Curriculum developers need to know those misconceptions commonly held by students in order to select and organize intended learning outcomes that would challenge the alternative explanations and help students restructure them in light of relevant scientific experiences.

Clough & Wood-Robinson reported the results of an interview study with 84 students in which they indicate that students' theories about inheritance may be well-developed and coherent (though many do not conform to accepted scientific theory) before the topic is taught in high school biology. This research alerts teachers to a number of commonly held viewpoints of students--for example, intra-specific variation is often explained in terms of developmental defects, many students believe that acquired characteristics are inherited, and many also appear not to understand the equality of parental gene contribution or the mechanism of inheritance. Although the results of this investigation suggest some improvement in understanding with age, several alternative viewpoints persisted in the older groups. The authors cite the need for a greater emphasis on the significance of genetics to life, and to humans in particular. They encourage biology teachers to find ways of incorporating ideas from everyday experience into the biology classroom.

Treagust & Haslam developed an instrument to assess students' misconceptions about photosynthesis and respiration in plants. Their instrument is discussed in Section Four. The instrument was completed by 438 students in grades 8-12 in science classes in Perth, Western Australia. The diagnostic test shows that across grades 8 through 11, and in some cases grade 12, a high percentage of students do not comprehend the nature and function of photosynthesis, do not comprehend that respiration in plants is an energy conversion process, view photosynthesis as an energy providing process, consider respiration to be synonymous with breathing, and have little comprehension of the relationship between photosynthesis and respiration. The results illustrate how students' misconceptions about photosynthesis and respiration in plants are retained throughout secondary school despite the fact that these concepts are taught each year as a topic (or integrated into other related topics). They indicate that in order to improve student learning that the teaching approach to this topic should be modified in order to address identified misconceptions.

Murr's dissertation investigated the instructional issue raised by Treagust & Haslam. She identified biological misconceptions that were present in a significant number of high school and lower division college students. She then designed a study to test whether a method of instruction that calls students' attention to misconceptions about plant respiration and photosynthesis at the high school level would be effective in remediating such misconceptions. The results of her study indicated that the use of instructional strategies that integrate discussions, explanations, and concept maps especially designed to focus the students' attention on misconceptions were significantly more effective in accommodating misconceptions when compared to traditional methods of instruction. Similarly, **Jung** determined that Korean students have pre-instructional conceptual frameworks on mechanics that differ from Newtonian frameworks. He investigated the effects of pre-instructional conceptual frameworks on instruction. The results indicated that students benefitted from the instructional method used, in which teachers drew out the students' pre-instructional conceptual frameworks so they could be compared with the physicists' standard view; however, no significant interaction effect was found between the use of students' pre-instructional conceptual frameworks and students' reasoning abilities.

Marek (a) identified the fundamental concepts associated with instruction of the cell theory and measured high school students understandings and misunderstandings of the concepts. Only 15.8% of the 60 biology students in the sample demonstrated sound understanding of the cell--a concept that is fundamental and pervasive in biology. Sound understanding of the diffusion concept was demonstrated by less than 2% of the sample. Partial understanding of the cell and diffusion concepts was demonstrated by 28.1%

and 35.7% of the students, respectively. Thus, less than half of the students demonstrated any degree of understanding of the cell or diffusion. He concluded that instruction must be structured to enable students to develop accurate concept understanding. He also identified a number of research questions that must be addressed regarding concept understanding. **Gayford** considered the problems of teaching energy in relation to cell biology and ecological energetics with a sample of 296 students studying advanced level biology in England. It was found that there were important inconsistencies between the ideas concerning energy that are being put forward by biology teachers and physical science teachers in schools. These inconsistencies resulted in misconceptions and/or inadequate preparation for the concepts being presented in biology classes. It is therefore urged that the teaching about energy in biology be consistent with modern thinking in physical science. Whenever possible, biology students should be taught the relevant underlying physical science relating to atomic and molecular structure and the nature of chemical reactions together with basic thermodynamics. By doing this, the conceptual framework of students should be more secure. More importantly, biology teachers should be aware of what students are being taught in physical science classes so that they can teach accordingly in an attempt to create a coherent view of energy that is consistent throughout a student's science education.

Marek (b) also assessed the degree of understanding and misunderstanding of more complex biological concepts among high school biology students. For this study, he developed a conceptualization instrument to solicit essay-type data from students regarding two concept statements: food chains and ecosystems. For the food chain concept, of the 58 students in the sample, only one student had a sound understanding of the concept, 34% demonstrated partial understanding, 57% showed specific misunderstanding, and 7% did not provide a response. For the ecosystem statement, no student was able to demonstrate sound understanding, 31% of the students demonstrated partial understanding, 33% showed specific misunderstanding, and 36% of the students did not respond. It is evident that students are not acquiring the more complex concepts that are presented to them in biology classes.

Ivowi investigated students' misconceptions in conservation principles and fields, part of the five major concepts upon which the physics content in Nigeria is structured. A test consisting of problem descriptions and tasks was administered to 104 students ages 15-17 (Form 5) and 49 students ages 17-19 (Form 6) toward the end of their second term prior to their 'O' and 'A' level General Certificate of Education examinations, respectively. This study reveals that the majority of students are unable to make use of the conservation principles. They appear to guess in objective questions as they are unable to explain their choice of response in such a test. It appears as though misconceptions formed in earlier years persist in spite of instruction. **Terry & Jones** suggest that students will resist making changes unless they are dissatisfied with their conceptual model of the situation. They highlight the difficulties that 16 year old 'O' level students in the UK experienced with Newton's third law. Their results indicate that we should be more concerned with students' overall understanding of the concept of

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force and that this understanding is underpinned by an understanding of the third law.

Ben-Zvi, Bat-Sheva & Silberstein investigated students' views about atoms after they had been exposed to half a year of high school chemistry. The conclusions derived from their study formed the basis for the development of a new introductory chemistry course, in which the atom is presented as an ever developing model--the characteristics of which change in accordance with new facts that have to be explained. They found that such an instructional model is effective in preventing some of the misconceptions found among students in traditionally taught chemistry classes. They point out that the difficulties that students have in adopting the particulate model should not be surprising, since it took scientists about 2000 years to develop the model. The intuitive models that students have place them in the Greek period. The new course was designed to show students how and why this model was changed.

Hewson addressed the issue of how students acquire knowledge by focusing on the question of how they incorporate scientific knowledge into their own world of view. She examined the conceptions related to density of a group of students from a non-Western culture, whose living conditions are non-technological, whose home language is non-Western, but who have been exposed to certain orthodox conceptions in science in schools. The results of the clinical analyses of Basotho high school students in South Africa, on the problem of sinking and floating, show that relatively few students answered in terms of the orthodox scientific definition of density. Many students answered in alternative conceptions of mass, volume, density, and force. These results indicate that the new conceptions of orthodox science do not necessarily replace the existing conceptions, but both may exist together, as an unresolved anomaly. These results suggest that it might be the presence of alternative conceptions that prevents the learning of orthodox scientific conceptions. These findings have implications for students in non-Western and Western cultures alike, since students apparently acquire alternative conceptions as a consequence of everyday experiences which are in conflict with the orthodox conceptions presented to them in school. Instructional strategies and curriculum development efforts must take into account students conceptual frameworks.

Sere also considered the knowledge students derive from their everyday experiences and the spontaneous interpretations of experiments presented to students during the teaching about air and gases. Students' spontaneous interpretation of experiments designed to teach physical concepts led her to the conclusion that, in relation to gases, students aged 11 and under have not yet acquired the concept of conservation of matter and that students sense intuitively that something changes when the pressure of a gas changes (these changes are frequently described in animalistic terms). Again, the finding is that the thinking of young learners is rather remote from the procedures and thinking of scientists; and, that instruction must take into account the images used by students if we wish for them to acquire the accepted scientific conception.

Gorodetsky & Gussarsky sought to assess whether students acquired mastery of the chemical equilibrium concept by means of a school achievement test, a misconceptions test, and a free sorting of 18 concepts related to chemical equilibrium that served as a tool for cognitive structure mapping. Students' performance on the misconceptions test was poorer than on school tests and low performance on the misconceptions test are reflected in the latent categories of the free sorting of the appropriate group. The combination of data from these evaluative methods is useful in analyzing students' understanding and misconceptions of scientific subject matter.

2.144 Post-secondary

Research at the post-secondary level reveals many of the same misconceptions and trends that were identified at the elementary, middle school, and high school levels. The results of such research efforts raise fundamental questions regarding the effectiveness of curriculum and instruction in grades K-12, as well as the effectiveness of college level science courses that perpetuate such misconceptions.

Anderson, Sheldon & DuBay assessed 105 university sophomore, junior, and senior non-science majors understanding of the processes of respiration and photosynthesis. They found that serious misconceptions persisted even though most of the students had taken one full year of biology in high school. Students gave definitions of respiration, photosynthesis and food that were markedly different from those accepted by scientists. These incorrect definitions were associated with more fundamental misunderstandings about how plants and animals function. While high school biology seemed neither to improve students' performance on the pretest nor to prepare them to master the concepts presented, college course instruction resulted in misconceptions persisting for many students. **Strauss & Levine** also studied a population of non-science majors enrolled in a chemistry course. They recorded the interpretations of specific chemical symbolism in 500 students before presenting modern concepts of atomic and molecular structure, in an attempt to understand the thought processes entering students as they interpret symbolism. Their results tend to confirm the idea that most students are concrete operational. The concepts they bring into the university classroom regarding abstract chemical symbolism are for the most part memorized facts representing concepts and models accepted early in this century. These models are often appropriate for instruction of the concrete operational student. The authors contended that in order to encourage expanded cognition that the laboratory experience must be conducted in a very careful and thoughtful fashion. Students must be made aware of the fact that they can temporarily treat concepts at a deeper level as chunked even if they do not understand it completely. They should be able to treat various portions of a symbol as a gestalt so that meaningful relationships at a level of interest can be understood. It is apparent from these two investigations that the issue of how to provide adequate instruction for non-science majors must be addressed.

Koch investigated how student comprehension and knowledge of major concepts and principles in molecular genetics was affected as a result of laboratory instruction. He conducted clinical interviews with seven college freshmen prior to and after a laboratory session. The interview was effective in revealing students' pre- and post-laboratory misconceptions. The number of misconceptions decreased after laboratory experiences, indicating a substantial gain in meaningful conceptual linkages and differentiation of concepts. He also reported that the data generated from interviews were substantially greater than information gained from multiple-choice test scores on student comprehension of molecular genetics.

Goldberg & McDermott conducted interviews with 65 college students before and after instruction in geometrical optics to assess student difficulties in understanding image formation by a plane mirror. The results of their investigation reveal that many students emerge from instruction in geometrical optics unable to connect the formal description of image formation by specular reflection with what they see in a mirror. They present some instructional strategies that their research suggests enables students to apply concepts from physics to the interpolation of the image formed by an actual plane mirror. Among the successful strategies are demonstrations with questions to provoke classroom discussions that involve students in confronting some of the misconceptions that were identified. **Searle** also indicates that instructional strategies must place more emphasis on the qualitative aspects of physics and encourage more discussion in the analysis of problems. His conclusion is based upon an investigation with 19 male first year engineering students that focused on misconceptions regarding circular motion. He noted that students did not possess a sound understanding of the principles of Newtonian physics and that the responses of most students indicate a combination of taught Newtonian concepts and intuitive ideas about motion.

Dawson & Rowell studied the responses of 34 science graduates to control of variables problems in biology and physical science set in experimental planning and interpretation of data formats. The subjects were enrolled in a junior high school science teaching methods course. Their results show that many students use inappropriate strategies, utilizing prior and (with respect to the problems encountered in this investigation) irrelevant knowledge of plants and pendulums. Students also possessed a restricted understanding of control in biological experiments. The implications of this study are important. Science courses claim to develop general skills of experimental design and data interpretation. Yet, even science graduates who intend to become teachers possess misconceptions regarding the use of such skills. If prospective teachers adopt idiosyncratic solutions heavily influenced by specific knowledge of the problem content, presumably their students will do the same. The influence of problem content on solution strategy needs to be recognized in our teaching methods. They concluded that students must be provided with experiences across a variety of content and problem formats so that they acquire the ability to abstract and transfer procedural knowledge (knowing how), as well as recognize the need to apply such knowledge (knowing when). Such planning skills and interpretation skills are imperative for life outside of school.

Cros, Amouroux, Chastrette, Fayol, Leber & Maurin investigated the preconceptions of first year university students regarding the constituents of matter and the notions of acids and bases. They conducted free interviews, followed by semi-structured interviews and a questionnaire-based enquiry, with 400 students at two universities in France prior to the beginning of the university year. The constituents of matter were well known to students, but interactions between these constituents were either totally unknown or were the subjects of several misconceptions. They indicated that students' knowledge tended to be qualitative and formal, and note that the lack of students' ability to transfer such knowledge to everyday life is distressing. They maintained that these problems are a result of an education that revolves too much around books and that is not sufficiently linked to experimental work and the practical aspects of chemistry in everyday life and the modern world.

In addition to the sources of misinformation cited in many of the previous inquiries, **Feder** noted that many of the pseudo-sciences are based on assumptions or make claims that are directly in conflict with accumulated scientific understandings. He surveyed students in introductory science courses at the college level and concluded that an alarming percentage of students express some level of belief in extreme claims made concerning the fields of astronomy, archaeology, paleontology, and psychology. Student belief levels concerning unverified or speculative claims made in the name of science could not be significantly correlated with age, grade point average, year in school, or even major field. It would appear then, that students, in general, do not seem likely to apply the basic methods of scientific reasoning learned in their general education science courses to specific claims made in the name of science and appearing in the popular media. He contended that science classes can have a positive impact on student thinking regarding such notions if the claims are dealt with explicitly in classes. He indicated that we need to examine the differences between the methods of science and pseudo-science and explicitly examine the extreme claims related to each scientific discipline.

2.145 Summarizing the Misconceptions Literature

Research on students' conceptual frameworks in science is an expanding field of inquiry that is rapidly generating interest among science educators. **Andersson** indicates that there is a need to find common elements in the seemingly disparate research results in order that the various findings form a cohesive group, and also to achieve a deeper understanding of the students' reasoning. Thus, he sets out to demonstrate that there is a common core to students' explanations and predictions in such widely differing areas as temperature and heat, electricity, optics, and mechanics. He refers to this core as the experiential gestalt of causation (EGC). EGC, as described by Andersson, involves direct physical contact between an agent and instrument and between instrument and object. The idea of EGC represents an attempt to gain a full understanding of students' knowing and learning in science, not only an understanding of specific alternative frameworks. Andersson offers a full and varied set of examples to document his assertions and to introduce the interesting research results from this branch of research.

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Hashweh notes that in spite of the concentrated research efforts related to conceptual change, we still lack an adequate explanation of conceptual stability and change. That is, an adequate explanation would entail specifying some external factors that affect conceptual change and stability. Specifying such factors makes the explanation refutable and, hence, testable. Hashweh offers an alternative explanation of conceptual change. The practical problem facing science teachers and educators is to get the student, who uses a certain alternative conception to interpret a certain phenomenon, to use the scientifically accepted conception in interpreting that particular phenomenon and, possibly, other phenomenon as well. The theoretical problem is to explain the process through which this change is effected. Thus, it is argued that the problem of explaining conceptual stability and change can be divided into three parts; accounting for conceptual change entails specifying some factors affecting each of the following: old conceptions' persistence, new conceptions' acquisition, and cognitive restructuring. Factors affecting each of the three sub-problems of inducing change are identified and discussed. The contention is made that only by paying equal attention to each of these sub-problems can we expect to induce change successfully. The claim is made that until now researchers have focused only on one or two pairs when discussing conceptual change. What is needed now, then, are theoretically based endeavors to test the significance of either the factors identified above or other explanations of conceptual change.

The conceptual change literature is already having an effect upon curriculum development and organization as well. **Giordan et al.** describe the efforts of a working group of teachers and didactics specialists at the University Pierre et Marie Curie in France and their attempt to analyze the content of biological knowledge in order to develop an integrative conceptual network for biological education at the university level. They contend that the establishment of a network of relations between concepts and ideas appears to be absolutely necessary if students are to gain the skills to function in society.

Finally, **Fisher & Lipson** remind us of the fact that errors are valuable and normal occurrences in the process of learning science. Alternative mental conceptions about scientific phenomena and observable errors in expression of scientific knowledge provide insights into the learning process. They are a window through which glimpses of mental functioning can be obtained. More importantly, errors can be used by students to develop a greater understanding of a concept--as long as the error can be recognized and appropriate, informative feedback can be obtained. An analysis of the nature and patterns of student errors is potentially useful for devising more effective teaching strategies, especially when this information is used with a powerful model of cognitive functioning. The application of ideas being generated from research on alternative conceptions will require a fundamental change in how science is taught.

2.2 Characteristics of the Learner

What are students like? What factors affect student achievement, attitudes, and skill attainment? Whereas the preceding section focused upon the nature of learning, this section summarizes research endeavors that sought to assess characteristics of the learner and the concomitant effect of those characteristics upon student performance in science classes. In summarizing a set of research studies as disparate as the following, we felt compelled to group them by grade level in order to allow the reader to make appropriate generalizations.

2.21 Characteristics of Elementary Students: Should we really stop teaching science after third grade?

Yager & Penick synthesized results from The Third Assessment of Science conducted by NAEP (1978); the 1982 follow-up conducted by Hueftle, Rakow & Welch; and a sample, comprised of students in science classes taught by NSTA members, obtained from a larger research project conducted by Vargas-Gomez (1984). Their analysis reveals that the more years students are exposed to science in school, the less they like science. Science classes are perceived as being most fun by 9 year olds; nearly two-thirds report science classes to be fun. This falls to 40% for 13 year olds, and to 25% for 17 year olds. The figure falls even lower for young adults as they reflect upon their school science experiences. A similar pattern emerges as students are asked to respond to whether science classes are interesting and exciting. Similarly, while most third graders report that their science classes make them feel successful, curious, and useful for either further study or in the future, the percentages decrease across the four groups in the three studies conducted over a seven year period of time. The authors state that if one of our goals is for students to enjoy science and feel successful at it, then we should quit teaching science in third grade when students feel positive about the discipline; or, we should begin teaching science in a manner that fosters positive perceptions.

Kyle, Bonnstetter, Gadsden, McCloskey, Fults & Shymansky describe the implementation and evaluation efforts associated with an elementary science program that addresses the curricular issue raised by Yager and Penick, by striving to teach science so that student perceptions are enhanced and maintained throughout their elementary experience. **Bonnstetter & Kyle** conducted a two year longitudinal study to assess and analyze the attitudes toward science of students in first- and second-year SCIIS classes compared to students in non-SCIIS classes. The results of their investigation substantiated the fact that students have a clear preference for process-approach science classes. Student attitudes were significantly enhanced and maintained during the first two years of project implementation across each grade level. Significant entry level attitudinal differences between males and females were also eliminated as a result of the change in curriculum. In accordance with the Concerns-Based Adoption Model and the district's original intent to implement a curriculum that was process-oriented and addressed the current national goals, the SCIIS program was modified in the third year of project implementation to address the current goals in science education. As part of the same program evaluation, **Kyle & Shymansky** assessed specific student behaviors in first- and second-year implementation classes compared to student behaviors in non-SCIIS classes. They observed and coded the behaviors of 199 randomly selected students in 34 classes in grades K-6. Each student observation was 10 minutes in duration. Three dimensions of the interactions were coded: the teaching/learning mode, the activity context, and the exhibited behavior. The results of this investigation substantiated the fact that students in SCIIS science classes are more actively engaged with the processes of science compared to students in traditional science classes. SCIIS students spent 75% of their allocated science time working with manipulatives, whereas students in control classes spent over 50% of their time in large group settings without manipulatives.

Crocker examined the relationships between performance on science thinking skills and reading comprehension skills among 1,240 third and fifth grade students. Students participated in S-APA modules while using the Harcourt Brace Bookmark series. Student performance on reading and science tests were recorded for individual items. Information about performance at the objective level was computed by combining student scores at the test item level. The student scores of the performance levels on the objectives were factor analyzed by grade levels and examined for correlations to determine if reading comprehension skills and science skills were discrete. Statistically significant correlations occurred between reading and science and these skills merged into the following factors: organizing information, synthesizing information, analyzing information, interpreting information, and application of information. Thus, science and reading classes should be organized in such a way as to ensure that students have the opportunity to practice and enhance these valued thinking skills. Thus, the nature of the curriculum and, in fact, the integration of reading and science activities to enhance thinking skills, has a significant impact upon student achievement.

It appears as though the grade range in which student attitudes change most dramatically is also the area least studied in term of learner characteristics. In addition to the vast amount of knowledge that we have gained regarding the nature of learning at the elementary level, we must continue to investigate characteristics of those learners that impact the learning process.

2.22 Characteristics of Middle School/Junior High Students: Is there a growing discrepancy between our society's need for scientifically educated individuals and the availability of individuals with those skills?

A school has both a teaching and a socializing function. The relationship between teaching and socializing students is complex. Kilbourn reflects on that relationship by considering relevant data from a case study of science teaching in a Canadian metropolitan junior high school. He investigated issues related to what was taught, how it was taught, as well as the socialization aspects of the classroom (e.g., management and control, classroom climate, and nature of interactions). He reveals that lack of explicit conceptual continuity, discreteness of activities, emphasis on procedure, and lack of reasons all tend to work toward an environment in which students do things, not for good reasons or for their inherent worth, but because they have been told to do so. It is in this sense that the substance of science teaching can become an agent for socialization and can sabotage some of our more noble (and frequently espoused) goals, such as intellectual curiosity and critical thinking. The lack of reasons given in the classroom with respect to socialization and teaching is of particular concern. A substantial part of an academic's world involves giving reasons and justification, and consequently, in an observational role, the disparity between that world and the world of the junior high classroom is particularly striking. If the environmental setting described by Kilbourn is generalizable, what are the characteristics of students in such classes?

2.221 Attitudinal Characteristics

The development of better attitudes toward science is increasingly being recognized as an important aspect of science education. **Kelly** conducted a longitudinal study of students' attitudes toward science between the ages of 11 and 13, paying particular attention to variations by sex and social class. She also monitored the results of some interventions that were designed to improve females' attitudes toward science. Student attitudes in most areas of science declined over the two year period of time, with the notable exception that both males and females became more interested in finding out more about human biology. Student opinions about science and scientists became generally less favorable, but they became more willing to view science as suitable for females. The attitude changes varied considerably from school to school, and were slightly better in schools that had implemented a program of interventions to improve student attitudes toward science. She noted that individual schools seem to affect their students' attitudes in quite different ways. Thus, much more case study work is necessary to identify why some schools are more successful than others in maintaining and even enhancing students' attitudes toward science.

Rakow & Harris report that half to two-thirds of the 7,873 13-year olds in the Minnesota Science Assessment and Research Project national survey conducted in 1981-82 held positive attitudes about their science classes, science teachers, or science careers. Only one-third of the students indicated that their classes were fun, while one-fifth of the students were seldom or never bored in their science classes. These figures are about the same as those reported by NAEP in 1978.

Hofstein & Yager compared 2,500 thirteen and seventeen year old students in the United States with 350 thirteen year olds and 340 seventeen year olds in Israel using NAEP (1978) items. Significant differences were found in several instances. The differences between the educational systems in the two countries may provide some basis for explaining the differences observed in the two countries. Such a binational study helps with the identification and understanding of students' perception of the science they experience. A mutual understanding and partial adaptation of the positive points in each country may lead to general improvements in outcomes and basic knowledge of the schooling process.

Tunhikorn investigated attitudes toward science and achievement among 709 students in seventh, eighth, and ninth grade in science classes in Thailand. The findings reveal that: males possessed significantly more positive attitudes toward science; there were no grade level differences; males' attitudes toward science increased with years of schooling, whereas females' attitudes declined with schooling; no differences in physical science

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achievement were noted in grades seven or eight, but there was a significant difference in grade nine with males performing better; and, a significant difference in biology in grade seven was noted with females scoring better.

Harty, Samuel & Beall examined the relationships among the constructs of attitudes toward science, interest in science, science curiosity, and self-concept of science ability. They collected data from 228 sixth grade students on four Likert-type instruments, each of which assessed a given attribute. The results indicate that attitudes toward science, interest in science, and science curiosity are highly correlated. They cite a number of suggestions for further research including the notion that we need to understand how these attributes are influenced by environmental and sociological factors beyond the elementary school science classroom.

Talton & Simpson examined the relationship of self, home, and classroom environment with attitude toward science. Self-variables explained between 38-55% of the variance; family variables predicted between 13-39% of the variance; and, classroom environment variables accounted for 46-73% of the variance. An overall model containing all categories of variables explained between 62 and 82% of the variance in attitudes toward science. The fact that classroom environment is under direct control of the educator is significant. By increasing teacher awareness to the important role that classroom environment may play in the formation of student attitudes toward science it may be possible to substantially increase student interest and achievement in science. For example, the attitudes of students to laboratory work may be particularly salient. **Okebukola** (a) explored the effects of cooperative learning on the attitude of students toward laboratory work. The Attitude to Laboratory Work Scale was administered to 113 students in experimental cooperatively structured laboratories and 108 students in control non-cooperatively structured laboratories. The results of this investigation indicate that cooperative learning, featuring intergroup competition, is a potent way of developing favorable attitudes toward laboratory work. The cooperative learning strategy also enhanced the attitudes of female students toward laboratory work when they were compared to their counterparts in control laboratories. Thus, he encourages science teachers to integrate cooperative learning strategies in their instructional repertoire when they develop laboratories.

Raat & de Vries investigated the conception of and attitudes toward technology of 13 year old students in the Netherlands. Twelve students were interviewed to find out what they thought of technology and how important they thought it was to them. Forty-eight additional students responded to 10 open-ended questions to determine their ideas about technology. These results were used to construct a questionnaire that was administered to 3,000 students. Factor analysis revealed that students thought that technology was a broad, important, and not too difficult subject, but it was hard for them to say what it was and why it was not the same as physics; females were less interested in technology than were males; both sexes believed that females have the aptitude for technology; and, students with a technologically oriented parent were more aware of the importance of technology.

Two studies focused upon students' attitudes toward specific science content areas. **Wandersee** (b) probed 136 junior high school students' relative interests in plants and animals against the backdrop of their other topical preferences. Students preferred animals to plants. Females had a significantly greater preference for animal topics versus plant topics, as well as a greater preference for biological topics when compared to males. Ninth grade students demonstrated a significantly greater preference for biologically oriented topics when compared to seventh and eighth grade students. These results suggest that it would be desirable to facilitate a broadening of interests as students progress through their science experiences from elementary school through high school. **Oldman, Black, Soloman & Stuart** studied 241 students' everyday knowledge of the dangers of electricity. They noted that 61% of their 11-12 year old sample mentioned danger in association with electricity, while 35% of their 13-14 year old sample expressed similar fears. They conclude that danger is a part of many students' conceptualization of electricity. A fear of electricity may affect motivation to learn and may be exemplified by a reluctance to participate in laboratories involving feared materials. This could explain the dichotomy between students who find electricity exciting and motivating and others who are inhibited and expressive of such fears. They conclude that class discussions should link everyday experiences with school science knowledge. Teachers must provide a supportive, non-threatening environment for students to discuss fears associated with scientific and technological concepts.

Parker & Rennie reported on the attitudes of 10 year old students in Western Australia before and after their teachers participated in an inservice program in which one of the goals was to reduce sex-stereotyping of science. This investigation was premised on the notion that teachers' science related attitudes and behaviors are a critical influence on the attitudes to science developed by their students. Thus, a major aim of the inservice program was to develop attitudes and skills conducive to effective, non-sexist teaching of a physical science topic--electricity. The findings indicate that students' attitudes about science became less sex-stereotyped. While the attitudes of males were relatively unaffected, females gained more confidence in working with batteries, wires and bulbs, as well as more confidence in their own personal ability to become an electrician. In a similarly designed investigation, **Clency** also found that there was a greater influence on females' attitudes than on males' attitudes toward sex equity, attitudes toward science, and attitudes toward mathematics.

The question of how to influence the attitudes of adolescents through the use of role models was also investigated. **Granville** compared the attitudes fostered by exposure to male science role models versus female science role models. Her sample was comprised of 154 sixth grade students, 75 males and 79 females. She discovered that exposure to female scientists did not enhance the attitudes of students toward women in science, exposure to male scientists did not decrease students' attitudes toward women in science, exposure to either male or female scientists resulted in females having more positive attitudes toward scientists in general, and the attitudes of males and females toward scientists in general continued to show gains even after the treatment. Thus, it appears as though science career education units

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utilizing scientists of either sex as role models are an effective means for altering student attitudes. However, the treatment is more effective for females than males in that females evidence greater gains and thus evidence less sex stereotyping. **Smith & Erb** also investigated the effect of using female science career role models. They reported that students in their experimental group were found to have significantly more positive attitudes toward women in science. Females, when compared to male students in their sample, were found to have a more positive attitude toward females in science. However, both male and female students in the experimental group developed more positive attitudes toward females in science when compared to their counterparts in the control group. Further, the experimental group had a significantly more positive attitude toward scientists in general. The results of these two studies indicate that middle school teachers should expect positive effects as a result of integrating career awareness units, in which students are provided science role models, into the curriculum.

Oliver & Anderson determined how junior high students perceive science teaching as a career. Students rated the desirability of science teaching as a career relative to: careers in science, careers in teaching of other subjects, careers that require a four-year degree not related to science or teaching, careers that require professional or graduate studies beyond the four-year degree, and careers that require a high school or technical degree. Relationships were also investigated between career choice and gender, race, mother/father education and/or career, and educational aspirations. Their findings reveal that students do not view science teaching as a highly desirable profession. Only one student out of a sample of 430 students chose science teaching as the best possible career. Students with the highest educational aspirations tended to rate science teaching the highest. Black students tended to rate science teaching higher than white students. The gender of the respondent was not an important predictor in the rating of science teaching as a career, however, males rated chemistry and physics teaching higher than did females. They concluded by indicating that we need to begin to assess why students rate science teaching as negatively as they do so that we can begin to address the need of attracting more talented individuals to the classroom.

2.222 Achievement

Ekeocha sought to: identify students' correlates of science achievement, hypothesize a model that would explain the relationship between the correlates and achievement, and test the model using available data. The data for this study were obtained through the administration of the Second International Science Study (SISS) instruments to 2,909 fifth grade students in the United States. Three major constructs were identified as potentially influencing science achievement: the home, classroom experience, and student attitudes. The results from the causal models using the individual student as the unit of analysis indicate that the home environment and student attitudes have a positive direct significant effect on science achievement. The effect of the classroom construct on achievement was greater through mediation than by direct path. The results also revealed sex differences in science achievement, with males significantly outscoring females in the life and physical sciences, as well as in the first levels of Bloom's Taxonomy. A separate analysis of the home environment variables indicated that possession of books in the home had a significant effect on science achievement. For the classroom component factors, the instructional methods and behaviors of teachers significantly influenced achievement.

National assessment achievement results reported by **Rakow & Harris** indicate that the average score for 13 year olds in 1982 was about the same as in the NAEP (1978) survey. Student scores increased slightly in biology and decreased on physical science, earth science, and integrated topic items.

Dozier investigated the relationships between objective measures of logical reasoning abilities and science achievement among 107 seventh, eighth, and ninth grade students in a non-public school in South Carolina. A relationship was found between specific logical reasoning abilities and science achievement. The relationship between the subtests and science achievement may imply a need for the construction of objective measures of specific logical reasoning abilities.

Two studies focused upon characteristics of gifted students. **Goldstein** studied the relationships between the science achievement of potentially gifted students and their verbal reasoning quotient (VRQ), spatial ability, curiosity, and science interest levels. The findings of this investigation indicate that spatial ability correlates more significantly with science achievement than does VRQ. However, although males demonstrated significantly greater spatial ability when compared to females, there were fewer significant differences in their science interest levels. Significant differences were found in curiosity levels, and correlations of curiosity. Interest with science achievement yielded significant positive coefficients. When data were grouped on the basis of the students' stated career choices, categorized as science or non-science occupations, highly significant coefficients were obtained when the physics and chemistry scores of the science-career group were correlated with their interest scores. **Al-Hemaisan** investigated selected characteristics related to giftedness among 208 seventh grade Saudi male students. Differences and similarities among gifted and non-gifted students concerning their science achievement, learning motivation, attitudes toward science, and divergent creativity were investigated. The results revealed that gifted students demonstrated significantly higher achievement scores, more positive attitudes toward science, higher learning motivation, and more divergent creativity as compared to non-gifted students. Science achievement was the best discriminator between gifted and non-gifted students.

Graphing competence is essential to many subject areas, including mathematics, science, and social studies. **Padilla, McKenzie & Shaw** examined the line graphing ability of middle and high school students in order to provide baseline data on the mastery of line drawing subskills. The Test of Graphing in Science was administered to 625 students in grades 7-12. Mean scores for the various grade levels indicate a gradual increase in scores between grades 7 and 12 with a slight drop in grade 11. Seventh and eighth grade students were less successful in graphing than high school students. This might suggest that graphing skills should be introduced in earlier grades and be properly emphasized in both the science and mathematics curriculum.

Arzi, Ben-Zvi & Ganiel conducted a longitudinal study of science learning in an ongoing school setting in order to gain better insight into many facets of retention, and consequently obtain a "real" estimate of long-term retention, which would hopefully lead to relevant instructional inferences. This study addresses the following issue: Can the students' background at the beginning of senior high school be related to previous studies in junior high school? If so, is antecedent learning exhibited to the same extent by different retention measures? The results of this study demonstrate that retention of meaningful school materials does exist from one course to another, even over relatively extended intervals. Thus, if we make more frequent use of students' functionally available knowledge perhaps we can motivate, interest, and inspire students to acquire additional knowledge. By recognizing students' entry behaviors and characteristics we should improve the efficiency of sequential learning and smooth the transition from one educational level to the next.

2.23 Characteristics of High School Students: Can we provide students with a set of experiences that are likely to enhance their perceptions toward science and better prepare them to function in society?

What are the behavioral characteristics of students at the classroom level? **Northfield & Gunstone** concluded that thinking is an uncomfortable experience for many students. When provided with a range of activities, students tend to choose the tasks that require straightforward responses from a book. They also noted that very few students are able to apply concepts to everyday experiences. When alternative instructional strategies are used to provide students with a greater awareness to gain control of their own learning, it becomes increasingly more difficult to assess student performance. Students are used to the assessment techniques required for rote learning. Alternative assessment strategies are only effective once students have received instruction related to the use of such techniques. They also conclude that some organizational characteristics of schools are not conducive to the implementation of learning strategies that enhance student learning. Schools tend to be organized so that groups of age cohorts can function effectively. The result is that school classrooms are a compromise where competing functions of schooling and the constraints are balanced.

Are there variables that influence the amount of science coursework that students take or the quality of those experiences? **Goggins & Lindbeck** sought to identify a set of variables that characterize science course enrollment by black high school students. Using the High School and Beyond 1980 data, four composite variables were identified as the best set of predictors: locus of control, mother working, self-concept, and socio-economic factors. Other factors, such as grades of mostly A's and B's in English, were found to influence the number of science classes black students selected as part of their schooling. It is apparent that many of these variables are amenable to manipulation and can provide the science educator opportunities to enhance black students' achievement in science and their awareness of career opportunities.

Various reports have indicated an under-enrollment of female students in high school and college elective computer science courses. **de Pillis** theorized that student patterns would show clear male versus female polarization to account for the male-female disparity in course enrollments. She found that sex was a minor variable in the enrollment patterns. The factors that most supported the choices of the 287 students surveyed were: non-school computer-related experiences; perceived peer, instructor, and family support; perceived relevance to future career and personal goals; self-confidence with respect to computer science; and, perceived sex appropriateness of the subject. Sex appears to be a deceptively significant factor because females tend to receive fewer related-computer experiences and less peer, family, and instructor support than do males. Her conclusion was that any qualified student, male or female, deprived of the support system necessary for positive computer involvement will avoid such involvement. Females, being most deprived, are most likely to choose avoidance.

Between 1959 and 1982 over 100,000 high ability and motivated secondary students participated in Secondary Science Training Programs (SSTP) at various colleges and universities throughout the United States. **Pizzini** summarized research related to the effectiveness of pre-college programs. He noted that these programs have had a significant impact upon the student participants by facilitating academic and career opportunities, increasing subject matter competencies, increasing science proficiency in the laboratory, positively enhancing student attitudes, and enhancing student's self-concept. He encouraged all science educators to work diligently to insure that students from all socio-economic backgrounds have access to such programs. **Michalek, Johnson, Cookfair & Mirand** summarized the effects of a specific program that has been offered each summer since 1953 at Roswell Park Memorial Institute in Buffalo. They confirmed the fact that their program has been most successful in preparing high school and college students for science studies and careers. It is apparent that programs such as those modeled after the NSF SSTP's have provided a select population of students with valuable experiences.

2.231 Attitudinal Characteristics

Rakow & Harris also summarized the attitudes of 7,974 17-year olds. They note that little attitudinal change occurs between ages 13 and 17. The little change that was noted existed in the domain of senior high students being more negative about their science classes, finding the classes more difficult, less interesting, and being less comfortable with their science experiences. They did, however, have slightly better perceptions of their science teachers than did junior high students.

Schibeci & Riley investigated the influence of students' background and perception on science attitude and achievement. Causal modeling procedures were used to analyze data from the 1976-77 NAEP survey. The model shows a strong causal chain as follows: perception of science instruction -> attitudes -> achievement, thus providing support for the proposition that attitudes influence achievement rather than the reverse. They report that females scored lower on both science attitudes and achievement measures;

racial background influenced achievement with white students scoring higher; and that home environment, homework, and parent's education also had substantial influence. The results of this study supported the notion that what teachers do in the classroom does make a difference in student attitudes and achievement. More importantly, science teachers can not overlook the attitudinal entering behaviors that students bring to their classrooms. Teachers must utilize instructional behaviors that are likely to positively influence student attitudes, which have a positive influence on students' achievement.

Jacobson & Doran summarized the attitudinal results of the Second International Science Study. They reported that students in general seem to have a positive view of science. However, a student's view of science seemed to be less positive when they considered the expenditure of public money for science and scientific research. Ninth graders indicated that most of the time they used textbooks in science classes. About 20% of the students reported never doing laboratory work as part of their science lessons. Students seem to become more critical of their science experiences as science begins to have an impact upon their lives. These results echo the findings of **Yager & Penick** (earlier). Students were also quite critical of their schools and their experiences therein. If we desire an informed citizenry supportive of scientific and technological endeavors, then we must begin to address some of the valid concerns that ninth graders are beginning to raise regarding the nature of their science instruction in particular, and schooling in general.

Akpan investigated the factors influencing the choice of science subjects among 1340 students, ages 12-18, in Benue and Cross River States in Nigerian secondary schools. The findings revealed that students with favorable attitudes toward science are likely to continue to study science. Students do not study the physical sciences if they regard them as too difficult, or if the lessons are not enjoyable. Students appear to like to study science if they have favorable attitudes to its social implication and if their perception of the scientist within society is a favorable one. High intellectual ability-- especially spatial and numerical--and personality traits of stability, tough-mindedness, and extroversion also enhance the likelihood of studying science. Males are more likely to study science than are females. The place of age in science choice is not distinct, probably because it interacts with the more favorable attitudes of younger students and the higher intelligence of students continuing science study among the older students. **Banu** also investigated attitudes and factors influencing the development of attitudes toward science among 450 students in Gongola State in Nigeria. He also reported that students in general were favorable toward science, with males being more positive and likely to pursue careers, and females being less positive toward social implications of science. He reported differences between individual schools and also noted that students in schools with special programs showed more positive attitudes toward science. These results are similar to the findings of Kelly in the preceding section. Banu also reported that female students in single-sex schools showed more positive attitudes toward science than females in mixed schools. He concluded that the low enrollment in universities was not due to students' attitudes or lack of interest in science. He cited the lack of

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guidance, the lower status of science careers compared to administrative positions in Nigeria, and the lack of clearly defined jobs other than teaching for science graduates for the tendency of students to avoid advanced science study.

Harvey & Stables assessed the attitudes toward science of 2300 third year secondary students in mixed and single-sexed schools in the southwest of England. Their findings revealed that: regarding attitudes toward science, chemistry, and physics--males had a more positive attitude than did females, females in all-female schools were more positive than were females in mixed schools, and there was no difference in males by school type (males in mixed physics classes showed more positive attitudes than in single-sex classes); regarding attitudes toward biology--males in all male schools showed more positive attitudes; and, finally, regarding attitudes toward school--females in mixed schools were more positive, whereas males in all male schools were more positive. **McEwen, Curry & Watson** studied the science subject preferences of students in single-sex and coeducational schools in Northern Ireland. Their results indicated that school type had minimal effect on science choices, and that the most powerful indicators of science choice were ability and social class. However, both males and females in coeducational schools had a slightly greater tendency to study at least one physical science course in comparison to their single-sex counterparts. Their results failed to confirm the purported disadvantage attached to coeducation for females that has been reported previously.

Watson conducted a study to determine if any factors influenced females' interest in science careers. She identified the following predictors of interest in science careers: science interest, teacher influence, sex-role stereotyped ideas, parental influences, overall grade point average, and the population of the community in which the high schools are located.

Five studies focused upon student attitudes as they relate to specific disciplines or science topics. **Okebukola** (b) examined a number of factors that affect students' attitudes toward chemistry laboratory work. Twelve factors were identified. Students' attitudes toward chemistry as a subject and their participation in laboratory activities are the first and second factors influencing attitudes. The findings of this study suggest that a greater degree of participation in laboratory work may produce more positive attitudes toward the laboratory. He suggested that further research should focus on examining factors that can lead to the development of favorable attitudes, as well as investigating how students' interactions in the laboratory can be structured to improve their attitudes toward their chemistry experiences. **Maddock** focused his investigation on attitudes to community and personal health and awareness of health issues. The results of this investigation indicate that while health awareness increases markedly with increased schooling, schools have not been very effective in achieving their stated attitudinal objectives. He noted that programs need to extend beyond information providing. More effective programs have to depend on a balanced analysis of internal (attitudinal) and external (social normative) factors. He noted that both factors are so entwined that to dichotomize adds nothing to their relative contributions. **Davis** assessed Tasmanian students' attitudes toward various energy conservation measures such as passive solar house design, the use of insulation, and knowledge of sources of domestic energy usage. Students' knowledge of energy and energy conservation did not correlate with the expected knowledge based upon syllabus requirements. Students possessed misconceptions regarding their knowledge of domestic energy usage. Attitudinally, students were most receptive to altering behaviors on hot water usage, switching lights off, and setting thermostats lower. Students exhibited negative attitudes regarding personal choices of transportation. Students were apathetic on the idea of forming an energy conservation club. The least interest in this idea was shown by students with the highest socio-economic background. Such strong negative attitudes perpetuated by influences outside the school will make it particularly difficult for educators who wish to positively influence students' attitudes toward conservation and the environment. **Adams, Newgard & Thomas** developed a model of human orientations toward wildlife, which provided the prescription needed in the development of alternative biology curricula. The strength of the model lies in its ability to analyze diverse populations in each component. Thus, educators can develop curricula based on known attitudes, perceptions or actions of public misinformation or uninvolvement with human wildlife orientations. **Nielsen & Thomsen** concluded that the organization of the Danish mathematical-physical branch physics course compared to the mathematical-natural science branch and the mathematical-social science branch scares a substantial proportion of the students--especially females. The mathematical-physical branch, however, is the key to many high status educational institutions. The reported student perceptions are in spite of the fact that they think physics is an interesting subject. Students also reported that physics is the most difficult subject that they have encountered in their schooling.

Tobin conducted an ethnographic study with 15 teachers and their classes in two Western Australian high schools. He found that laboratory activities were perceived by a majority of teachers and students as an effective means of learning science. While the results of this study suggested that students do value laboratory experiences, Tobin noted that laboratory activities are not implemented in a manner that facilitates the type of learning desired. Implications of these findings were discussed in Section 1.12.

We conclude this section by noting that Ajzen and Fishbein's Theory of Reasoned Action states that a person's intention to perform a behavior is made up from two relatively independent components: a person's attitude to the behavior and their perceptions of what others will think about them performing that behavior. **Stead** used this theory of reasoned action to study a group of high school students' intentions to study or not to study science in subsequent years of their secondary schooling in several New Zealand schools. He reported that males expressed a stronger intention to continue with the study of science in school, that males attitudes were much more positive than females, and that students who have positive attitudes toward the study of science and who believed others thought they should study science, intended to be successful in their next year's science studies.

In light of Stead's finding, and many of the attitudinal findings reported in this section, it is apparent that we have a long way to go to ensure equity among students, as well as to ensure that school science enhances the perceptions of secondary students to science and the application of science and technology in their daily lives. If attitudes do indeed determine successful achievement, as the model presented by **Schibeci & Riley** suggests, then perhaps addressing issues related to the enhancement of students' attitudes, especially the attitudes of females and minorities, should become a global research agenda for science educators in the 1990s.

2.232 Achievement

Since 1969, the performance of 17 year olds on NAEP items has consistently and significantly decreased. In fact, **Rakow & Harris** noted that for many of the biology items of related focus there was very little difference between the performance of 13 year olds and 17 year olds. Additionally, whereas there was little difference in achievement by sex for 13 year old students, significant differences were noted for 17 year olds. While a sex difference favoring males was noted for biology test items, the disparity in scores on physical science items was even greater. **Zerega, Haertel, Tsai & Walberg** explored the size and influence of science learning differences among 3,049 males and females. They also used NAEP data for the 17 year old population citing the fact that level and production of science knowledge and attitudes of late adolescents are issues of national concern in public policy. They reported significant differences favoring males in the area of achievement, attitudes, and motivation. They noted that the high school years have a significant differing effect because females attained the same scores as males at the start of high school and performed significantly worse at the end of high school. They noted that science may still be viewed as a male domain, and in high school it is very important to be accepted by peers. In that light, females, according to the stereotype, are not supposed to be good in science and so they conform to what peers expect. When students are in the elementary school, they are still for the most part teacher-oriented and parent-oriented, and often will please adult figures. But, during adolescence, this is likely to change and peer acceptance may become decisive. Thus, a negative perception of women in science may lead to lower achievement and motivation for 17 year old females, and therefore deny opportunities to females, and thus a source of human intellectual capital or resources to our nation and the global society as well.

Hammond studied the degree of astronomy literacy and the sources of knowledge of 10th graders, adults 35 years old and less, and adults older than 35 who had completed high school prior to the new science curricula implementation period. There appeared to be no relationship between astronomy literacy and the age of the subjects. Further, there was no relationship between those subjects who completed a ninth grade earth science course and astronomy knowledge. A positive relationship did exist between a college degree, regardless of major, and astronomy literacy; as well as having taken a high school or college astronomy course. Males consistently scored higher than females on astronomy knowledge. Finally, television appeared to rival public school education for the source of astronomy information to the general public.

Benbow & Minor investigated the question of whether sex differences in science achievement are related to sex differences in mathematical reasoning ability. The subjects were drawn from the first three talent searches of the Study of Mathematically Precocious Youth (SMPY). The sources of data were the seventh or eighth grade SAT scores and an after-high-school follow-up questionnaire that 1,996 college freshman students returned (91% of the sample returned the questionnaire). They found that differences in mathematical reasoning ability also related to sex differences in measures of science achievement, and possibly to differences in science course participation in physics. The greatest sex differences were in the area of physics. Although course taking and course grades were similar for males and females, knowledge as measured by achievement tests was not. SMPY males achieved at a higher level than SMPY females, especially in physics. SAT mathematics scores could account partly for these differences. They concluded that sex differences in mathematical reasoning ability may explain some of the sex difference in science participation and achievement. These results may bear on why women are under-represented in the sciences. **Becher & Chang** also investigated sex differences in science achievement. They reassessed a quantitative synthesis of correlational research on science affect, ability, and achievement by meta-analysis using tests that fit categorical models to effect sizes. They also reported gender differences favoring males and noted that the size of the difference depended upon the discipline, the largest differences being in the physical sciences.

Two studies that investigated sex differences report alternative findings. **Tamir** compared the achievement of Jewish and Arab students in high school biology matriculation exams with special reference to male-female differences. He noted that Arab and Jewish females achieved as well as males. He discovered that Jewish students achieved better on tasks that required higher cognitive abilities, but this may relate to the fact that Arab students appeared to have greater difficulty taking multiple-choice tests. **Rallis & Ahern** reported on the status of high school students' mathematics and science preparation and the existence of sex inequities in Rhode Island. Their survey indicated that male and female high school graduates took similar numbers and types of mathematics and science courses, as well as indicating that female enrollment in upper level courses was equal to or greater than males. They also reported that females in their sample received higher grades than their male counterparts.

Three studies focused upon identifying variables that influence achievement. **Adams** isolated the effects of instruction and explained significant proportions of the variances in achievement and learning. Her sample was comprised of 63 high school minority students enrolled in a summer college course. In essence, she concluded that achievement and learning were predicted by students' aptitude. **Elliott** used causal modeling to investigate the relationships between physics achievement and Piagetian level, attitudes, English, mathematics and chemistry achievement. The results indicated that physics achievement was most influenced by achievement in mathematics, followed by mathematics and English language achievement. Piagetian intellectual development had a significant direct effect upon mathematics achievement and a significant indirect effect on physics achievement through mathematics achievement. **Gamble** investigated the role of mathematics in enhancing, supporting, or limiting progress in learning physics. The evidence presented indicated that it was the physics that students found difficult and not merely the presence of any mathematics involved in evaluating the quantification of relationships. Thus, the evidence suggested that one aspect of mathematics, namely using the expressions of the type a=b/c, need not in itself be a limiting factor. These results indicated a need for modification of the curriculum, as well as instructional methods.

Eisen & Yaakobi compared student performance in individualized biology classes, in which students completed modules, to students in traditional classes. They reported better achievement by students learning individually, especially average and fast students, as well as females. They indicated, however, that better results were not correlated with the desire on the part of students to learn individually. This contrasts with the positive student perceptions associated with cooperative learning reported in Section 3.321.

Leising investigated whether there is a relationship between personality type and process skills, logical thinking and achievement. He also examined whether certain personality types can improve their process and/or logical thinking abilities through an inquiry oriented teaching strategy. The intuitive personality type improved their logical thinking through the use of inquiry intervention. Females showed marked improvement over males on the test of logical thinking. Finally, the intervention did not adversely affect students' acquisition of knowledge.

An understanding of the nature of science is imperative if one is to exhibit scientific literacy. **Lederman** assessed what students and teachers understand about the nature of science and compared these understandings to the notion of an adequate conception. He concluded that both students and teachers possessed an adequate conception of the nature of science. This conclusion was in spite of the currently popular belief that both students and teachers possess inadequate conceptions of the nature of science. He contended that the more prevailing notion may be derived from research that has failed to sufficiently consider the notion of adequacy. Students and teachers in this study possessed beliefs consistent with the most commonly accepted attributes of scientific knowledge. Thus, he concluded that with regard to this particular aspect of scientific literacy, the present situation may not be as bad as we have been led to believe.

2.24 Characteristics of Post-secondary Students: Is there evidence of a scientifically and technologically literate citizenry among our most educated population?

Two studies at the post-secondary level focused specifically on students in teacher preparation programs. **Walsh & Lynch** were interested in knowing what factors influenced prospective elementary teachers to chose science as their major area of academic study. They conducted interviews with the 30% of the 832 students at the University of Tasmania who completed the required year one science course and opted to continue to study science in year two, given that their decision compelled them to study science in years three and four as well. Seventy-three percent of the students stressed that a practical "hands-on" approach to the teaching of science influenced their

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decision; 83% of the students reported a positive attitude toward science; and, 77% of the students reported that increased confidence and a renewed interest in science were major influences. **Anderson, Harty & Samuel** compared the perspectives of preservice teachers in 1969 and 1984 with respect to their understanding of the nature of science. The 1984 student group was significantly more in agreement with Kimball's Model Response than was their 1969 counterpart. From these data, they inferred that secondary preservice programs might be attracting students with a significantly better understanding of the nature of science or that science teachers may be providing students with a better understanding of the nature of science. The second inference would be in line with the data reported by Lederman above.

In recent years there has been an interest in the characteristics that influence participation in adult education. This is especially true in science, since we know that while attitudes toward science decreases with schooling, participation in informal science education activities has continued to increase steadily. **Dimmock** was interested in assessing what characteristics influenced participation in science and technology museum visitations, science magazine reading, and science television viewing. She identified the level of formal education and interest in science and technology as the best predictors of such participation. If this finding is true on a broad scale, then it becomes apparent that a small percentage of the population is engaged in multiple activities rather than a large percentage of the population participating in such activities. Further studies are needed to assess the degree of adult participation in informal science education.

2.241 Attitudinal Characteristics

DeBoer examined the factors that affect the academic choices that students make and the consequences of those choices for later participation in science. He hypothesized that males and females develop a belief about their ability in science during their school years that is in part based upon their participation in certain science courses and their level of performance in those courses. He felt that this belief about their ability in turn affects the science decisions that these students make when they enter college. Thus, students who believe they have ability in science would be more likely to choose a science curriculum in college than those who do not. The results indicated that even though the performance of females in high school science was better than that of males, females in this study rated their ability in science lower, and this rating had a negative effect on later participation in college science. The success of educational policy and programs in increasing the interest of students, especially females and minorities, in mathematics and science is largely dependent upon having knowledge of what underlying factors are associated with students' interest in such disciplines. **Thomas** sought to identify such factors and to determine if these factors differ for men and women or for blacks and whites. The results of this study indicate the importance of a number of factors that influence students' interest in mathematics and science, such as: interest during childhood in science hobbies; childhood aspirations of being a scientist; encouragement by significant others to pursue such coursework; grades in school; and, participation in clubs. Early interest in science hobbies was especially important for cultivating the interest of females in science. Participating in mathematics clubs was more strongly related to interest in mathematics for blacks than whites. High school grades in mathematics and science were significant factors associated with interest in these subjects for all race and sex groups.

Salters sought to determine the relationship between black college students' attitudes toward science, science self-concept, and other variables of occupational choice and the selection of an academic major. He found six variables that were most influential: science self-concept explained 21% of the variance in science as a major, the presence of role models explained another 11% of the variance, while an additional 10% of the variance was accounted for by course counseling, attitudes toward science, and high school science background.

Matyas addressed the concern of women being under-represented in the scientific work force as related to the differing attrition rate among males and females in undergraduate degree programs. She used attitudinal and socio-cultural variables, as well as traditional variables to predict attrition from science-oriented college majors. Females expressed a greater willingness to sacrifice career advancement for family responsibilities. However, attitudinal and socio-cultural measures were useful in predicting attrition among both men and women. The studies related to gender, race, and cultural influences reinforce the fact that students' career interests and aspirations are developed at an early age and highlight the importance of early family interventions, socialization, and encouragement in shaping students' interest and attitudes in mathematics and science.

Scherz, Michman & Tamir describe students' perceptions of their studies in the Preacademic School (a school that prepares students from low socio-economic backgrounds for university acceptance) at the Hebrew University. They investigated the attitudes, expectations, and opinions of these students with regard to a desirable preacademic preparatory program. Students in the preacademic school felt that their previous educational experiences were not adequate and that they needed additional preparation in order to succeed in university science studies. The students' main concern was with regard to their deficient abilities regarding learning skill activities. Students believed that improving their learning skill acquisition would influence their success at the university level. Thus, it is important for educators to recognize the need for teaching learning skills in addition to subject matter knowledge. The teaching of such skills can play an important role in remedial programs for disadvantaged students.

Fleming (c) assessed the views of high school graduates and university undergraduate students studying science on the interaction among science, technology, and society. The results indicated that the views held by undergraduates were nearly identical to high school graduates regarding their understandings of the relationship between science, technology, and society. The number of university science courses appeared to have little effect on this understanding. While the sample was not comprised of prospective teachers, he noted that drawing prospective science teachers from this pool of "scientifically literate" individuals presents STS teacher educators with a challenge. He suggested that to prepare prospective teachers to deal effectively with STS issues, teacher educators must move beyond the traditional methods course to remedy serious deficiencies in students' knowledge of the social context of science and technology. He did not foresee faculties of science addressing this concern in the near future.

Sieber investigated students' views on animal research, why they hold such views, what ethical or emotional needs of students are not met in biology classes, and how students' perceptions and emotions regarding animal research compare to those of scientists and teachers. The data suggest that most variations in individuals' attitudes about the use of animals lie in specific early experiences and not in overall socio-cultural background. All scientists expressed the importance of separating their tender feelings for animals from their need to do research with them. However, they did not consider it appropriate to talk about ethics or feelings with students in class. Many students stated that ethical analysis belonged at the beginning of any introductory class involving dissection. The majority of students and professionals favored giving students a choice in working directly with animals. The majority of respondents indicated that it is important to learn humane methods. Finally, to expect students to bury their feelings about the use of animals is not only cruel but counterproductive to science education. Science education must work within the emotional context of the learner--this is as important to good science as it is to healthy living.

Johnson assessed the effects of college biology instruction on students' attitudes toward evolution, as well as the correlations between understanding of evolution and science to the acceptance of evolutionary theory. Students' understanding of evolution and science was quite low. Acceptance of evolutionary theory was significantly correlated to both parameters. The teaching of evolutionary biology at both the high school and college level had positive effects on student acceptance of evolution. The completion of courses in genetics and physical science led to greater acceptance of evolutionary concepts. Parents had a negative influence upon students' attitudes toward evolution. This influence was only detected in the freshman and sophomore years. Coincidentally, while freshmen and sophomores were slightly negative toward evolution, juniors and seniors expressed positive attitudes toward evolutionary concepts.

2.242 Achievement

Carmichael, Bauer, Sevenair, Hunter & Gambrell addressed the following questions: (1) Can traditional variables predict performances of black students in first-year chemistry at a traditionally black institution? (2) How does predictive power for black males differ from that for black females? The ACT Composite test score was the best single predictor for performance in the first semester of college chemistry. Performance in the first semester of college was the best predictor for success in the second semester. High school grade point average and ACT Composite were also strong indicators of second semester performance. These results were true for both males and females. **Sanchez & Betkouski** were interested in finding what factors besides SAT scores and high school grade point average might be predictors of success in chemistry at the community college level.

They were also interested in factors that might differentiate between low achievers and high achievers. The best predictors were grade point average and prior chemistry background. They noted that the successful student could also be characterized as older, having a better grasp of science process skills, and having good grades in algebra. **Baker** investigated predictors of success in chemistry among nursing students. She identified the student's level of intellectual development and arithmetical and problem solving abilities as the two best predictors. Older students were less likely to succeed in her study (apparently there are differences between older students who return to school to community colleges and those who enter inner city nursing programs). She did note, however, that the mathematics component of the chemistry resulted in enhanced ability to solve professionally related computational problems and that academically weak students benefitted most from review and reinforcement provided by practice tests and written homework.

Stelzl investigated the sex related differences in preparation for the study of physics, the relationships between preparation for and grades in physics by sex, the sex related differences in attitudes toward physics, and the relationship between attitude and grades in physics by sex. She also compared the attitudes of science and engineering students to those of non-science and non-engineering students toward physics by sex. The number of years of high school mathematics, science and physics, and the number of hours of college mathematics were found to correlate with student performance in physics. Positive attitudes toward women in physics, confidence, low anxiety, the perceived usefulness of physics, and the active enjoyment of physics were correlated to grades among some groups of the sample. There were differences in mathematics and science preparation, as well as attitudes toward physics by sex. Since some of the attitudinal characteristics that affect grades in physics are sex related, she recommended that instructors examine their instructional methods and behaviors carefully to ensure that highly capable and qualified students are not discouraged from pursuing physics coursework and careers.

Hudson sought to determine if the act of providing diagnostic feedback to students had any impact on the correlation between performance in first semester general college physics and a test of simple, mechanistic mathematical skills. In addition, Hudson investigated whether there was any identifiable difference in performance on tests involving a variety of reasoning and problem solving skills among students who completed the course and students who dropped the course. The results of this study suggested that student performance on tests of mathematical skills and on tests containing word problems involving proportions and translations do not serve directly as indicators of success or failure in a physics course. There is, however, a strong possibility that the cognition used in working the problems of such tests is different for students who complete college physics and those who drop out. Students who complete the course appeared to have skills for solving the reasoning questions that were independent of the skills used in purely mechanical mathematical operations. This study also revealed that when students were given the results of mathematical skills tests in a diagnostic mode, with feedback on specific areas of weakness and

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time to remediate with self study, the correlation between mathematics and physics was lower than when the test was given without feedback.

Amstutz examined the relationship between a variety of predictor variables and performance in science classes for both science and non-science majors. While the results indicated a low to moderate correlation between many of the predictor variables and performance, the fact that science majors were taking second semester physics and non-science majors were enrolled in a physical science class confounded the interpretations of the results.

Molinaro tested pre-medical students before and after the Medical College Admission Test (MCAT) to determine the presence of test anxiety (as measured by the Test Anxiety Inventory [TAI]) and its effect on MCAT scores. She also attempted to determine if Beta-endorphin responds to that type of situational stress. Anxiety measures were significantly inversely related to grade point average and there were positive correlations between GPA and MCAT scores. Regression results indicate that select items from TAI, GPA, and Beta-endorphin could be used to predict performance on particular MCAT subtests and that MCAT scores were influenced by test anxiety.

2.3 Summary

In our introduction, we noted the need for science education research to have a greater impact upon classroom practices. We also noted that historically researchers have been able to discover what should be taking place in science classrooms but, an inherent inability to put knowledge into practice has hindered efforts to improve the process of schooling. Section 2, entitled **Learning and the Learner**, perhaps best represents the dichotomy between research and practice. Slightly over one-third of the science education research reported in 1986 focused upon **The Nature of Learning** (Section 2.1) and **The Characteristics of the Learner** (Section 2.2). Within this tremendous volume of literature we are able to see the advances that have been made with regard to our understanding of the nature of the learner and the resulting failures as poignantly portrayed by the characteristics of students in science classes in general.

The above dichotomy may be related to the researcher's neglect of the context in which learning takes place. **White** addressed this concern, noting that the context has been neglected due to the dominance of the scientific paradigm, the nature of the people who do research, and the stability and uniformity of schools and the schooling process. He stated that since context can determine the behavior of participants and the results of a study, that researchers need to think more seriously about the physical conditions, the people involved, and the social conditions in the planning and reporting of research. He also suggested that researchers need to seek replications in widely differing contexts if we wish to affect practice. To this list, we would like to add the fact that researchers have invested far too little time investigating the process of change and how change can best occur in the context of a stable and uniform schooling environment that exists in a rapidly changing social environment. Perhaps one way to encourage teachers and school districts to be more receptive to change would be to encourage teachers to engage in collaborative replication studies. Through such collaborative activities teachers might better appreciate the process of science education research and the findings that specifically impact students in their classes, as well as gain a feeling of confidence when their findings have actual classroom practicability. Recent research provides a clear and relentless message; however, the process of schooling must change if we wish to prepare citizens for life in the 21st Century.

Related to the notion of change, the work of Walberg (1984), **Welch, Walberg & Fraser** and **Staver & Walberg** demonstrates the power of nine factors that influence learning. The educational productivity model posits that increased affective, behavioral, and cognitive learning requires optimization of the following nine factors: ability or prior achievement, development, motivation or self-concept, the quality of instruction, the quantity of instruction, the home environment, the classroom social group, the peer group outside of school, and the use of out-of-school time, specifically the amount of leisure-time television viewing (Walberg, 1984). Many of the variables that account for variation in learning are able to be altered by educators. For example, increasing the quality and quantity of instruction can result in vastly more effective and efficient academic learning. Variables that account for variation in elementary science learning are alterable as well (**Welch, Walberg & Fraser**). This contrasts with the fact that many of the major differences in student achievement between public and private schools appear attributable to relatively fixed characteristics of students and to their experiences beyond the school environment, rather than to factors easily alterable by educators (**Staver & Walberg**). The message here is that the process of schooling can be altered to enhance learning. We are quick to point out, however, that the nature of change must address the current goals in science education. We can no longer afford to perpetuate the nature of schooling as described by Bloom (1984) when he stated that, "Our instructional materials, our classroom teaching methods, and our testing methods rarely rise above the lowest category of the taxonomy: knowledge" (p. 14). Merely increasing the quantity of instruction without addressing the issue of quality will have little impact upon our future citizenry.

In conclusion, it is apparent that our search for excellence has just begun. An imperative for science educators in the 1990s will be to use the knowledge that we have acquired regarding the nature of the learner to structure an environment that significantly impacts the characteristics and behaviors of students as they progress from elementary school to life as productive citizens in a global community.

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3.0 CURRICULUM AND INSTRUCTION

A section entitled "Curriculum and Instruction" can be extremely perplexing to the reader. This is especially true in the context of a summary of research. Some readers might ask whether such a section truly belongs in a summary of research. Others may question whether either term could exist or function without the other.

We felt that a curriculum and instruction section was not only appropriate for an annual summary of research, but that it could be most enlightening. Further, the theoretical and conceptual nature of the terms curriculum and instruction are quite distinct. For that reason, we will dichotomize our discussion in a focused manner around each term.

Studies and reports regarding **Curriculum** (Section 3.1) have been categorized as follows:

- 3.11 Philosophy, Policies, and Models
- 3.12 Development and Evaluation

Studies related to **Instruction** (Section 3.2) have been categorized as follows:

- 3.21 Instructional Strategies
- 3.22 Instructional Materials
- 3.23 Instructional Context
- 3.24 Instructional Repertoires

We conclude this section with a summary of studies related to **Exemplary Science Programs** (Section 3.3). We opted to separate these efforts due to the recent interest in the "science education search for excellence." Although the number of studies in this category is limited, we suspect that such efforts will increase in the future. Similarly, while many of these studies integrate (and often confuse) the issue of whether the focus is upon curriculum or instruction, we feel that with time the efforts of such inquiries will become clearer.

3.1 Curriculum

Curriculum as a field of study is relatively young. Most experts would agree that it was born in the second or third decade of this century, in part, of administrative convenience rather than intellectual necessity. And, while the study of curriculum has yet to establish itself clearly as a discipline, Giroux, Penna & Pinar (1981) expect this to occur within the next twenty years or so based upon the evolution of this field and the processes that have underpinned its formation.

The term curriculum is used in diverse although categorizable ways by writers in the field. Rarely, however, is the commonsensical definition of "a course of study" used by curriculum specialists. Giroux, Penna & Pinar

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(1981) note three theoretical frameworks that govern specific approaches to curriculum issues: traditional, conceptual-empirical, and reconceptualist. They note that each of these frameworks can be characterized by the dominant and subordinate assumptions that govern knowledge and values which underlie their respective modes of inquiry.

The traditional framework lends itself to transmission forms of instruction. It places a high priority on knowledge that is functional, it raises questions about the best or most efficient way to learn a specific kind of knowledge, and strives to provide a curriculum that keeps the existing society functioning. Traditional curricularists tend to be less interested in basic research, in theory development, in related developments in allied fields than in a set of perceived realities of classrooms and school settings. The traditionalist is also dedicated to the "improvement" of schools. This dedication is evidenced by accepting the curriculum structure as it is, with "curriculum change" being measured by comparing resulting behaviors with original objectives. In essence, their work is focused on the schools (Pinar, 1981). The traditional framework guided science education curriculum until criticism about the quality of science education surfaced in the 1950s. The emphasis upon design, behaviorally observable change, and "improvement" is still manifested in school practice.

During the Golden Age of Science Education, conceptual-empiricists from the many academic disciplines replaced traditionalists in the curriculum field as policymakers and innovators. Conceptual-empiricists are concerned with the structure of the discipline (e.g., Schwab, 1962). Education is viewed as an area to be studied by the disciplines and the work is concerned with developing hypotheses to be tested, and testing them in ways characteristic of mainstream social sciences. Until recently, most of the curriculum work in science education and associated research adhered to the conceptual-empirical perspective.

In the early 1970s, a diverse group of educators mounted a new challenge and criticism to the assumptions underlying existing modes of curriculum theorizing. In the early stages of this development, theorists such as Michael Apple, Maxine Greene, Dwayne Heubner, James Macdonald, and William Pinar played a significant role in reconceptualizing the major issues, concerns, and modes of educational inquiry that provided a focus for curriculum theory and practice (Pinar, 1975).

These theorists sought to offset the relatively apolitical, ahistorical, and technological orientation that had characterized the field for the last fifty years by drawing selectively from such European intellectual traditions as existentialism, phenomenology, psychoanalysis, and neo-Marxism. Giroux (1981) notes that: "The new sociology of curriculum group strongly argues that schools are part of a wider societal process and that they must be judged within a specific socioeconomic framework...the curriculum itself is viewed as a selection from the larger culture. From this perspective, the new critics argue for a thorough reexamination of the relationship between curriculum, schools, and society" (p. 103). Among the purposes of the social struggle in which reconceptualists are engaged is developing more flexible and humanizing modes of curriculum rationality that:

1. cultivate critical theoretical discourse about the quality and purpose of schooling and human life,
2. are viewed as part of an ongoing development of complex, historically bound social conditions and formations,
3. address themselves to the concrete personal experiences of specific cultural groups and populations,
4. abandon the ideological pretense of being value-free, and
5. subordinate technical interests to ethical considerations (Giroux, 1981, p. 103-104).

The intellectual climate, as evidenced by the resurgence of curriculum development in science education, appears to be a synthesis of the conceptual-empiricist and reconceptualist perspectives. Such a synthesis may well be what is necessary to ensure that the contributions of such curriculum efforts impact our global society.

3.11 Philosophy, Policies, and Models: Can science educators agree upon a curriculum rationality?

It would appear as though science educators in the 1980s have been striving to address reconceptualist curricular issues through a conceptual-empiricist perspective. This has led to a great deal of confusion. Debate has often focused upon the what and how of science teaching before addressing the why. A curricular imperative for the 1990s will be for science educators to debate and delineate clearly the purposes and goals of science education. Resolution of purposes and goals for the discipline that will be providing future citizens with their cognitive, affective, and aesthetic awareness of science and technology will ensure that subsequent curricular development conforms to such a curriculum rationality. Much of the debate has been in progress since the early 1980s. Many of the efforts reviewed in this section could contribute to such a discussion.

The 1985 NSTA Yearbook, entitled Science - Technology - Society (Bybee, a), addressed some basic questions about the science, technology, and society theme. Bybee (b) also identified the background, rationale, and goals for technology's and society's inclusion in science programs. Similarly, the 1985 AETS Yearbook, entitled Science, Technology and Society: Resources for Science Educators (**James**), addressed the needs of science teacher educators in light of the redirection of K-12 science to include a focus on the interactions of science, technology, and society.

Ogawa proposed a new rationale for science education in a non-Western society. Noting that the science-society scheme proposed in Western societies does not bring a clear rationale for science education in non-Western society, it is proposed that the concept society be replaced by culture. Such a perspective would make it clear that the science education as it is practiced in Western societies does not represent a standard for all science education. The model proposes that science should be viewed in a

cultural context and be relativized; characteristics of science as a culture should be compared with those of their traditional culture; and, science as a culture should be seen within the context of students' traditional culture.
A model such as the one proposed by Ogawa would be characteristic of the reconceptualist framework. Reconceptualist curricularists address themselves to the concrete personal experiences of specific cultural groups and populations. Giroux (1981) noted that the call for cultural pluralism is empty unless it is recognized that the relationships for different cultural groups is mediated through the dominant cultural system (in this case, Western science). Thus, our task as science educators is to unravel these relationships for different cultural groups (more specifically, minorities of culture, class, color, gender, etc.) so as to emancipate them from the imposed kinds of definitions that students have a history of in our global society.

Another example of reconceptualist thought was offered by **Bentley & Watts.** They urged curriculum change in order to meet the needs and expectations of females in science. They emphasize that it is school science that must change--not females--and that the responsibility for change lies with curriculum developers. They painted a picture of feminist science that was particularly humanistic, offering four major consequences for the practice of school science:

1. School science should be reshaped in terms of the views it has of people in science.
2. School science should be recast in terms of its portrayal of the nature of objectivity in scientific investigations.
3. School science must be revisited in terms of what constitutes evidence and explanation, and the nature of the relationship between the two.
4. School science must be re-written in terms of the views it has of the status of scientific knowledge.

They argued that a feminist science curriculum would allow females to grow and develop in a manner fitting their own expectations. They discussed implications of the proposed curricular changes for school science.

Penick & Yager summarized the major trends in school science programs that could be gleaned from the NSTA Focus on Excellence monographs. These trends include: significant involvement of local communities in program development and instruction; science, technology, and technology as a curricular focus; laboratories defined as the real world; and a focus on qualitative considerations to enable students to think quantitatively.

It would appear as though trends among exemplary programs are not indicative of the condition of science education in general. **Stronck,** in light of the many commissions indicating a need for educational reform since 1978, surveyed elementary and junior high science teachers in British Columbia, Canada, to determine trends in their recommendations for change between 1978 and 1982. These teachers describe themselves as shifting their classroom practices toward passive learning and memorization. The teachers, however, have consistently demonstrated that they desire inservice education that will enable them to provide a more relevant and locally adapted program. Thus, while these teachers have not lost their recognition of appropriate goals, they have not been provided adequate support in the form of inservice programs to develop and implement programs of educational value. The need for inservice education as it relates to science teaching was confirmed in an investigation by **De Angelis**. In assessing the trends and changes of science teachers and scientists (1959-1983) to statements bearing on issues related to science and science teaching, it was concluded that the education of a teacher involves more than the accumulation of science content, and that there must be periodic updating.

It is apparent that staff development and administrative support are imperative for the success of any curricular implementation at the district level. The 1986 AETS Yearbook (**Spector**) addresses key issues related to staff development. A major responsibility for science educators as we approach the 21st Century will be to ensure that the curriculum rationality that is developed becomes a part of the process and culture of schooling.

Prather identified issues and opportunities for science educators as they prepare for the twenty-first century. He reviewed the history of science and its relation to society over the past 2,500 years and examined the role of science education. He recommended: the amalgamation of the content-expertise of the science education community and the instructional technology of the adult/continuing education community in an effort to meet the lifelong science learning needs of all students, including adults; the incorporation of the history and philosophy of science into the curriculum for the purposes of resolving misconceptions that students have as they engage in the acquisition of conventional science concepts; and systematic employment of philosophical enquiry to illuminate and define the fundamental purposes and objectives of science education.

J. K. Miller conducted an analysis of science curricula in grades 5, 9 and 12 in the United States. The results of her investigation, part of the Second IEA Science Study (SISS), revealed overlapping similarities in the coverage of content and skills at all grade levels, particularly in the science curricula intended for all students. Instructional objectives dealing with basic science skills (e.g., knowledge, comprehension, observation, laboratory skills) were stressed over coverage of specific science content. The inclusion of applied and integrated science was also documented. Courses that focused upon any of the four science disciplines tended to be more oriented toward specific science content. **Finegold & Mackeracker** reported on the analysis of science curricula carried out across Canada within the framework of the SISS. Their results were similar to those of Miller.

While the identification of the current status of a discipline is important (e.g., J. K. Miller and Finegold & Mackeracker), the categorization of what is taught in particular courses of study is a traditional curricularist focus. Similarly, while results of such inquiries serve as a useful point of reference, they should not guide the debate and concomitant development of a curricular rationality that must be addressed by science educators.

Stinner examined the notion of scientific literacy and its implications for teaching science (physics, in particular). He concluded that scientific thinking cannot be accounted for by any simple specifiable "scientific method." Rather, scientific thinking must be understood as a high-grade activity that involves the continual re-thinking of the presuppositional structure of a science, and responds to such fundamental questions as the relationship between mathematical thinking and scientific thinking, and to the question of how we can go from limited observation to universal generalization. In the absence of a "scientific method," the role of imagination in science, the nature of confrontation in the scientific community, and between science and the humanities become important. It is argued that confrontations in science often occur when paradoxes and asymmetries arise that require the re-examination of the presuppositional structure of science. Confrontations between science and society, however, often take place because of the belief in the reality of "the scientific method" and the subsequent institutionalized split between the scientific culture and the general educated culture of a time. It is concluded that an outline of a pedagogy that responds to the nature of scientific activity as "contexts of inquiry," rather than as "scientific method" is required to teach scientific literacy.

Drugg noted that one of the areas in junior high and high school science curricula as presently constituted that has been identified as problematic is the lack of attention given to the process of ethical/moral decision making in relation to social issues precipitated by our use of technology. **Byrd** assessed the impact of required readings and discussions of philosophical and ethical issues on the understanding of the nature of scientific knowledge of students taking introductory college science courses. While the use of readings and/or discussions did not enhance student understandings of the nature of science, students in biology classes appeared to possess better understandings when compared to students in natural science or geology classes. **Phillips, Birley, Bentley & Buckle** surveyed teachers to determine the amount of socio-economic, technological, and environmental aspects of science included in science courses for students aged 16-19 (high school through college) in the UK. The majority of the respondents favored the inclusion of such issues into the science curriculum. A large majority of the teachers felt that the traditional syllabi should be replaced with syllabuses emphasizing the socio-economic, technological, and environmental aspects of science. In general, physical science courses at the college level have a higher degree of social, environmental, and economic content. Paradoxically, while college instructors were more innovative in terms of developing new courses, they were more conservative in wishing to retain the present format of science discipline structure of courses and to the inclusion of a process-centered approach to teaching science.

Thus, it appears as though science teachers are receptive to many of the conceptual notions that have been identified as part of the new (developing) curriculum rationality in science education. The time is right for science educators to organize themselves and take the appropriate action to influence the nature of the science education that will be delivered to students who will spend their entire adult life in the 21st Century. The struggle to replace the existing traditional curriculum, replete with

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behavioral objectives for outdated and irrelevant facets of scientific knowledge, with a mode of curriculum rationality that addresses the needs of our discipline and the populations it serves cannot be approached as a technical task only. It must be viewed as a political, social, and economic struggle. A significant aspect of the struggle will be to cope with the issue of how to bring about change in a social institution that, at times, appears to abhor the notion of change. The challenge is ours!

3.12 Development and Evaluation: Can science educators effect change in the culture of schooling?

Elliott & Nagel assessed the extent to which ten recently published elementary science textbook series (1984-1986) appeared to promote scientific literacy. They concluded that, although the programs cover science content, they do not promote or encourage the development of scientific thinking or attitudes, nor do they engage students in applying the cognitive processes that are basic to understanding the content covered.

These results lend support for the fact that science educators can not afford to let publishing companies "dictate" the nature of the science education that students will receive. Science educators must actively espouse the goals they aspire for the discipline of science education. The results further substantiate the fact that methods instructors and science coordinators must stress (to prospective teachers and classroom teachers, administrators, and school board members, respectively) that a textbook is not a curriculum. It is clear that a viable role for science educators is to participate actively in curriculum development efforts and to assist teachers in their use of instructional materials, including textbooks. **Blosser** noted that historically research has focused upon "programs" rather than textbooks. She indicated that because teaching with textbooks is the dominant instructional material in many science classes, that research is needed on such issues as how students learn to use textbooks to become independent learners, and how to author textbooks to promote more efficient learning.

Dekker & van der Valk reported on the efforts of a team of people from universities and schools in the Netherlands that were involved in developing a new, three-year curriculum for pre-university physics education for students ages 15-18. This curriculum emphasizes the connections between physics and daily life, society, and technology. The new course stimulates the use of a variety of teaching methods and encourages differentiation. Evaluation research and research into conceptual development are being completed in association with this curriculum.

A number of curriculum development efforts were reported in 1986. The following individuals engaged in curriculum development efforts that focused upon the integration of science, technology, and societal issues into the science curriculum: **Hirshorn** (urban ecology), **Duca** (aerospace education), **Morphet** (Galileo and Copernican Astronomy: how the nature of scientific ideas interacts with society), **Cheek & Hasselbring** (a systems approach to health), **Jamison** (science and technology in society), **Paley** (technology in Western civilization), and **Bull & Hazeltine** (intermediate technology).

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A number of individuals were engaged in curriculum development efforts in the science disciplines. Many of these development efforts also assessed some aspect of the instructional environment, as follows: **Iamnoy** (secondary science/a model of instruction for teaching science as inquiry in Thailand), **Quackenbush** (high school biology/the use of teacher-developed science text-lab manuals), **Sanchez** (high school or college biology/a synthesis of modern learning theory and inquiry techniques), **Cervellati, Perugini, Benedetti & Quartieri** (an innovative high school chemistry course), **Hofstein** (high school chemistry/attitudes), **Rabal** (high school chemistry/problem solving), **Brownstein** (high school chemistry in China/conflict between Chinese educational purposes and Bloom's Taxonomy), **Nasseri** (high school chemistry in Iran/learning cycle strategies), **Ecoff** (college chemistry/individualized instruction), **Boontae** (college chemistry/inquiry approach in Thailand), and **Brown** (college physics/the use of an artificially intelligent, learner-based, computer-assisted tutor).

Olorundare investigated how an officially prescribed science curriculum was interpreted and translated into classroom practice in Nigerian elementary schools. He employed an ethnographic approach. The results revealed that, due to various pressures and constraints, contents of the official curriculum were not transmitted to students in their original forms. The activity-based and child-centered official curriculum was replaced with a teacher-dominated chalk and talk approach. The transacted curriculum was generally inferior; most topics were incomplete, incorrect, oversimplified, or modified. Teachers' understandings and interest in science were major factors of the instructional realities of the science classroom. Additional factors were inadequate government commitment, as well as the cultural and social characteristics of the students' environment. The results also suggested that science activities are better understood when they are presented as phenomena to be explained, rather than as procedures to be taken for granted.

Atash & Dawson integrated quantitatively the collective research regarding the effects of ISCS on student performance. The weighted mean effect size was found to be 0.09, indicating that the performance of the ISCS students was 0.09 standard deviations above the performance of students in traditional science courses. The authors concluded that curriculum development in science and mathematics needs to focus on designing programs such as ISCS that will enhance positive attitudes toward science and mathematics through actively involving students in their own learning processes. We caution the reader, however, that such curriculum development efforts should not merely be in light of the positive virtues of the curriculum projects of the 1960s and 1970s, but that such efforts should be in accordance with the emerging science education curriculum rationality for the 1980s and beyond.

Doran, Dryden & Ekeocha surveyed high schools in New York State (USA) in order to ascertain information regarding advanced science offerings. They report that the most widely offered advanced courses were in biology, with those being labeled as Advanced Placement being the most common of the offerings. More seniors enroll in an advanced biology course than in a first-year physics course. There are half as many advanced chemistry offerings, while few schools offer advanced courses in physics or earth

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science. They compared their findings to the High School and Beyond Study where 18.0% of the students took an advanced biology course, 4.4% of the students were enrolled in advanced chemistry, and 1.7% in an advanced physics course. **Standridge** investigated the status of advanced placement biology courses in secondary schools in Alabama (USA). Her findings indicated that: the teachers of such courses are experienced and well-prepared academically, teachers have little opportunity to communicate with other teachers of advanced placement courses, the courses are comprised of mostly juniors and seniors who are highly motivated academically, and the course enrollments are low, with slightly more females than males enrolled.

Gilmar investigated the life cycle of an elementary school science reform by looking at the ten-year history (1971-1981) of a single district. She studied the change factors that were critical to the process of institutionalization. The implications of the findings are as follows:

1. although there was teacher involvement in the adaption process of SCIS in 1971, it was not enough to provide a secure foothold for the curriculum,
2. teachers' attitude toward science played a role not only in the lack of acceptance of SCIS but in their lack of fidelity to the inquiry approach,
3. collegial help is important in the institutionalization process,
4. principals have a key role in the process of change and reform,
5. staff development for institutionalization is seen as the role of the principals,
6. macropolitical considerations can generally address the concerns of "time," and "more courses"--it can not deal with issues such as how a school works and strengthens itself,
7. the characteristics of the innovation have important implications for the process of institutionalization.

Sabar also investigated the reasons behind the lack of enthusiasm among teachers in implementing a new biology curriculum in Israel. The data indicated three possible reasons for the teachers' disappointment:

1. The high expectations set at the ideal level regarding the implementation,
2. The greater role given to verbalization in the curriculum (e.g., discussions),
3. Dull implementation which occurs when teachers are too faithful to the written instructions.

In essence, this study revealed that it is possible to implement a good number of the intentions of the developers, provided that there is a clear expression of these intentions in the resource materials at the formal level. However, in addition to development of suitable formal materials appropriate to the declared objectives, there is a need for clear and specific definitions of the intentions of the planners so that there will be no room for conservative interpretations.

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Linn (a) noted that the explosion of new technologies and new information has challenged science educators to revise traditional approaches and set new priorities. She noted that the potential of computer-learning environments for teaching problem solving remains largely untapped. She also noted that microcomputer-based laboratories provide powerful representations of scientific concepts. In addition to developing microcomputer-based curricular materials, we must refine our understanding of the power of microcomputer-based laboratories for imparting representations of scientific concepts. **Kracjik, Simmons & Lunetta** stressed the need to improve research on computers in science education. They noted that research is needed both to enhance our understanding of learning and to serve as a basis for the design and use of good software.

At the Conference on Technology and Teacher Education (**Linn**, b), deans of schools of education, teacher education faculty, researchers, and developers in technology and education explored the promise of technology for the improvement of education and suggested ways for each of the major participant groups to meet the challenge of systematically planning and incorporating technology into teaching and learning. The following four interrelated recommendations were made:

1. Establish partnerships among universities, industry, and schools to respond to the challenge of technology in education.
2. Create centers for collaboration on technology and education.
3. Create model classrooms and schools where multidisciplinary teams can explore teaching, learning, and technology in real educational settings.
4. Create opportunities for educational leaders, policymakers, and others concerned about education to reflect on education, technology, and society.

Linn (b) noted that the schools of the future must help build a society in which citizens can constantly absorb and adapt to new information. Education must prepare students to be lifelong learners. The curriculum rationality that we identify will determine whether the educational system accomplishes its stated goal.

As was mentioned previously, understanding the process of change in schools and addressing the staff development needs of teachers are essential components of the work of science educators as we strive to impact the quality of science education offerings in schools. Our success in these two domains will be measured by the decisions that students entering elementary school today make when they confront scientific and technological issues upon graduation from high school in the year 2001.

3.2 Instruction

There are different definitions of the term instruction drawn from the viewpoints of the traditionalist, conceptual-empiricist, and reconceptualist. We will illustrate these alternative meanings, by summarizing from the work of Giroux, Penna & Pinar (1981), so as to underpin the connections between instruction and the process of education.

Traditionalists have emphasized the overly practical dimension of classroom pedagogy to the exclusion of other points of view. "If it works, use it!" reflects the traditionalist stance, with little attention to finding out how and why a particular classroom intervention is successful in the teaching-learning process. This pragmatic approach to instruction requires the translation of educational goals into behavioral objectives that are ultimately reduced to instructional activities for the practitioner.

Conceptual-empiricists attempt to resolve problems in the practitioner's world through categorization and investigation. They use classification schemes and teaching-learning models in the attempt to identify the best instructional environment and mode of instruction. Such an orientation offers practitioners and researchers opportunities for further study and practice. This framework, however, ignores questions regarding the meaningfulness of the tasks, the value of the knowledge acquisition, or the student's perception of the learning process.

Reconceptualists attempt to find new meaning in the term instruction. They link instruction ideologically and overtly to the process of schooling and to larger political, economic, and cultural phenomena. Thus, reconceptualists are not only concerned with what is taught but also with what is rejected. Reconceptualists point out the weaknesses of modes of educational inquiry that fail to link the form and function of classroom instruction to the political and economic values in society.

3.21 Instructional Strategies: Does varying the instructional strategy affect student performance?

Instructional strategy refers to the way in which a science teacher uses materials, media, setting, and behaviors to create an environment; to produce an effect. Thus, "inquiry teaching" conjures up a complicated set of factors which are usually different for different people unless the factors are specified. The research reviewed in this section deals with studies which involved integrated sets of factors. The studies are further divided into three sections by grade-level focus (K-8, 9-12, and post secondary), since the number of studies reviewed is large.

3.211 Elementary School (K-8)

Yore (a,b) studied an open-area classroom containing 42 grade four and five students to determine the effect of lesson structure on science achievement, the degree to which lesson structure compensated for lack of student logical structures, and the degree to which lesson structure interacted with student cognitive style to affect achievement. In addition to several differences in student science achievement which could be accounted for by student conservation ability and cognitive style, he found no overall effect of lesson structure nor any compensation effects. He saw the results as support for using unstructured activities rich in manipulatives in elementary science classrooms.

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Allison & Shrigley studied a different form of lesson structure dealing with teacher use of operational questions. Specifically, the investigators were interested in determining if instructor modeling and instructor modeling combined with student practice in writing operational questions affected the number of operational questions students write following a demonstration. Their results showed that both instructor modeling alone and the combination of modeling and student practice were more effective than control demonstrations in terms of the number of questions students were able to write. However, they suggested that the experimental group students may have also experienced greater cognitive dissonance and more meaningful teacher interactions, which could also explain some of the superior performance.

The extent to which special instructional strategies impact student performance in related areas continues to draw the attention of researchers. **Heffer** studied students in 84 fourth-grade classrooms in the Houston area to determine the effects of "process science" and "non-process science" strategies on Iowa Tests of Basic Skills mathematics scores. Her analysis revealed no significant differences in the scores which she explained as probably a Type II error.

The sequence and composition of laboratory activity, student use of text materials, and discussions and lectures were studied by **Ivins** in six seventh-grade earth science classrooms. He found that a sequence of textbook laboratory exercises followed by textbook readings and classroom discussion was more effective than a sequence of textbook reading or teacher lecture followed by verification labs in terms of science achievement and retention.

The concepts of holistic education and teaching to both sides of the brain are as potentially fruitful for science education as in any area. But studies in these areas are still slow in emerging. **Naveh** studied an intact class of 22 sixth-grade students to determine the effect of guided imagery experiences in science on feelings and attitudes. Using data collection procedures which included classroom observations, individual interviews, and tests of mental imagery and creative thinking, subjects reported positive feelings about the guided imagery experience and exhibited increased involvement, interest, and concern for science activities. Naveh's results were somewhat tempered, however, by **Kuehn** who found that attempts to increase the inventive ability of fifth- and sixth-grade students were generally ineffective (see also, **Kuehn & Krockover**).

In a study of the effects of instruction oriented toward the processing modalities of the left hemisphere, the right hemisphere, or the interaction of both hemispheres on science achievement and attitudes, **Hider & Rice** exposed a total of 65 fifth- and sixth-grade students to one of three strategies: text-only instruction targeted at left hemisphere processes; activity-only instruction targeted at the right hemisphere; and a combination of text and activity targeted at both hemispheres. Students exposed to the combination of text and activity scored significantly higher on both the attitude and achievement measures than the other groups.

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3.212 High School (9-12)

There probably has not been a time when the cost-effectiveness of science laboratory activity has not been challenged. **Coleman** reviewed twenty-nine research studies which attempted to study experimentally the effectiveness of laboratory instruction. The studies in her review dated back to 1918. From her review she identified a pattern of positive effects on manipulative skills tests but inconsistent effects on other performance areas. She pointed out in her study, however, that poorly executed studies and inadequate designs could explain the inconclusive results.

Tobin & Gallagher conducted an ethnographic study of fifteen science teachers in the Perth area to investigate the nature of academic work in high school science classes. In addition to collecting field notes from the observation of about 200 science lessons, written self-report data on student engagement, questionnaire data from teachers and interview data from teachers and students were collected. Among their results they found that: teachers used tests and grades as the primary means to motivate students; teachers planned activities around specific schedules of content coverage; teachers used future science requirements as justification for course content; science for low-ability students emphasized fact recall and little laboratory activity compared to what high-ability students experienced; and that, although teachers and students regarded laboratory activity highly, laboratory activities were rarely coordinated with the lecture/discussions and the cognitive demands of the labs were rated low by observers. From their study, they concluded that teacher education programs need to spend more time helping participants build solid rationales and functional plans for integrating laboratory activities into the science curriculum.

Several studies of the effects of instructional strategies on targeted areas of student performance such as problem solving or concept attainment were reported in 1986. **Bunce & Heikkinen** investigated the effects of teaching an explicit problem solving approach on the mathematical chemistry achievement of college preparatory students. Using 200 students registered in a special chemistry preparatory course at the University of Maryland, students in the treatment group received special problem solving instruction based on information processing theory while control group students received training in conventional methods of dimensional analysis. Analysis of scores on regularly scheduled course examinations revealed no significant difference between the groups; however, the authors noted that treatment students were reluctant to adopt the new problem solving strategy during examinations, preferring instead to use dimensional analysis techniques learned previously. Thus, the authors cautioned that the results may not reflect the efficacy of the treatment. **Schmidkunz & Buttner** described a structure for chemical education based on a spiral curriculum model where students achieve different levels of understanding which could explain the reluctance of the treatment group to adopt the information processing model. The information processing technique may simply require a higher level of understanding in the spiral.

Healy studied the effect of advance organizers and prerequisite knowledge passages on the acquisition and organization of concepts related to a unit on light. Analysis of scores from retention and a framework of knowledge test administered six weeks after the instruction revealed no significant differences in performance between groups. What is not clear from the study though, is the extent to which students in the groups understood the mechanisms of the pretreatments involved. Without knowing such data it is difficult to judge the results. In a similar study on the topic of light, **Obioma** studied 120 secondary students who experienced either expository or guided discovery instruction for four weeks. His results showed significantly greater achievement on a post-test favoring the expository treatment.

A running debate among science educators is whether or not it is possible to accelerate the development of reasoning processes in students through direct instruction; in effect, train students to think in prescribed and efficient ways. **Chandler** conducted a study related to this issue. In her study she investigated the effects of a training program aimed at inducing combinatorial reasoning on the learning of material in chemistry. Using a combinatorial problem involving switches which controlled an electric train set and a form of Piaget's first chemical experiment as the criterion measures, she found that students in the experimental group scored significantly higher than students in the control group. On subsequent tests on rates of chemical reactions following instruction, the experimental students performed significantly better in generating subsumer concepts underlying the topic covered and scored higher on the recall of knowledge test pertaining to the topic.

Seddon & Moore studied the use of models as a way of improving students' ability to visualize the effects of rotations on three-dimensional structures portrayed as diagrams. In the treatment students manually rotated models and compared the changing profiles of the models with the profiles of line diagrams produced on a television screen. The treatment produced no significant short-term learning; in fact, showed deleterious effects when compared with the videotape alone (without manual manipulation) treatment.

To study the effects of student first-hand experience and teacher demonstration, **Glasson** tested ninth-grade students using a declarative knowledge test and a computational word-problem test of procedural knowledge. He found that students in the first-hand experience group significantly outscored students in the teacher demonstration group on the procedural knowledge test but that declarative knowledge scores were similar. These results were consistent for students across levels of cognitive reasoning ability. In a study of ninth-grade students exposed to similar contrasting strategies, **Doty** found that hands-on activity was effective in improving student achievement scores but had no effect on student attitudes or process skill development.

Other studies comparing the effect of student-centered, hands-on instructional strategies to traditional teacher-centered, lecture-demonstration approaches include those of **Abunejmeh** who studied high school chemistry classrooms in Florida and **Ohanenye** who studied science classrooms in Nigeria. **Ohanenye** found that students experiencing the more individualized strategies scored higher on achievement than traditional class students while

Abunejmeh found that, although students were able to detect differences in strategies, they showed no preference for any of the learning environments.

Our understanding of the impact of instructional strategies is greatly increased when the parameters defining the strategies are highly specified. Research on the "learning cycle" provided some of that specification and is, therefore, rich in implications for classroom instruction. **Abraham & Renner** conducted a study of learning cycle activities in high school chemistry to determine which phases of the cycle are most critical. Using experiments with distinct sequences in six classrooms, they found that the position of the "invention phase" is most critical to optimum learning. For a concept new to students, learning seems to be optimized when the invention stage comes after an introduction and before an expansion. If the concept is being reviewed, they found that placement of phases depends on the students' intellectual development level: for concrete operational students, it is best to place the invention phase last; for formal operational students, it is best to place the invention phase first.

In a study to determine the effect of imagery on generation of science rule learning related to Boyles', Charles', and Gay-Lussacs' gas law, **McIntosh** studied four intact ninth-grade classes at an all-boys school. Two of the classes were told to make special use of imagery techniques such as drawing what a gas would look like as it underwent various changes while the other classes were required to write and repeat rules for the behavior of gases. Analysis of criterion test data on the laws revealed curious results. Encouraging students to use imagery seemed to have no effect on either rule recall or transfer. But students from both groups who reported using high imagery scored significantly higher on recall of rules but showed no advantage on transfer of rules. The author suggested that further studies of students "uninitiated" in imagery techniques are needed to sort out its effect on performance.

Several studies of the effects of lesson strategies on student performance related to specific content areas were also reported in 1986. **Gabel & Samuel** conducted a study in which analog tasks were used to determine difficulties that high school chemistry students might have in solving molarity problems. From their analysis they concluded that simple analog problems that contain fractions seem to be more difficult than problems containing whole numbers; that students find dilution and concentration problems more difficult than other types of molarity and analog problems; that achievement for certain types of problems might be enhanced if students understood the connection between the analogs and the chemistry problem; and that chemistry lecture and discussion do not help students understand the principles behind the problems. **Shamal & Stavy** did report, however, that a short introductory course on the techniques of qualitative analysis prior to teaching chapters related to acids and bases, hydrolysis, and equilibrium did enhance student performance on achievement tests.

Stanley & Stanley studied the effectiveness of three-week summer courses on "College Board" scores of "intellectually highly able youths" and concluded that the usual high school science courses in biology, chemistry, and physics

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may be much too slow. They suggested that such compressed format courses be used for able students to gain advanced placement credit for college.

Friedler & Tamir investigated the effects of a learning module designed to teach inquiry skills such as problem identification, hypothesis formulation, and experimental design. Students showed substantial gains in understanding and in their ability to plan investigations and formulate deductions. Studies by **Tunley** with geology topics and **Collins** in the area of transmission genetics also support positive effects on inquiry and problem solving skills among students.

3.213 Post Secondary

Studies in post-secondary science settings are usually conducted in introductory-level content courses or general courses for non-science majors. This pattern held for the post-secondary studies reported in 1986. **Davis & Black** surveyed students at the University of California, Davis, to determine student opinion of investigative laboratory instruction. Students were surveyed upon completion of a one-semester introductory course (N=1200) and upon completion of several different follow-up courses (N=600) to see if opinions had changed. They found that students consistently preferred the "individual experiment" stressed in the introductory course to the standard structured laboratories. Students felt the laboratories increased their understanding and appreciation of the problem-solving process involved in the development of scientific theory.

Isom and Rowsey studied 233 college freshmen over four academic quarters to determine the effect of a special "prelaboratory preparation period" (PLPP) on achievement in chemistry. Compared to standard 20-minute prelaboratory lecture and discussion, the PLPP's with their 45-minute meetings one or two days prior to the laboratory improved student performance on lab reports and quizzes. The PLPP's were especially effective when unfamiliar, abstract concepts were involved in the laboratory activities. In a similar study, **Morgan** observed positive effects of advance organizers on student attitude and achievement among students in an introductory biology course.

Benson & Yeany studied 43 preservice elementary education majors enrolled in an introductory biology course to determine the influence of locus of control (LOC) and diagnostic testing with prescribed remediation (D-P) on short- and long-term achievement. They found that the D-P had different effects on achievement for different units of instruction. For example, they found no significant difference in achievement between D-P students and control group students (experiencing standard procedures where performance objectives were used to guide instruction) on the first unit dealing with Mendelian genetics but a significant increase in achievement by D-P students on the second (modern genetics) and third (evolution) units. The LOC factor, however, proved to be insignificant for two of the three units studied.

Supporting the ineffectiveness of performance objectives without specific remediation or follow-up activity, **Rickard** found that behavioral objectives or behavioral objectives in combination with instructional objectives produced no significant changes in student achievement in a freshman chemistry course. **Gifford & Williams** also found that teacher-structured reviews did not greatly help student achievement.

College science educators have become increasingly concerned about the apparent lack of understanding of fundamental science concepts among students after repeated study of precollege and college science courses. **Rastovac & Slavsky**, upon observing a clear lack of understanding of the causes of the earth's seasonal variations among college students, investigated the effect of using paradoxes on students' conceptual development in an introductory weather and climatology course. They found that the paradox strategy produced higher levels of achievement than the standard expository discussion of weather concepts and explained the results in terms of the students' greater use of cause-and-effect reasoning.

In a novel study of problem solving and reasoning skills, **Gorman** studied falsification strategies in experimental and classroom simulations with a sample of college students. In three separate experiments, students were assigned to different instructional conditions: confirmatory, disconfirmatory, or control. Using a task in which subjects are challenged to generate a rule or law from examples involving a number triple (2,4,6), confirmatory students were urged to test their hypotheses by proposing triples they thought would be correct; disconfirmatory students were urged to test their hypotheses by proposing triples they thought would be incorrect; and control students were instructed with a combination of elements from both strategies. The three groups were given two more problems to test the generalizability of the strategies. In two of the three experimental simulations, students in the disconfirmatory group significantly outperformed the other students in the problem solving. Because of the importance of generating and testing alternative hypotheses in science, Gorman suggests that disconfirmatory strategies and falsification activities be incorporated in laboratory classes routinely.

Results of a study by **Frank** offer further support of strategies which help students develop problem solving skills. In his study, freshmen chemistry students worked on novel problems in small groups during class focusing on a "what do you do when you don't know what to do" theme. When compared with students experiencing standard teacher-directed homework review sessions, students in the experimental group scored significantly higher on classroom examinations.

As we mentioned in the introduction to this section on lesson strategies, it is very difficult to tease-out the effect of specific lesson elements on student performance. The recent rash of ethnographic studies suggests researchers may be growing tired and/or frustrated with such process-product research. But we believe that studies of these isolated elements are still needed. While we agree with the ethnographers that effects must be interpreted in context, studies of specific instructional elements provide valuable reference points for other researchers and practicing science teachers interested in learning more about the effect of those isolated factors in the context of their own classrooms.

3.22 Instructional Materials: How do lesson materials affect student performance?

The materials and media used as tools for teaching science represent another critical instructional factor. In the research reviewed, two tools in particular stand out: the textbook and the computer. From a research perspective, each lends itself to study because of the relative ease with which its content and structure can be manipulated. Both are prime research targets because each can be studied from multiple research perspectives, e.g., information processing, artificial intelligence, cognitive psychology. Finally, both are interesting to researchers and teachers because of tradition, in the case of the textbook, and potential, in the case of the computer.

The textbook has long been a key in the instructional plan of science teachers and will likely continue to be so in the near future. The computer is the new kid on the block. It has the potential to displace science textbooks, especially with its interactive capabilities. It is not our purpose to debate the merits of either tool or make predictions about the future in this section. We simply want to share the results of the several studies reported in an easy-to-follow fashion. For this reason we have chosen to break out the studies dealing with textbooks (printed materials) and computers into separate sub-sections.

3.221 Printed Materials

Research on reading in science has blossomed in recent years due to criticisms leveled against textbook publishers for "dummying down" content and making materials "inconsiderate" and to attention focused on exemplary science programs which have been characterized as non-textbook-based programs. A hotly-debated topic in science education continues to be: Can science learned with the textbook or other printed material as the primary tool of instruction be exciting, relevant, legitimate and meaningful?

Responding to the growing sentiment that students do not seem to learn and understand important concepts from textbook-centered instruction, **Roth** investigated the text processing strategies used by middle school students as they read about photosynthesis in three different texts. One text was an experimental one written to challenge and change common misconceptions held by students; the others followed traditional expository formats. Using interviews and pre- and post-tests, she identified six different text processing strategies in use across the texts, only one of which was effective in helping students undergo conceptual change learning. However, six of the seven students using the experimental text adopted the effective strategy and improved their comprehension scores while only one student reading from a traditional text adopted the effective strategy. From this Roth concluded that texts structured to challenge student misconceptions can help students develop effective science reading strategies.

In a related study, **Rowan** developed a model integrating ideas from communicative research and rhetoric which he tested by having university students read a passage about light and then try to write an explanation for an elementary school audience. He found that student ability to generate clear, rich passages which addressed the counter-intuitive, naive concepts of the hypothetical elementary students was associated with rhetoric and writing skills as much as with knowledge of the topic.

Several researchers investigated the effects of variations in text format or features on student achievement. **S. W. Gilbert** found that analogy-rich text produced no significant gains in student biology achievement, although students using the texts did use analogies more in their own explanations. Studying vocabulary development among fifth-grade students, **Shupe** found "mnemonic keyword" and "flashcard" methods superior to "science text" and "science test" methods on recall and delay-recall tests.

Leonard (a) studied variations in the placement of questions in passages, using a sample of 425 students enrolled in a one-semester university general biology course. Questions placed at the beginning of the passage seemed to enhance short-term retention of concepts; however, he found question placement to have no effect on long-term retention. In a similar but more complex study of in-text question placement and prescriptive feedback based on information-processing techniques, **Farragher & Szabo** found significant differences in instructional time and learning efficiency and marginal differences in achievement between groups. They concluded that, although the application of information processing theory to learning from in-text question placement looks promising, further refinement and study needs to be done.

Worksheets and other teaching ancillaries are an established part of textbook-based science programs. **Spraggins & Rowsey** reported the results of a study comparing the effect of worksheets and simulations on student achievement in high school biology. Though general effects were not found, they did find that low-ability females utilizing simulations and low-ability males utilizing worksheets scored higher on retention tests. Considering the attractiveness of simulation games, the authors suggest that such games be considered as an alternative form of review for select groups of students.

Diagrams and illustrations have also been a long used and little understood learning adjunct. **Winn** reported a study designed to investigate the effect of varying the amount of detail in the elements of a circuit diagram on student ability to perform "successive" and "simultaneous" processing tasks. A successive processing task is one that requires the student to use elements in a sequence. A simultaneous processing task is one that requires the student to use all the elements at once. A group of 41 high school students were asked either to study and draw from memory an electronic circuit (simultaneous task) or to study and remember a list of the individual circuit components in a particular order (successive task). He found that symbols on the diagrams helped students with the successive task but hindered them on the simultaneous task.

Hawk's research showing that "graphic organizers" developed by teachers enhanced the achievement of sixth- and seventh-grade students on a biology unit support the power of concept organizing schemes. However, **Winn**

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mentioned a subsequent experiment which showed that having students label the elements of the diagram did not hinder their performance on the simultaneous task. This suggested that students may use the labeling activity as an opportunity to organize the ideas in a way that is unique and meaningful for them.

Providing information is certainly the primary use of written materials in the classroom. But testing has to be second. Two studies of variations in written test format were reported in 1986. **Blum & Azencot** found that students in Israel taking a national examination preferred multiple-choice items to essay items almost five-to-one. **Irby** observed the same preference among tenth-grade biology students in the United States. But Irby also found that as a diagnostic/learning aid, only students of low-verbal ability benefited from multiple-choice items dealing with knowledge level (fact-recall) items. Students of higher-verbal aptitude benefited most when the items dealt with comprehension and application levels of thinking.

A tool is only useful in the hands of a skilled person. So it is with instructional materials. **Berglund** reported a study designed to investigate student comprehension of text material as a function of two distinct reading instructional strategies. In the study she compared the interactions of teachers and students participating in a "teacher-manual generated" lesson using a "directed reading activity" approach (TMGL/DRA) and a "teacher-student generated" lesson using a "directed reading--think aloud" approach (TSGL/DR-TA). Analyses of the audio taped lessons showed that the TSGL/DR-TA generated higher level student responses, more student participation, and more teacher and student "linking-back" comments than the more conventional teacher-directed strategy.

What research is needed in the area of reading in science; where do we go from here? **Yore (c)** reviewed the recent research done in the area and suggested several avenues of approach. To begin, he suggested we think about attacking reading in the various content areas of science separately. Assuming "science is science is science" when it comes to reading may just confuse the issues. He also suggested that more naturalistic research be done. Because it is so easy to modify vocabulary, question placement, graphics and text format, there is a tendency of researchers to gravitate to studies which treat reading as strictly a decoding process. We need to study reading as a total process--that means studying what the reader does to make sense of the reading material. Finally, he suggested we look at how reading materials are used in the science classroom. Just as it may be unwise to assume that "science is science is science," it may be equally unwise to make the same assumption about reading.

3.222 Computer-Based Materials

Studies of variations in computer-based instructional materials for all areas of the curriculum will continue to increase as new hardware becomes available and as more schools purchase systems. But the increase in research and application is most likely to mushroom in science because of the data-generating and analysis applications. And, like instructional television before it and textbooks even now, computers are being utilized in the science classroom in ways about which we know nothing of their effects. For example, new lab-interfacing equipment and software packages are already changing our notion of the "teacher demonstration." It is critical, therefore, that research in this area expand to keep up with the increased use and growth of the technology.

In this section we review those studies which attempted to deal with computer-based instruction as a major study variable. Unlike the studies reviewed in sections 1.12 and 1.22 under "Teaching and the Teacher" which dealt with teacher attitudes toward and use of computers, the studies in this section focus on the impact of computers on student performance.

Computer simulations account for much of the instructional use of computers in science. Simulations are not the panacea many educators envisioned; they have not and should not replace all first-hand work with actual systems. But their potential in the science classroom has not been fully investigated yet. **Kinnear** reported on college student reaction to solving problems related to linkages and dominance in the area of genetics using CatLab and **Birdbreed**. Students reported that although the activities required more time on the computer, they felt the simulations made it easier to "visualize" and solve problems.

The power of simulations to identify and change conceptions was the target of a study by **Zietsman & Hewson**. Using a simulation dealing with concepts of velocity, they found the simulation to be equally effective as work with real objects in identifying misconceptions held by a sample of 34 tenth-grade students and more effective in changing the misconceptions when students experienced the remedial sequences of the simulation.

Suits studied the effect of inductive and deductive sequences in simulations dealing with introductory chemistry concepts on student achievement but found no differences in a sample of 438 college students. But in another study of problem solving in chemistry, **Freeland** found that a system based on effective solutions by novices ("model-based rules") was superior to other designs ("flashcard-like templates" or practice on specific target reactions). In the model-based rules strategy, students applied several general rules to write the products of a given reaction. In the template strategy, students identified the reaction type and applied one template to find the molecular structure of the products. Following experience with one of the two strategies or work on specific target reactions, analyses revealed that model-based subjects solved more problems correctly and solved more transfer problems than the other two groups on a delayed post test.

There is a growing consensus that explanations held by novice or naive learners provide the best starting point for instruction. Software design experts at "Technical Education Research Center" (TERC) are taking the notion even one step further in designing microcomputer-based laboratories (MBL) for naive college-level students. In studies of the use of a special motion probe which measures the student's own body movement, **Thornton** and **Mokros** found both sixth-grade and college students studied showed substantial gains in understanding of motion and graphing concepts.

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In a study of fourth-grade children's decision-making behavior, **Park** found that children working with real objects were able to generate more alternative solutions on a problem dealing with the distribution of elements than those trying to solve the task with a simulation alone. Moreover, the presence of real objects during the simulations didn't seem to make a difference in the number of alternatives produced either. But it is interesting to note that the "real objects" studied here fall short of the "real object" discussed in the reports by **Thornton** and **Mokros**--those objects were the students' own bodies! This might explain the difference in results.

One common criticism of simulations is that they are often not cognitively demanding enough to be effective. **Dalbey, Tournlaire & Linn** filed a preliminary report of a project designed to study the effect of computer programming on building higher cognitive skills in eighth-grade students. They found that students were able to apply "structure diagramming" for planning solutions to simple problem specifications but were considerably less successful when asked to produce a diagram where the superficial features of the problem did not match the form they had been taught. The authors suggested that much more research is needed to understand the chain of activities involved in programming and how higher cognitive skills come into play.

Several papers reporting the impact of computer-based strategies on student performance were published in 1986. In a study of high school physics students, **Bennett** found that achievement and attitude were positively enhanced when regular activities were supplemented with computer-based materials and that constant reinforcement schedules further increased the benefits of the computer-based supplements. **Ybarrondo** and **Dalton** found similar positive effects in a study of high school biology students and Reed reported that computer-assisted instruction (CAI) materials in conjunction with review worksheets were more effective in enhancing the performance of underachieving high school biology students than either the CAI or worksheets alone.

D. G. Miller, however, did not find similar gains in achievement or attitudes among students using (CAI) materials in a community college biology laboratory course. Similarly, **Ayoubi** found that high school chemistry students spending about half their class time on CAI only matched students who spent no class time on CAI on various achievement measures. As additional time was spent on CAI, students of average ability showed improved performance. This performance, however, could have been due to simple time on task rather than work on CAI.

But in another study of college biology students, **Curts** found that a software system designed to teach students how to fit simple response functions to experimental data using modern data analysis techniques was more effective in helping students with low and low-average mathematical skills than it was for students with high background.

In other studies of computer-related questions, **Beaulieu** found that immediate versus delayed feedback produced no difference in retention of computer terminology among junior high students, while **Rawwas** found that computer-based materials with a moderate level of verbal communication structure ("kinetic structure") produced a cumulative detrimental effect on student achievement across units dealing with the mole concept.

Who might benefit most from CAI? This general question was addressed in three studies. In an investigation to determine the relationship between CAI and student learning styles, attitudes and achievement, **Martini** found attitudes consistently high among all groups, but significantly higher for students placed in instructional settings where the CAI was used in a way to complement their learning style. Studying achievement among community college physical science students exposed to a CAI, audio-tape workbooks (ATW), or supplemental reading assignments (SRA) strategy, **Johnson** found no significant difference between the groups but did find that "superego" and CAI achievement related directly while superego and non-CAI achievement related inversely. This superego factor accounted for only 23% of the total variance in achievement.

Kim studied the achievement of concrete and formal operational students as a function of the cognitive level of CAI. Students were exposed to CAI in which the instructions either varied between concrete and formal level or stayed consistently at the concrete or formal level. He found that students who were given CAI instructions consistently matched to their level (formal or concrete) scored significantly higher on the concrete-level questions than students of a comparable level who received varied level of CAI instructions.

A fear expressed early by educators regarding the use of CAI was that the computer might be seen as a convenient and inexpensive substitute for the classroom teacher. That scenario was pursued in a study by **Waugh**. Using a simulation called Volcanoes and a group of eighth-grade students, he set up two computer lab classes: one in which the teacher interacted with students while they worked through the simulation and a second in which the teacher simply stood off in a corner and offered no assistance. His analyses showed no difference between the groups on attitude or achievement; however, he tempered the results with a discussion of other factors unaccounted for in the study.

Where is computer-based education (CBE) in science headed? From research in mathematics education, **Waugh & Currier** report that CBE has proven to be very effective. However, they point out that this track record has been built on materials with a "drill and practice" focus which may not be as applicable to science instruction. Science is very much a hands-on activity at most levels of instruction. Even the most interactive forms of simulation which utilize lab-interfacing devices for collection of data from real systems can be criticized as being too "black box" for the uninformed, unsophisticated science student. But the technology keeps coming and the instructional possibilities keep expanding. **Leonard** (b) field-tested two interactive videodisc instructional (IVI) systems dealing with "respiration" and "climate and life" and reported extremely positive student reaction to the systems. Students felt the materials were very efficient and reported being excited in simply using the "high tech" systems.

Generalizations about the research on computer-based instruction are not easy. Again, it is probably more instructive to look at the pattern of what researchers seem to be studying than to attempt any syntheses. Surprisingly missing from the studies reported is the teacher factor or discussions of how teachers might moderate the effect of computer-based materials. There is a real danger that research in this area will ignore the teacher factor the way studies of the "new curricula" of the sixties did. The major difference is that computer technology will continue to be developed with or without the accompanying educational research. The task of the research community is to make sure that development and application of that technology reflect the best of what we know about how students learn and teachers teach.

3.23 Instructional Context: How do grouping and setting affect student performance?

The third Handbook of Research on Teaching (Wittrock, 1986) contains a full chapter devoted to "Classroom Organization and Management" (**Doyle**). In that chapter Doyle identifies several themes in the research and explores their contributions to our understanding of classroom order. In one section he discusses "participation structures," and "academic work" as "contexts" for what he calls "programs of action," what we have been calling "instructional strategies." Academic work as a context may be especially unique in science because of the cognitive demands placed on and perceived by students. Because science teachers often stress the ambiguity and tentativeness of science, the risks are high and the possibility of failure great in a science classroom. This academic work context factor then interacts with the participation structures context factor to produce a complex set of instructional outcomes. Research related to the effect of the academic work context factor is reviewed, for the most part, in Section 2.2 (Characteristics of the Learner) of this report.

This section focuses on the participation structures in science lessons. Papers dealing with student, teacher, parent, and other person grouping are reviewed in the first sub-section, 3.231 and papers dealing with special lesson settings are reviewed in sub-section 3.232.

3.231 Participant Structures

Hofstein & Lazorowitz used a modified version of the "Learning Environment Inventory" to study student perceptions of biology and chemistry classes in a sample of Israeli schools. Their analysis showed that biology students perceived their classroom environment much more positively than did chemistry students. But both groups perceived the environment as too competitive, the studies as irrelevant, and learning science as generally too difficult. **Okebukola** (a), however, observed different levels of preference and achievement with regard to competitive-cooperative strategies. Studying 493 ninth-grade biology students in Nigeria who were placed in classes using competitive or cooperative strategies on the basis of scores on the "Learning Preference Scale (LPS) - Students," he found that groups matched to the strategy of their preference achieved significantly higher than mismatched groups. On a related point, **Hacker** observed the behavior of 202 boys and girls in matched coeducational and single-sex environments and found that equal opportunities were provided for girls and boys to interact with both the teacher and resource materials and that the presence of a male teacher did not disadvantage girls in any observable way.

The benefits of matching students to competitive or cooperative participant structures on the basis of preference scores are not entirely clear. While **Sherman & Zimmerman** were reporting no significant difference in achievement between students learning biology in cooperative classroom environments, **Okebukola** (b) and **Johnson, Johnson & Stanne** were reporting positive effects on students across the board. This study is especially interesting because computer learning was the focus of the cooperative-competitive activity. Analyses revealed that students in the cooperative setting achieved more, exhibited more task, management and social interactions related to the activity, and nominated more female classmates as desired future work partners than did students in the competitive and individualistic conditions. **Okebukola** (c) reported that mixed-ability cooperative groups also performed significantly better on achievement tests than a competitive control group in a study of 225 secondary school chemistry students.

The increased purposeful interaction among students when thrust into cooperative learning conditions is further supported in a study by **Gilbert & Pope**. In their study in Germany five small groups of middle school students were given line-drawings and asked to decide what the drawing had to do with energy and persuade others in the group of their idea. In effect, the study was an attempt to see if students could use conceptual change teaching strategies to teach other students. They found students most willing to engage in discussions, but not prepared to carry on a productive conceptual change interaction. They suggest, however, that students can be taught the skills needed to participate in student-dominated conceptual change lessons.

An extension of the idea of fostering conceptual change learning among student groups is reflected in a study by **Gennaro, Hereid & Ostlund**. They conducted a follow-up study of 126 families who participated in family learning courses in science two to three years earlier. The middle school pupils and parents remembered the experiences as both challenging and positive. In another study, however, **Hertel** found that sixth- and seventh-grade pupils did not score significantly higher on tests of achievement or attitude when student peers were replaced with parents as class partners. The results of these two studies suggest that there is a "threshold" of parent involvement beyond which student gains are diminished or even reversed.

What about extending the peer group to include scientists? How would students and/or teachers react? **O'Sullivan** reported on a study which examined the effects of cooperative biological research investigations involving high school biology teachers, their students and university scientists on teacher and student attitudes toward science and the team's reaction. Despite the non-significant differences in student or teacher scores on tests of understanding of science process skills, the three participant groups were generally positive about the experience. Moreover,

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teachers' attitude toward the social implications of science and students' attitude toward inquiry improved. These results suggest that partnerships beyond the science classroom may be worth pursuing. They are at least worth further study.

3.232 Special Settings

Informal science education has become a hot-bed of activity in recent years. Its importance has been recognized increasingly in recent years. Its importance has been recognized increasingly in the National Science Foundation's programs of research and development. Nine studies of science in special settings were reported in 1986. Of these nine, seven involved trips to a museum or zoo.

It is generally recognized that students of all ages enjoy going on special trips during school time and that teachers, parents and administrators support the practice (**Bokhorji-Ghawanni**). Certainly the novelty of a zoo or museum is a powerful motivating factor; just getting away--anywhere--from the routine of the classroom is enough to account for student enthusiasm for "field trips." There is always the question, however, whether students learn better or more from field trips than from in-class instruction. For example, **Parks** found no effect of a visit to a museum exhibit on "dinosaurs" on sixth-grade students' achievement or attitudes when compared to a group who studied the topic in class. In a study of fifth- and sixth-grade students, **Borun, Flexer, Casey, & Baum** observed no cognitive advantage of having students experience an exhibit on simple machines prior to a classroom-type lesson. Students did indicate, however, that they found the lesson more interesting, enjoyable and motivational than the classroom lesson.

The cognitive effects of learning in special settings are often subtle. For example, **Kern & Carpenter** found no difference in student scores on a comprehensive final examination in a study comparing a field-study strategy to a laboratory strategy in a college-level earth science course. But analysis of specific test items showed that students in the field-study strategy scored significantly higher on questions involving application, comprehension, analysis, and synthesis--questions requiring higher order thinking skills.

Other investigators studied the impact of museum visits with special themes. **Finson** reported that middle school students' attitudes toward science and science-technology-science (STS) were significantly affected by a visit to a museum with an "STS" theme. **Birney** found significant differences on tests of facts and related concepts between groups exposed to museum exhibits rich in habitat information and zoological exhibits among sixth-grade students.

For some educators the knowledge that trips to special settings such as museums motivate students is sufficient reason for making such trips. But the question of how to make field trips more productive on the cognitive side remains a critical issue for teachers, administrators and parents. **Fire** investigated the effects of "attention cues" and "test cues" in conjunction with a visit to a hands-on museum exhibit on "shells" on achievement, curiosity, and mental effort among sixth-grade students. She found that merely supplying attention or test cues did not ensure learning for all students. However, she did find that students high in verbal ability learned more when they received test cues but no attention clues, while students low in verbal ability learned more when attention clues were provided.

Kubota reported on a study designed to explore the relationship between novelty, on-task behavior, and cognitive learning in a trip to the Pacific Science Center. Using a vicarious exposure treatment designed to reduce the novelty of the field trip, a placebo designed to be informative but not novelty-reducing, and the actual field trip itself, she observed that novelty-reducing resulted in more on-task exploratory behavior and greater cognitive learning. Her results provide encouragement and concrete strategies for those who utilize special settings in their programs of instruction.

Only one study of science fair activity was reported in 1986. In that study, **Silverman** found significant increases in interest in science among seventh-, eighth-, and ninth-grade students who participated in individual or group science fair projects but no significant change in student laboratory skills nor effects by student gender. He also investigated the impact of providing cash prizes to students and interestingly found no effect.

Most of us recognize the potential for learning science in the field or in other special settings. But our research base is very thin. In addition to developing and researching better ways to design exhibits and field experiences, research on pre- and post-trip activities is sorely needed to help teachers make the field-trip something more than a break from "real" learning in the classroom. Without attention to strategies for helping students engage in cognitive restructuring as a result of the special experience, field trips or museum visits probably cannot be justified purely on the grounds that students find them enjoyable.

3.24 Instructional Repertoires: How do teacher behaviors and practices affect student performance?

In this sub-section we review research which emphasizes teacher behavior over other instructional variables as determinants of student performance. Research relating teacher behavior to student achievement enjoyed prominence in the 1950's and early 1960's due largely to the pioneer efforts of Flanders, Smith, Medley, and others. But this form of "process-product" research dropped considerably in popularity in the late 1960's and early 1970's despite research such as Rowe's which showed that teacher "wait-time" does influence student behavior. Research of this type is again experiencing a resurgence, thanks to the work of Good, Brophy, Evertson and others in the "effective schools" movement. Reported in this section are studies relating some teacher factor to student performance.

Hewitt-Dortch investigated the relationship between elementary students' achievement during an activity-based series of lessons and teacher classroom management strategies. Eleven teachers were rated on eleven dimensions of classroom management by a team of observers consisting of a principal, peer

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teacher, and the investigator using the "Pilot Teacher Performance Assessment Instrument" (TPAI). Regression analyses showed a significant relationship between teacher management behaviors and student achievement.

In a related study by **Butler & Beasley**, one particular teacher management skill, initiating activity transition, was found to be effective in keeping students "on-task" during science activities. **Sanford & French's** report of an observational study of a tenth-grade honors biology class, on the other hand, suggests that topic complexity may be the most critical factor in the planning and managing of classroom instruction.

Lederman's study of 409 high school biology students and their 18 teachers uncovered several patterns of teacher behavior which were found to discriminate between teachers/classes determined to have a high or low conception of the nature of science as measured by the "Nature of Scientific Knowledge Scale" (NSKS). Using gain scores of students and three observations of each classroom across a semester, he was able to identify specific teacher variables such as use of anecdotes, use of humor, and instructional digressions which seemed to be related to student gains on the NSKS.

In another study of the relationship between teacher behavior and student performance, **Okebukola & Ogunniyi** observed fifteen preservice biology teachers in Nigeria using a Flanders (FIACS) system and their students using a "Class Participation Scale" (CPS) and administered a 40-item biology achievement test to the students at the end of an 8-lesson series. They found that the preservice teachers were able to modify their indirect-to-direct (I/D) behavior patterns as a result of special training. They also found that students in classes where the teachers' I/D was "high" scored significantly higher on the biology test and had a significantly higher class participation score.

Tobin (b) studied the relationship between student task involvement and achievement in fifteen intact grade six and seven classes in suburban Perth, Australia. He was specifically interested in the levels of student overt and covert activity. Using a coding system with eight on-task categories, the predominant behavior of each student and teacher was observed and recorded each minute. The proportion of time allocated to each of the eight categories was also calculated as a measure of time allocated to specified tasks. He found that teachers allocated 25% of lesson time to investigation planning tasks, 37% to data collecting, and 30% to data processing. Students spent an average of 90% of class time on-task. A significant positive correlation between formal reasoning (as measured by the "Test of Logical Thinking") and the proportion of time students' engaged in overt generalizing tasks suggested that students with higher reasoning ability tended to engage in data interpreting activities more so than students with lower reasoning abilities. Engagement on allocated tasks was related to achievement (as measured by a modified form of the "Test of Integrated Science Processes"), but formal reasoning scores accounted for more of the variance. It appeared that students were overtly engaged in learning tasks to a greater extent as the lesson sequence progressed, prompting Tobin to suggest that teachers will probably have to make a conscious effort to plan activities that require students to engage in a more overt manner for longer periods of time.

How does teacher reasoning level and teaching style preference relate to student gains in reasoning ability? **Lawrenz & Lawson** studied 30 fourth- and seventh-grade teachers and their students using reasoning tests developed by Lawson (1978) and others and a teaching preference instrument developed for the study. Using extreme scores on the reasoning and preferences instruments, four groups of teachers were formed. They found that students of teachers rated as "concrete-inquiry" made the greatest gains in reasoning ability while students of "formal-inquiry" teachers made the least gains. They also found that only the gains exhibited by students of concrete teachers (both expository and inquiry) were statistically significant. Lawrenz and Lawson were quick to point out in their article, however, that teachers were not observed in their study; teaching mode (inquiry/expository) was that merely expressed by the teachers--not necessarily practiced. They recommended additional study with direct classroom observations among other things.

Cusak, Wideen, & Sherwood did, in fact, observe 18 junior secondary science classrooms to determine the extent to which teachers promote formal operational thought. Using a specially developed observation schedule, they found that teachers most commonly attempted to create disequilibrium in students through questions and other encouraging techniques. However, they concluded that the observed teaching patterns did not resemble those generally considered to be ideal for promoting formal operational thought.

Wait-time research has consistently shown that how and when a teacher responds to students affects a variety of student outcomes. **Riley** investigated the effect of combinations of teacher "wait-time (one)" and question level on the science achievement of students in grades two through five. While he found that a 50/50 knowledge-to-comprehension question level and a long wait-time alone did result in significant differences on the total test score and on the comprehension subtest score, a combination of low-level questions and extended wait-time produced lower total test and knowledge scores. Thus, he viewed these results as support for a "wait-time threshold," but only when low-level, factual-recall questions are used.

Considering that the teacher is generally considered a critical, if not the most important, instructional variable in the science classroom, it is worrisome to see so few studies investigating the teacher's impact on student performance. Studies of teacher behavior require extended, direct observation of classrooms and teams of researchers. This translates to time and money, neither of which is usually available to researchers. Video tapes of classrooms cut down on some of the researcher's time, but place greater burden on an already overworked school staff. Perhaps the solution is to generate observational data of classrooms for research through activities that are done routinely in schools. For example, observations and/or video tapes resulting from teacher skills development projects conducted by local schools might serve double duty as research data with minimal amounts of additional guidance from a researcher. Teachers themselves might be stimulated to become an active investigator on the research team and computer networks such as "PSI-NET" could be used to link remote sites and share results. Whatever the mechanism, it is critical that research on teacher effects utilizing direct data collection in classrooms be expanded.

3.3 Exemplary Science Programs

About six years ago NSTA launched a "Search for Excellence" in science that simultaneously created a surge of optimism among teachers and administrators and a new area of study for science education researchers. The first round of activity saw school staffs trying to put on their best face so that they might be selected as exemplars. Almost immediately, however, science educators began to ask questions about the criteria defining excellence and the methods used to identify excellent programs. For example, what role does the teacher play in programs dubbed "excellent?" Can the behaviors which characterize excellent teachers be isolated, refined, and shared with others? What resources and support are needed to achieve excellence? In this section papers describing the status, evolution, and character of science programs are reviewed.

3.31 What characterizes exemplary science programs?

Yager described the genesis of the "search for excellence" in his report of a study to find common characteristics of teachers and programs identified in the NSTA's 1983 program. Based on the reports of the seventeen science educators who made two- to five-day visits to six centers of excellence, he summarized the common features of the programs. At the top of his list of critical and common features was one person with a vision. But the vision was always shared by others in the district including parents, administrators, and other teachers. Curricula in these programs were usually developed locally and focused on personal needs, societal issues, and career awareness. Significant time and funds were devoted to staff development and community spirit and involvement of local persons in science-related fields were usually evident. The importance of home activity and involvement of persons in science-related fields in the instructional program is also supported by two different case studies of nationally recognized schools in New England (**Micik** and **Dudley**).

Other characteristics of outstanding science programs were also reported by **Linas**. She lists teacher commitment, preparedness, and professional involvement as critical elements. For example, 95% of the teachers in programs identified as "exemplary" in Illinois majored in science; 60% held advanced degrees; and all schools encouraged participation in professional organizations.

3.32 How is science treated in textbooks?

Yager's analysis of exemplary science programs also listed the "de-emphasis on a single textbook" as an attribute of exemplary programs. The primary reason given for the de-emphasis was that no textbook could capture the contemporary issues on which the exemplary programs seemed to thrive. Teachers in exemplary programs consistently claimed that science textbooks failed to present a view of science as a human activity with complex societal interactions and implications. **Garcia** analyzed five earth science textbooks in terms of their treatment of basic science knowledge, investigative skills, nature of science, and interaction of science, technology and society. He found only one of the five offered any kind of balance among the four foci. His analysis revealed that 80% of the message in earth science textbooks is devoted to knowledge acquisition.

Researchers also reported on how textbooks handle special topics such as evolution and what factors influence textbook content. **Cain** traced the history of biology teaching in the Chicago area schools as a function of textbooks used and found clear evidence of societal pressure on key topics in the curriculum. In a study of ten paired editions of earth and life science textbooks to determine the influence of creationist groups on the treatment of evolution, **Grine** found that the topic was de-emphasized or eliminated altogether to avoid controversy.

Deciding what should and should not be included and emphasized in a science textbook that is going to be used as the basis of a course is not an easy matter, even when controversial topics such as evolution are not at issue. For example, **Hines** surveyed a nationwide sample of genetics instructors and counselors to determine what should be taught in a human genetics course for the lay public. Significant differences in the recommendations were found. Instructors used human genetic diseases and defects as ways to stress the mode of transmission while counselors saw the need to stress their clinical aspects.

3.33 On what should the science curriculum focus?

This difference in perspective reflects the central issue in the debate of a balanced science/technology/society (STS) curricula. A fundamental question is: What should drive the curriculum for the general student population? **Bybee & Maw** surveyed 325 science educators representing 41 countries regarding their position on science and technology related global problems and curricula. Topics related as critical for inclusion in a science curriculum included world hunger and food resources, population growth, air quality, and water resources. In addition, 89% of the respondents recommended that courses in STS be required of all students.

Studies describing science curricula in various countries reveal a wide range of emphasis on societal and technological issues. In Papua, New Guinea, for example, **Deutrom & Wilson** reported that efforts to implement a "science for all" theme with an emphasis on qualitative science with a practical application focus have been very successful in grades one through ten. **Al-Rashed's** study of science curricula in Saudi Arabia, on the other hand, revealed a very traditional content focus with emphasis on recall of factual knowledge. Then there is a third kind of curriculum that is common in countries with non-centralized systems as reported by **Rosier**. In describing Australia's science curricula he reported little evidence of an explicit or implicit core curriculum in most schools and low-level coverage of those topics which are included. Not until grades eleven and twelve did he note a consistent inclusion of topics, and then, these were treated from a theoretical rather than a practical perspective.

High school science teachers often perceive pressure from the universities to pour on the content in high school classes. Whether this is true or not depends on who is asked and when. Most recently, **Druger** surveyed college science professors in the United States to find out their views on ways to help them improve science teaching at the college level. In addition to calling for more funding for laboratories and staff, 90% of those responding expressed the feeling that students were being poorly prepared in high schools. The survey did not pursue what the professors meant by the phrase "poorly prepared." But data such as these are difficult to counter when trying to convince a traditional high school or middle school science teacher that most science content is irrelevant.

3.34 What characterizes the classrooms of exemplary science programs?

Other teachers are particularly interested in knowing what teachers do in science classrooms tabbed "exemplary." **Fraser, Tobin** (c), and **Treagust** presented three papers at a NARST symposium dealing with "Exemplary Practice in Science Classrooms" in which they described research conducted in 13 science and mathematics classrooms. They used interpretive research techniques to gather data including extensive classroom observations, numerous interviews with students, teachers, and others, and various written instruments. Their discussions defy simple summarization in a review such as this, but several things are worth noting about their reports. For instance, one of the first results mentioned in their paper set took the form of a caution. They reported that teachers identified by peers as exemplary were usually not strong in all areas of instruction--a fact which they viewed as not surprising but critical in procedures designed to identify exemplary teachers. They recommended that identification of exemplary teachers or programs be based on extensive observation rather than hearsay or written testimony. They also discussed ways in which research on classroom teaching can be used to change teacher behavior including peer coaching and rehearsal.

It is also interesting how they approached their study of the exemplary teachers. They distinguish between the "intended curriculum," the "implemented curriculum," the "perceived curriculum," and the "achieved curriculum" in their analysis--another critical element in the identification of exemplary programs. This distinction was not made in NSTA's early efforts to search for excellent programs nor is this distinction usually made by school administrators in procedures to "rate" teachers and programs. We suspect this question of the intended vs. the implemented vs. the perceived vs. the achieved curriculum will become more critical in the future and should be considered in research on teacher effectiveness.

3.4 Summary

What trends can be identified from the research on curriculum and instruction reported in 1986? What can we expect in this area in the next few years? Studies of curriculum development and evaluation represented only a small fraction of the total research in the area of "curriculum considerations" in this review, but it is likely that we will see increasingly more studies of this type as current funding of elementary and middle school science programs begins to generate trial materials. We should also see more studies of "informal science" materials and "STS" materials as more attention is focused on learning science in non-traditional contexts.

It is surprising and disconcerting that so little research has been done in science under the banner of "effective teaching." Programs to improve teaching skills have swept the country in the past few years, but little or none of the strategies are based on research done in the science classroom. Increasingly, science teachers are being asked to adopt instructional methods derived from research in reading and math which stress content acquisition and skill development. Unless the science education research community can provide a body of research to support alternative methods to facilitate student generation of concepts and higher order thinking skills, our efforts to develop curricula to achieve these goals will be thwarted.

The identification of exemplary programs of science education and the honors workshops are activities where carefully executed research programs to accompany the activities could pay high dividends. Publications related to the exemplary programs for the most part describe program components and detail factors associated with the teachers and administrators. These are interesting and stimulating, but they fall short of explaining how nonexemplars can become exemplary or why exemplary programs generate the enthusiasm they do and create the successes they enjoy. Research is needed to expose the underlying mechanisms that explain the successes of the exemplary programs and to develop models of teacher preparation that will help teachers improve. It is not sufficient to know that something is successful. We need to know why and how!

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4.0 INSTRUMENT DEVELOPMENT AND ANALYSIS

Traditionally, the field of educational and psychological measurement includes instrument development, scaling and metrics, reliability, and validity. Shavelson, Webb & Burstein (1986) note, however, "...that any discussion of psychometrics cannot, and should not, be divorced from the phenomena they are used to model" (p. 86). Thus, while the focus of this section is to summarize research efforts related to the development and validation of instruments to measure the process of teaching, learning, and schooling in science education, such efforts will be reported in the context of the topics under investigation. We have categorized the studies summarized herein into the following three domains:

4.1 The Measurement of Teaching and the Teacher
4.2 The Measurement of Learning and the Learner
4.3 The Measurement of Curriculum and Instruction

The reader will note that this section raises as many questions regarding the assessment of teaching, learning, and the process of schooling as it answers.

4.1 The Measurement of Teaching and the Teacher: Can we improve our efforts to assess teacher effectiveness, classroom processes, and teachers' cognitive processes?

The attitudes of many preservice elementary teachers toward the teaching of science are less than positive. Developing methods of accurately assessing the attitudes of preservice teachers should be a priority of science educators-- as should taking action to enhance the well reported negative perceptions of this target population. **Thompson & Shrigley** note that central to attitude research is the availability of reliable and valid instruments to measure attitudes. They recommended that it may be more reasonable to revise existing scales than to expend effort and additional resources on developing new instruments. Revising existing scales requires that attention be given to validation of the instrument. Thus, they revised the Science Attitude Scale (Shrigley, 1974). Six basic principles were followed to obtain a better estimate of the validity of the instrument. The Revised Science Attitude Scale contains 22 items, with a coefficient alpha of 0.89, and a range of adjusted item-total correlations from 0.27 to 0.82. They reported that the revised scale is a reasonably valid and reliable instrument ready for use in comparing treatment effects of groups of preservice teachers toward the attitude object of teaching. They noted that, with minor changes, the scale could be used to assess the attitudes of preservice teachers in junior high and high school. They also indicate that it may be possible to modify the scale so it could be used with inservice elementary teachers as well.

Abdel-Gaid, Trueblood & Shrigley designed a systematic procedure for constructing Likert attitude scales as supported by the sociopsychological and measurement literature. The 15-step procedure includes logical and psychometric tests for reliability, content, and construct validity, and unidimensionality. The second aspect of their study was to model the procedure to develop a scale to test the attitudes of preservice and inservice teachers toward the use of microcomputers in the classroom. A 23-item Likert microcomputer attitude scale with the following characteristics resulted:

a. a coefficient alpha of 0.89,
b. range of adjusted item-total correlations from 0.29 to 0.60,
c. range of interitem correlations from 0.04 to 0.60,
d. correlation of 0.20 with a mathematics attitude scale, and
e. favorable factor analysis and emotional intensity data.

They recommended that science educators who use the scale should continue testing its reliability and validity. They suggested that convergent and divergent tests should continue, perhaps with scales other than reading and mathematics attitude instruments. They also suggested that known group validation should be considered.

Ellis & Kuerbis reported on the development of an instrument to measure the computer literacy of science teachers in grades K-12. The instrument, the Test of Computer Literacy for Science Teachers (TCLST), is part of ENLIST Micros--a project to develop a curriculum for training science teachers to use computers. The instrument contains questions to assess 19 essential competencies for computer literacy for science teachers. A 12-step procedure for developing and validating criterion-referenced tests was used to develop the TCLST. At the time of their NARST report, the instrument was being pilot tested with 200 preservice and inservice teachers. The results of the pilot test were to be used to establish instrument reliability and its construct and decision validity. It is anticipated that this instrument will be able to be used by universities and school districts as a diagnostic test to determine if preservice and inservice teachers have achieved computer literacy, as well as by researchers interested in computer literacy as it applies to classroom teachers.

Scharmann, Harty & Holland describe the development, refinement, and partial validation of an instrument to assess preservice elementary teachers' "process orientation toward science." This construct is defined as "the ability to recognize/identify the basic and/or integrated science process skills consistent with their application within and contribution to an emergent understanding of the nature of science" (p.376). The instrument contains 25 items with an alpha coefficient of 0.83 and item to total correlations ranging from 0.28 to 0.62. The authors also reported predictive validity in that a significant Spearman's rho correlation was calculated between the entry level process orientation toward science of preservice elementary teachers and their science process achievement levels four months later in a course whose content was based upon the understanding, recognition, and application of science process skills. Construct validity was determined by comparing three groups of respondents with "known group differences."

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The findings of the **Scharmann, Harty & Holland** investigation reveal that it cannot be assumed that by teaching preservice elementary teachers the processes of science that they will necessarily understand the underlying philosophical constructs/tenets. Further, preservice elementary teachers may not exhibit the very understanding of the integrated process skills toward which they should be orienting their students. Thus, they contended that attempts to promote teacher inservice preparation on the uses of National Science Foundation sponsored curricula might do well to consider incorporating an orientation to the underlying philosophical tenets inherent to those programs, rather than simply conducting programs on "how to implement" the curricula. They noted that such a recommendation is supported by the findings of Wood (1972), Rutherford (1964), and Shymansky, Kyle & Alport (1982). This recommendation is further substantiated by the inservice model described and the curriculum implementation and evaluation results reported by **Kyle, Bonnstetter, Gadsden, McCloskey, Fults & Shymansky.**

Cheng developed and validated the Teaching Competency Evaluation Battery (TCEB) for assessing teaching competencies of prospective secondary biology teachers in Taiwan. The TCEB was used to examine the extent to which the Secondary Biology Teacher Education (SBTE) program of the National Taiwan Normal School is achieving its stated objectives. In addition to measuring teaching competency, biology subject matter, attitudes, and process skills were also assessed using existing instruments. The findings revealed significant differences in the TCEB scores of seniors compared to juniors, sophomores, and freshman. There was no evidence of a difference in scores between students' freshman and junior years, however. The biology subject competency improved as students progressed between freshman and senior standing, although their attitudes and understanding of the processes of science remained constant. Finally, students in the SBTE program generally met the standard for subject matter competency, but not for teaching competency.

Tobin reported on a study to extend the concurrent and predictive validity of the Teacher Performance Assessment Instrument (TPAI) by including a sample of middle school science teachers. The validity criteria for the study were student engagement and integrated process skill achievement. The results obtained in the study provide support for the concurrent and predictive validity of the total TPAI score, some TPAI competencies, and some TPAI indicators in a middle school science context. The TPAI data were sufficiently sensitive to reveal differences in performance that, in many cases, were positively correlated with student engagement and process skill achievement. Higher teacher performance as measured by the TPAI tended to be associated with higher rates of student engagement and process skill achievement. While citing several cautions regarding the interpretation of the results of this study, he encouraged science educators to use the TPAI measures in classroom based studies.

Fisher, Docker & Fraser provided an overview of several instruments for assessing school environment (as distinct from classroom environment), giving particular attention to Moo's Work Environment Scale (WES). The WES was designed for use in any work milieu. They note that its 10 dimensions of

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work environment seem well suited to describing salient features of the teacher's school environment: involvement, peer cohesion, staff support, autonomy, task orientation, work pressure, clarity, control, innovation, and physical comfort. Thus, they developed a slightly reworded version of the WES and assessed the validity of the instrument when used for the first time with school teachers. The initial administration of the instrument to 114 science teachers in 35 high schools revealed KR-20 reliability coefficients of 0.60 to 0.85. The WES was then cross-validated with larger samples of elementary and high school teachers responding to an actual form (N=599) and a preferred form (N=543). Data analysis attest to the internal consistency, reliability, and discriminate validity of both WES forms. The authors also considered applications of the WES in science education and, in particular, they presented profiles depicting interesting differences in the environments of elementary schools and high schools. We feel that this instrument may have potential in characterizing the school environments of exemplary schools, perhaps even enabling teachers and administrators the opportunity to work together to strive to create such environments.

Connelly & Clandinin outline a narrative method for the study of classrooms. The main feature of the method is the reconstruction of classroom meaning in terms of narrative unities in the lives of classroom participants. The work is epistemological in character but deviates from epistemology as commonly understood in curriculum studies by focusing on personal experience rather than upon reconstructed formal logic. Thus, the working question of their investigation was, "What is the meaning of specific classroom actions for teachers and students?" The theoretical character of the work is introduced through comparison and contrast with Schon's (1983) The Reflective Practitioner: How Professionals Think in Action. The empirical basis for the work is drawn from an in-depth, long-term case study with elected science teachers in schools. They summarized paradigmatic material drawn from studies with two teachers to illustrate the narrative method and to develop the notions of personal philosophy and narrative unities as part of participants' personal practical knowledge. They concluded with possibilities of the narrative method for the study of teaching and outlined how the notion of participants' narrative unities contributes to our understanding of science classes and of school improvement.

4.2 The Measurement of Learning and the Learner: Can we improve our efforts to assess the nature of learning and the characteristics of the learner?

Crow & Piper noted that many schools use mental ability tests as a basis for grouping students and planning their educational needs. The widespread use of such test scores throughout public and private schools demands that test items be unbiased. They contended that a way in which tests could be biased that has not been investigated thoroughly is the inadvertent use of analytical skill items favoring one perceptual orientation over another. Thus, they investigated analytic skill items on the Otis-Lennon Mental Ability Test for field independent bias. Analysis of variance and discriminate analysis revealed that the test was biased in favor of individuals with a field of independent perceptual orientation. This study addresses the importance of investigating test items for field independent bias. The authors noted that the presence of such bias should be of particular interest to science teachers. If mental ability tests favor those students who are able to use analytic skills more effectively, then high scores may predict high aptitude in science. More importantly, science teachers need to be able to recognize perceptual orientation bias on tests and need to be able to develop nonbiased tests. They also noted that the interpretation of the sum score of a mental test should be viewed as less reliant than interpretation of general mental ability tests that identify subsection scores.

Blum & Azencot noted that much has been written about the superiority or abomination of multiple-choice questions. They indicated that few attempts have been made to compare students' performance on multiple-choice and essay-type questions when students could choose between the two types of questions. Thus, they developed an examination that was divided into six sections. In each section students could choose to answer one out of two alternative questions. The content of the two sets of questions was the same. The large majority of the students chose the multiple-choice items. There was no significant difference between the scores that students obtained on the multiple-choice items versus the essay-type questions. These results shed doubt on the fact that students inherently perform better on multiple-choice type tests. It is interesting to note, however, that the interscorer correlation between the two examiners of each examination paper was practically perfect for the multiple-choice items (0.99), while it was very low for the essay-type questions (0.36). Thus, they concluded that multiple-choice questions appear to be much more reliable without influencing the level of grading.

Staver investigated the effects of problem format and the number of independent variables in the problem on the responses of students to a control of variables reasoning task. The results of this investigation indicate that adding independent variables to a control of variables reasoning problem leads to an overload of memory, which in turn affects performance. He recommended that science teachers pay close attention during instruction, as well as evaluation, to the demands placed on working memory. The challenge here is not to omit concepts that are abstract, complex, or difficult. Rather, it is to use methods of instruction and evaluation that reduce the overload on working memory as such ideas are introduced and evaluated.

Schibeci noted that a major problem in science education is the proliferation of instruments to measure student attitudes toward science. He noted that many of the instruments have been criticized on conceptual and empirical grounds, while many have been designed specifically for one study never to be used again. He stressed two reasons for examining currently available instruments. The first reason is the fact that with the large pool of instruments, research can be focused upon validation of these instruments. The second reason is to allow for direct comparison of student variables in different countries, a task more validly pursued when the same, or slightly modified, instrument is used. Thus, **Schibeci** identified the Student Opinion Survey in Chemistry (SOSC), developed by Heikkinen (1974) as part of the evaluation program for the Interdisciplinary Approach to Chemistry, as a

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suitable instrument for the formative evaluation study of the Academy of Science's School Chemistry Project in Australia. The instrument was slightly modified to make it more suitable for use with Australian secondary school students. The modified SOSC has a high internal consistency, with values of Cronbach's alpha ranging from 0.90 to 0.95. Item-remainder correlation coefficients were also computed, with values ranging from 0.47 to 0.76. **Schibeci** also factor analyzed the student response data (such data were not reported by **Heikkinen**). Three factors emerged such that these data together with the high values for the Cronbach's alpha, suggests that the SOSC is essentially a unidimensional instrument. It is apparent that the SOSC is a worthy instrument to assess student attitudes to chemistry.

Methen & Wilkinson developed an instrument to explore student perceptions of their science teachers' classroom behavior, personality traits, and attitudes. They were interested in determining the factors that students in high school associated with good teaching, as well as to what extent students' perceptions of the ideal science teacher correlated with the results of other student-rating studies. A sample of 210 students from four Kuwaiti high schools were asked to specify the five most important qualities of both a 'good' and 'bad' science teacher. From the more than 2100 statements generated, 99 statements survived the initial judgement criteria and were subjected to item analysis. The resulting Science Students' Perception Questionnaire (SSPQ) contains 46 items, and is characterized by a split-half reliability coefficient of 0.95 after applying a Spearman-Brown correction and a KR coefficient of 0.87. The list of classroom behaviors, personality traits, and attitudes is extensive and we encourage you to review the manuscript. In essence, it was found that students' views of the ideal science teacher corresponded very closely with findings of other research studies attempting to use student ratings to measure teacher characteristics. The authors cite potential uses of the instrument. We would certainly encourage that this article be used in science methods courses so that prospective teachers gain a better appreciation for the factors that students regard as prerequisites for success.

Adey & Harlen explored the application of a Curriculum Analysis Taxonomy (CAT), founded in notions of stagewise cognitive development, to test items designed to assess certain science process skills. A sample of Assessment of Performance in Science (APS) items, which was to be included in the 1983 survey of 11 year olds in Britain, was analyzed using the CAT to estimate the level of cognitive demand of each item. The main instruments were the sets of test items used by APS to survey science (mostly process) skills and the Concepts in Secondary Science and Mathematics taxonomy of science objectives. The results indicated that there was strong evidence that the limiting difficulty of items testing process skills could be predicated from the cognitive demand that each makes, determined with a CAT based on Piagetian ideas of stagewise development. There was also good evidence that the ratio of the actual difficulty of an item to its limiting difficulty was a measure of the extent to which faculty levels may be raised by modest improvements in curriculum or teaching methods. There was also support for the notion of a hierarchy of process skills (we refer the reader to a discussion of hierarchical relationships among Piagetian cognitive modes and integrated process skills by **Yap** and **Yeany, Yap & Padilla** in Section 2.11),

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as evidenced by systematic differences in faculty of different item categories, by a corresponding difference in cognitive demand levels, and by the apparent difficulty of writing items referenced to the criteria of different process skills which are nevertheless of similar faculties. Thus, Piagetian analysis can yield information about the relative effect of experiential and cognitive constraints on the difficulty of items. It is apparent that the application of Piagetian analysis to process skills has proven fruitful.

McKenzie & Padilla developed and validated a multiple-choice test of graphing skills appropriate for science students in grades seven through twelve. Skills associated with the construction and interpretation of line graphs were delineated and nine objectives encompassing these skills were identified. Twenty-six items were then constructed to measure these objectives. The objectives and the Test of Graphing in Science (TOGS) was submitted to a panel of reviewers to establish content validity. TOGS was first administered to 119 7th, 9th, and 11th graders. The initial reliability was 0.81. Poor items were rewritten and the revised version was administered to 377 students in grades 7 through 12. The KR reliability was 0.83 for all subjects and ranged from 0.71 for 8th grade students to 0.88 for ninth grade students. The authors noted that graphing ability is an overlooked skill that should be addressed in all science programs. TOGS should be useful to the classroom teacher and/or the educational researcher. Teachers interested in NSTA's Every Teacher A Researcher program could use TOGS to assess entry characteristics of students, as well as to assess the effectiveness of various instructional strategies to instruct the objectives of the test.

Collis & Davey described the procedures in developing a set of science items to test a variety of intellectual skills deemed important in secondary school science. They then analyze the items in order to examine their construct validity in relation to a technique of evaluation which assesses the way in which individuals structure their responses to previously learned materials. The items covered the four sciences commonly taught in Australian secondary schools (geology, biology, chemistry, and physics). Each item followed the superitem format, consisting of a stem followed by four questions, each question showing an ability to respond at a particular level (unistructural, multistructural, relational, or extended abstract). The analysis showed that the developed items had construct validity in terms of theory and were viable for testing certain skills at the high school level. Further analysis at the middle school level revealed an apparent significant movement up the categories as students progress to high school. Further research is necessary in the domains of curriculum development, instructional strategies, and the correlation of curricular objectives to test items.

Treagust & Fraser developed the College and University Classroom Environment Inventory (CUCEI) to measure seven dimensions of student or teacher perceptions of either the actual or preferred environment in seminars or tutorials. Validation data were collected from a sample of 499 students and 20 instructors. The final version contains 49 four-point Likert scale items.

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Schibeci, Fraser & Rideng were interested in investigating the effects of classroom environment on students attitudes toward science. A secondary outcome of their work was the development and validation of the first instruments available in the Indonesian language for assessing classroom environment and science-related attitudes. The instrument was based upon the Individualized Classroom Environment Questionnaire and the Classroom Environment Scale. A three-stage development plan was utilized. The finding of statistically significant associations between environment and attitudes replicated much prior work in developed countries. For example, more favorable science-related attitudes on several scales were found in classes perceived as having more personalization, participation, investigation, order, and organization. This investigation again demonstrates the value of modifying existing instruments for use in cross national replications/comparisons. The results of such investigations, with comparisons to existing data bases, can be exceptionally fruitful.

In order to facilitate science teachers' use of classroom climate assessments, **Fraser & Fisher** developed economical short forms of the Classroom Environment Scale (CES), Individualized Classroom Environment Questionnaire (ICEQ), and My Classroom Inventory (MCI) which contained approximately 25 items each and are amenable to hand scoring. When each instrument was administered to a large sample of science classes, results supported each scale's internal consistency reliability, discriminate validity, and ability to differentiate between the perceptions of students in different classrooms. The methods for improving classrooms are illustrated by reporting some case studies of change attempts. For example, when the CES was used in an attempt to improve the environment of a ninth grade science class, the steps followed were, first, assessment of actual and preferred classroom environment in order to identify discrepancies between actual and preferred environment and, second, introducing interventions aimed at reducing these discrepancies. The interesting finding was that significant improvements occurred for the two dimensions on which change had been attempted. This finding demonstrates the reliable and convenient means in which the environment can be assessed and appreciable changes can be made to address the dimensions upon which change is desired on the part of the teacher.

The work of **Fraser & Fisher** suggests the potential usefulness of teachers employing classroom environment instruments to provide meaningful information about their classrooms and a tangible basis to guide improvements in classroom environments. These instruments offer another excellent opportunity for teachers who are interested in conducting classroom based research that has direct and meaningful implications for their own classroom. We also encourage science methods instructors to introduce these instruments to their students and encourage them to engage in classroom based research that could significantly enhance the quality of science education that they provide their students.

4.3 The Measurement of Curriculum and Instruction: Can we improve our efforts to assess the impact of curricular interventions and instructional variables upon learners?

Balaco developed a summative test for each of the two modules of a new high school chemistry curriculum, ChemCom. The tests were designed to assess students' understanding of basic chemistry and their ability to apply their knowledge to solve societal problems related to the Petroleum and Water modules.

The assessment of developmental reasoning is becoming a necessary part of teaching. Awareness of such information enables teachers to modify instructional strategies and helps teachers better understand students' intellectual development. **Roadrangka** developed the Group Assessment of Logical Thinking (GALT) test that validly measures six logical operations and can be administered in one class period. The GALT has a coefficient alpha of 0.85, inter-correlation among subtests ranging from 0.19 to 0.55, a one-factor solution with the factor loading structure ranging from 0.44 to 0.76, concurrent validity of 0.71, and predictive validity of 0.71. The reading level of GALT is appropriate for students in sixth grade and above.

Borst developed, validated, and established the reliability for a computer program that would: distinguish between concrete and formal thinking patterns related to control of variables; be easily administered to a class of secondary school students; preserve the interactive aspects of Piagetian tasks; be scored using a related computer program; and preserve the questioning of the Piagetian tasks. A sample of 75 secondary students (38 males and 37 females) was tested using the computer simulation, the Pendulum Task of Inhelder and Piaget, the Lawson Classroom Test of Formal Thinking, and the ACS Test of High School Chemistry. Based upon statistical relationships between the computer simulation and the Pendulum Task, it was concluded that the technique has a degree of construct validity. Concurrent validity was established on the basis of nonparametric correlations. The results also indicated a high degree of test-retest reliability, as well as demonstrating significant differences between males and females.

The use of microcomputers in teaching science is increasing rapidly. Teachers are faced with the need to identify quality software for inclusion in the curriculum. **Zohar & Tamir** indicated that one of the major applications of computer software in science teaching is in the simulation of actual laboratory and field investigations. In this context microcomputers play the role of invitations to inquiry. Thus, they developed an instrument to help teachers in responding validly and reliably to the item in the NSTA Microcomputer Software Evaluation Instrument asking, "to what extent the package gives attention to scientific inquiry and integrates science inquiry processes." The Computer Software Inquiry Inventory was developed based upon the Laboratory Structure and Task Analysis Inventory (Tamir & Lunetta, 1978). The CSI focuses upon five features of the software: nature of investigation, advantages of the computer program over actual lab investigation, inquiry skills, concepts related to inquiry, and level of inquiry.

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Lubert developed and evaluated a new educational instrument, Alternatives to Reality (AR). AR is the use of non-realistic data, generated by computer simulations, to teach specific topics within an introductory physics course. Four AR computer simulations were developed: Projectile Motion, Law of Inertia, Mass-energy, and Relativity. The first two were designed to help students overcome existing misconceptions regarding the physics of projectiles and inertia. The latter two were designed to make obvious the relativistic changes in mass, length, and energy that occur at speeds near the speed of light. In accordance with the developmental objectives, AR was shown to be an effective means of teaching specific introductory physics topics.

Treagust & Haslam developed an instrument to measure students' misconceptions about photosynthesis and respiration in plants. The two-tier multiple-choice diagnostic test reveals a number of misconceptions that students in grades 8 through 12 possess. These findings were discussed in Section 2.143. These results demonstrated the need for reliable and valid pencil and paper tests, that are easy to score, that will enable teachers to better assess students' understanding of science concepts and thus improve classroom instruction. Through the use of diagnostic tests such as the type developed in this study, science teachers can formulate clear images of the understandings that students possess regarding a specific scientific concept. Once misconceptions are identified, teachers will be more inclined to remedy the problem by developing alternative teaching approaches which address students' misconceptions.

Finley illustrated the advantages of using clinical interviews as a complement to paper and pencil achievement testing to provide specific insight into how students' knowledge changes as a result of instruction. While investigating the instructional effects of an educational television series on magnets with second grade students, it was noted that students who viewed the series did not perform any better on a paper and pencil test of magnetic concepts when compared to students who did not receive any related instruction. Clinical interviews, however, revealed that students who viewed the series learned a substantial amount of new information that changed their understanding of magnets and magnetic interactions and decreased errors in their descriptions and explanations. This study also indicated that changes in student conceptions can occur without corresponding changes in vocabulary. It is apparent that descriptions of the changes that occur during instruction are able to be acquired through the use of clinical interviews. Such information is necessary in order to be able to design effective curricular materials that can effect conceptual change. Test developers must now consider the importance that will be placed upon learning vocabulary, the importance that will be placed upon learning new conceptions, and developing items that will test for both if the latter is of importance in the evaluation of student performance. It is evident that traditional testing generally assesses the acquisition of vocabulary. The use of clinical interviews can certainly assist in the development of tests that will more accurately assess conceptual changes and yet be independent of the intended vocabulary.

Experimental work in science is more difficult to assess than theoretical material. **Alberts, van Beuzekom & Hellingman** indicate that this problem has been solved to a certain extent in The Netherlands by the project Experimental Tests of the National Institute of Educational Measurement. They described in detail the procedure of test development that was used. The development of standardized tests for experimental work fulfills an important function in the operationalization of goals. After all, the questions and tasks in a test still have another function, in addition to checking what students know and are able to do; they give us a concrete basis when we ask the question if it is indeed <u>these</u> goals that we want to accomplish with our instruction. Thus, experimental tests enable us to discuss the goals of practical work in science.

Kyle & Shymansky developed the Science Interaction Category System (SICS) to systematically assess teacher and student behaviors in elementary science classrooms as part of a curriculum implementation process. Of particular interest was whether teachers were implementing the curriculum in accordance with the desired instructional goals of the program. The SICS Teacher and Student Versions are based upon the Science Laboratory Interaction Category (SLIC) system that was developed for use in college science laboratories (see, Shymansky & Penick, 1979). Three dimensions of classroom interactions were coded: the teaching/learning mode; the activity context within the teaching/learning mode; and the specific behavior exhibited by the teacher or student. Intercoder reliability was 0.87 for teacher observations and 0.91 for student observations. The results of the study substantiate the fact that the nature of process approach science classes positively affects the interactive structure of science classes. The observational results also confirmed a number of self-reported needs of teachers related to implementing effective instructional strategies for process science. It is apparent, however, that when teachers receive the necessary district support, in the form of staff development and curricular resources, that they are able to effectively implement a curricular innovation that positively impacts student performance.

4.4 Summary

In this section we have summarized a number of efforts that strive to offer new and creative ways to assess the process of teaching, learning, and schooling in science education. While we wholeheartedly agree with the recommendation of **Schibeci**, admonishing the indiscriminate development of instruments when more research could be fruitfully directed towards the validation of existing instruments, science educators must balance this recommendation with the need to develop new instruments to address new questions! We must also continue to pursue cross national studies so that we can address the issue of quality science education from a global, rather than a national, perspective.

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