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ABSTRACT

This publication is designed to inform practicing science teachers of recent, relevant research results in the field of science education. Articles are written to identify ideas of practical application in the science classroom, to inform science teachers of the kinds of research which need to be done to supply answers to current concerns, and to make science teachers aware of relevant research in their field. This issue reviews science education research in the areas of: (1) science learning and gains in language and reading; (2) inquiry training and questionning techniques; (3) student science attitude and achievement; (4) learning in science laboratories; and (5) learning during field trips. (SL)

Volume I

WHAT RESEARCH SAYS TO THE SCIENCE TEACHER

Mary Budd Rowe, Editor

NATIONAL SCIENCE TEACHERS ASSOCIATION

THE ERIC SYSTEM

ERIC, an acronym for the Educational Resources Information Center, is a nationwide information system designed and supported by the National Institute of Education (NIE). ERIC is composed of a nationwide information ntework for acquiring, selecting, abstracting, indexing, storing, retrieving and disseminating the most significant and timely education-related reports. It consists of a coordinating staff in Washington, D.C., and 16 clearinghouses located at universities or with professional organizations across the country. These clearinghouses, each responsible for a particular educational area, are an integral part of the ERIC system.

Each clearinghouse provides information which is published in two reference publications, Resources in Education (RIE) and Current Index to Journals in Education (CIJE). These monthly publications provide access to innovative programs and significant efforts in education, both current and historical.

In addition, each clearinghouse works closely and cooperatively with professional organizations in its educational area to produce materials considered to be of value to educational practitioners.

PREFACE

Clearinghouses of the Educational Information Resources Information Center (ERIC) are charged with both information gathering and information dissemination. As Rowe points out in her introduction to this publication, there is a need for teachers both to become more aware of relevant research and to participate in research activities. Awareness must precede action. In an attempt to help teachers develop this awareness of research in science education and of how research can be used to improve teaching-learning, the ERIC Clearinghouse for Science, Mathematics and Environmental Education has commissioned a publication focused on some areas of science educatior research and the implications for classroom practices.

The ERIC Clearinghouse for Science, Mathematics and Environmental Education has worked cooperatively with the National Science Teachers Association (NSTA) on this publication. Personnel frcm NSTA selected an editor for the publication and authors for the various sections. The National Science Teachers Association plans to broaden the dissemination of this publication by holding conferences in various locations at which the publication's authors will discuss their findings with teachers. It is hoped that the publication and conferences will stimulate classroom teachers to become interested, and involved, in research.

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Volume 1

What Research Says to the Science Teacher

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Introduction

Research Can Help You

If science disappeared from the public school curriculum, would anybody miss it--except those teachers who would be out of work? Science programs at all levels are under assault: There is less money for equipment and materials. And there are encroachments on the time available to teach science coming from two sources: the "back-to-basics" movement, and the press to add more topics to the curriculum. We are also in an era in which accountability is a major value. Citizens want to know what they are getting for their money, and whether what they are getting is in some sense valuable to students.

What can we as science teachers say in reply? Much less than we would like to, for two reasons: First, our teachers are generally unaware of relevant research, and second, there is a need for a wider involvement of classroom teachers in research. The science of medicine progressed as its research base broadened, that is, as clinicians became involved in supplying data, and as knowledge of research results became available to them through journals. Similarly, writers in this publication hope not only to let you know what has been learned that may help you as a practicing science teacher, but also to specify some kinds of research which needs to be done to supply answers to our concerns.

Wellman, for example, supplies one answer to the back-to-basics enthusiasts who would steal time from science. She summarizes the results of eighteen studies of science learning in which there were also gains on general language and reading variables. In short, her research review suggests that the science program may be a more effective way for getting at some basic skills objectives than other more traditional approaches.

In the course of trying to teach students concepts and problem-solving processes, we teachers ask a lot of questions (it turns out that srudents ask very few). McGlathery suggests that if we are treating students to a constant diet of questions (that is, if we are professional question-askers), then the research on this process may help us do our job more effectively. Thus, he looks at what research shows is likely to happen to student achievement under different questioning strategies. His review invites us to look at the balance we have between high- and low-level questions, between open vs. focused questions. How many of our so-called open-ended questions are only vague? And what of students. . .do they need to be taught to ask questions? Some results in this area are exciting--clearly, classroom teachers need to be involved in research that relates to teaching students how to ask productive questions.

Classroom teachers have always known intuitively that student attitudes and achievement somehow related to the way students performed in school. In studies from 17 countries, attitudes toward the subject correlated more strongly with achievement in science than in any other field. What can we science teachers do to influence feelings and attitudes toward science? In what way, exactly, do attitudes and feelings change performance? Simpson discusses what we know and what we still must learn about the connections between feelings, attitudes, and performance in science.

High school science has typically been funded at a higher level than some other subjects, to meet the costs of operating the laboratory. But what are students learning in laboratory that could not be learned as well, and with less expense and time, by lecture and demonstration or by some audiovisual exposure? Bates examines the results of a number of studies on this question. These studies may upset your most dearly held beliefs, because a great many of them suggest that the laboratory is not an efficient or necessarily effective means for teaching <u>content</u> concepts. Do we expect students to get more than basic concepts from laboratory experiences? If so, we need to be explicit about <u>what</u> outcomes are important and how we can tell if they are being achieved.

Similar concerns arise in connection with other planned learning experiences, such as field trips. What do students get out of them, given the time and preparation they take? Watson discusses the rationale behind experiential learning, and reports that while there is some indication that attitudes are favorably influenced by some kinds of field-trip and museum experiences, the <u>objective</u> data respecting outcomes of any kind are very sparse. His paper constitutes an invitation to classroom science teachers and supervisors to do some field-based research related to our beliefs and hunches.

These papers may be especially important to read right now, since we stand on the brink of a major technological revolution that will have tremendous impact on education, particularly in science and mathematics. Technologies related to microprocessors have changed radically, even in the past two years, along the lines of miniaturization, speed of processing, and reduced costs. We may soon have at our disposal sophisticated processors that can be adapted to particular content areas by substituting insertable wafers. Increasingly sophisticated laboratory simulations will be possible. Thus, time will be available in larger chunks, with less wasted on onerous calculations and recalcitrant equipment. Before this age is upon us we need to think about what we know about learners, their attitudes, and the concepts and understandings that are important in science. You can count on it, there is a new age coming--and science teachers ought to be in the vanguard.

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Science: A Basic for Language and Reading Development

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The art of reading . . . includes all the same skills that are involved in the art of discovery: keenness of observation, readily available memory, range of imagination, and, of course, a reason trained in analysis and reflection . . . To whatever extent it is true that reading is learning, it is also true that reading is thinking.

- Mortimer Adler*

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*Quoted by Russell G. Stauffer in Teaching Reading as a Thinking Process. Harper & Row, New York, N.Y. 1969.

If we accept Mortimer Adler's contention that reading is thinking, then, to the extent that science teaching emphasizes intellectual skills, it should also develop student ability in language arts and reading. That is, science skills should enhance reading skills. And science programs, especially the newer ones, are increasingly stressing the importance of science processes--that is, intellectual processes such as hypothesizing, predicting, observing, classifying, and so on.

There are good reasons for suspecting that some modern science programs do, in fact, hold considerable promise for developing skills necessary for reading. These programs emphasize processes of inquiry, and provide children with direct experience with phenomena. Students learn the language and logic of inquiry by involvement in it. In addition, as Newport remarks, many of the activities are conducted in settings conducive to verbal expression. (24) Action, plus the chance to talk and argue on the basis of evidence, ought to contribute to language development, and ultimately to the ability to extract meaning from written prose.

Lucas and Burlando (19) further theorize that:

> Other reading skills appear to be "built in" for use in the discovery process being stressed by most new science materials. The scientific experiences are designed so that the student will be asked to define problems, locate information, organize information into graphic form, evaluate findings, and draw conclusions. In addition to these inherent skills, the new science curricula are more individualized and self-pacing in keeping with reading instruction. It becomes obvious that this type of science curriculum demands a myriad of skills concomitant with those of a well developed reading program.

What we must do, then, is examine educational research to see whether there are empirical data to substantiate the view that science can help students learn to read. We want to know whether children lacking in communication skills would benefit from hands-on science activities. We want to know how science teachers can facilitate language and reading skills in their classes, and whether special teacher training is necessary. We would like to know whether student experience with science will have any significant impact on standardized reading test scores.

This paper will attempt to synthesize and interpret research dealing with these questions, and will also suggest classroom applications at the elementary and intermediate levels. It will also present evidence to support the following contentions:

1. Active experience with science helps language and logic development.
2. Science instruction appears especially helpful for children who are considered physically or culturally "different."
3. Selected science activities accelerate reading readiness in young children.
4. Science activities provide a strong stimulus and a shared framework for converting experiences into language.
5. Reading skills stem from language and logic development, which comes after concepts are formed from repeated encounters with objects and events. Such encounters are provided by science experiences.

Science and Reading Readiness

Research supports the argument that early experience with science helps all children with language and logic development, regardless of their socioeconomic status. In one study, for example, Renner, et al. hypothesized that the Science Curriculum Improvement Study (SCIS) provided experiences which were more likely to develop reading readiness than the average reading program. (28,29) The hypothesis was tested using four first-grade classes in Ada, Oklahoma, which were randomly designated as "experimental" and "control." The two experimental groups used the SCIS Unit "Material Objects," while the control groups used a commercial reading-readiness program. At the end of six weeks, all subjects were given a Metropolitan Reading Readiness Test (MRT) which provided scores on these subtests: Word Matching, Listening, Matching, Numbers, and Copying. The experimental groups (those that used SCIS) made greater gains on all of the subtests, except copying.

Similar results were reported in another study by Renner, et al., designed to evaluate the effectiveness of the first-grade SCIS program ("Material Objects" and "Organisms"), as a reading readiness program. (30) After studying 60 first-grade children from Norman, Oklahoma, Renner concluded (a) that experiences with the SCIS first-year program greatly enhance children's ability to conserve (a logical operation involving keeping track of quantities despite changes in shape), and (b) that the ability to conserve contributes to readiness for reading.

The fact that a child's ability to think contributes to reading readiness was also reported by Almy in an earlier study:

> ...the findings in our studies of a rather substantial correlation between performance in conservation tasks and progress in beginning reading suggests that, to some extent, similar abilities are involved. A program designed to nurture logical thinking should contribute positively to reading readiness. (1)

In a study using measures from MRT, Frostig, ITPA, and "Material Objects" to assess the effect of selected science activities on reading readiness, Maxwell provided evidence that SCIS activities produce positive and significant effects on kindergarten children's reading readiness scores. (21) Maxwell's treatment group also outgained the control group in development of language facility and experience.

Neuman has also presented strong arguments for providing young children with experiences with natural phenomena as a way of improving reading. (23) He studied three kindergarten groups from central-city schools in Milwaukee, comparing the Metropolitan Reading Readiness Test scores of kindergarten children who had science instruction with those of kindergarten children who had no science instruction. He also compared reading achievement test scores of first graders who had had science activities during kindergarten with scores of first-grade children who had not had experience with science. His data revealed that (a) kindergarten children who had science instruction tended to score higher on reading-readiness tests (including subtests), and (b) the first-grade group that had science during kindergarten scored higher on the reading achievement test than the group that had no science during kindergarten. Specifically, Neuman's findings indicate that science activities can provide opportunities for manipulating large quantities of multisensory materials, which promotes perceptual skills (tactile, kinesthetic, auditory, and visual). These skills then contribute to the development of the concepts, vocabulary, and oral language skills (listening and speaking) necessary for learning to read.

Ayers and Mason have investigated the influence of Science: A Process Approach (SAPA) on reading readiness. (2) Their subjects were drawn from two kindergarten classes in Atlanta, Georgia. The treatment group used Part A of SAPA, which is designed for kindergarten children and emphasizes making observations and communicating them to others. MRT pretests and posttests were given to all subjects. Comparison of scores showed that the experimental group (which had SAPA) outgained the control group (which did not) on the subtests of Listening, Numbers, and Copying, and on total test scores.

Based on a later study of Appalachian kindergarten children, Ayers and Ayers concluded that SAPA influenced children's readiness for reading by refining their ability to use logic. (3) The children's ability to use logic was demonstrated by their performance on six conservation reasoning tasks: numbers, liquid amount, solid amount, length, weight, and area. This study substantiated what Almy had found earlier--that the ability to conserve is an important factor in beginning reading. (1)

Working with disadvantaged kindergarten children from inner-city schools in Columbus, Ohio, Huff and Languis found that SAPA produced a positive effect on the development of oral communication skills. (8)

Children who were exposed to SAPA far exceeded the performance of those who did not have any science on six oral language measures: language output, vocabulary, general meaning and skills, sentence structure, defining words, and listening behavior.

McGlathery also found that disadvantaged preschool and first-grade children showed significant gains in language development after participating in an activity-based science program. (22)

Wellman reported that Appalachian first-grade children greatly increased their vocabulary word size (number of letters per word) when they were taught science in a format that emphasized oral communication. (2)

Kolebas (10) and Macbeth (2) did separate investigations to determine the effects of SAPA on skill development and reading achievement of kindergarten and third-grade children. Kolebas found that children who had SAPA in grades 1-3 significantly out-scored the third-grade control group which had not been exposed to SAPA.

Macbeth, working with kindergarten and third-grade children, concluded that kindergarten children who used SAPA showed more extensive attainment of process skills than the control group. However, in his study, there was no significant difference in the attainment of skills at the third-grade level. Macbeth concludes that as they mature, children become less dependent on manipulative learning and rely more on verbal learning.

The implication of the preceding studies and others (6,14,36,38) is that direct, first-hand manipulative experiences with science enhance the development of process skills, at least in young children (these skills include: observing, describing, predicting and communicating). Attainment of process skills has a positive correlation with success in beginning language and reading achievement. Only two studies suggest that science facilitates reading at more advanced grade levels. These will be discussed later.

Science for Children Who Are "Different"

Children who are either culturally or physically "different" also benefit from science activities. Kral found that American Indian children scored higher on Stanford Achievement Tests after experience with Elementary Science Study (ESS) units, which are designed to develop process skills. (12)

Horn (7) and Stemmler (36) report that SAPA is culturally "fair" and positively influences oral language development in culturally "different" Spanish-speaking first-graders. The data showed an increase in complete spoken sentences, length of attention span, auditory discrimination, ability to follow directions, and listening ability.

Linn and Peterson (16) and Long (18) found that visually impaired and blind children attained science process skills and concepts when exposed to SCIS and SAPA units providing direct, concrete, manipulative science experiences.

Bybee and Hendricks (4) tested the hypothesis that language skills would improve in deaf children as a result of their using (and communicating about) ESS and SCIS units. Basing their results on a uniquely designed feasibility study of pre-school deaf children, Bybee and Hendricks reported that deaf children: (a) learned science concepts and evidenced applicative ability; (b) increased their vocabulary approximately 25 percent; (c) improved their reading skills; and (d) developed positive attitudes toward themselves.

Rowe reports that some ghetto children who could be considered functionally deaf (that is, many words elicit for them neither concepts nor mental images) bridged the communication gap through science. (33)

Content Reading in Intermediate Grades

This section will examine how science instruction can increase language and reading skills for intermediate-grade children (4,5, and 6), who are involved mostly with content reading--that is, who are beginning to read for information. Though less extensive, research suggests that science instruction does improve the attainment of reading skills at these grade levels, too. Some of the benefits that intermediate-grade children have been found to derive from science instruction are: vocabulary enrichment, increased verbal fluency, enhanced ability to think logically, and improved concept formation and communication skills.

Among the literature reviewed for this paper were certain studies which, taken together, suggest that a strong activity-oriented science program seems to strengthen the development of language/reading skills in intermediate-grade children. (5,9,11,25)

In addition, using fifth- and eighth-grade students from rural, suburban, and urban areas in seven states, Linn and Thier (17) investigated the effect of SCIS on development of logical thinking. They found that the fifth-graders who had experienced the SCIS unit "Energy Sources" appeared to be better logical thinkers than were fifth-grade groups who did not have SCIS. Also, the treatment group of fifth-graders had scores very close to the eighth-graders in comparable areas. This study did not, however, directly ask whether or not these students were also better readers.

A study conducted by Quinn and Kessler (26) with sixth-grade children again illustrates the relationship between language development and an inquiry approach to science education. These authors concluded that both science and language processes draw on the same cognitive base. Similarly, Rowe reported in two earlier studies that student-initiated and spontaneous speech during science classes exceeded spoken language in language arts classes by 200 percent or more. (33,34)

In a classical study, published in two parts, Rowe also showed how teacher "wait-time"--pauses after questioning a student and after the student's response--can influence the development of language and logic. (32,35) After six years of investigation (which produced over 300 tape recordings from grades one through six) Rowe concluded that teacher use of "wait-time" could significantly affect language and logic development.

Renner, et al. (30) and Webber (37) designed studies to test the effectiveness of SCIS on the achievement of fifth-graders. Based on data from both studies, SCIS does develop science processes (observing, classifying, interpreting, and communication) to a significant degree. An analysis of Stanford Achievement Test scores provided evidence that children who used SCIS materials also scored higher in subtests for mathematics application, social studies, and paragraph meaning. The implication is that when SCIS is taught, reading, mathematics, and social studies are taught also.

As a closing thought, Laffey has noted that teachers too often teach content through reading, instead of teaching reading through content. (13)

Conclusion

Research cited in this report builds a strong argument that the study of science helps young children to develop language and reading competencies. (See Table 1.) Though the research on the relationship between reading and science in the intermediate grades is much less extensive, there is some indication that science can play an important role in strengthening the logical processes necessary for effective content reading.

Table 1. A Summary of Studies Showing the Relationship Between Science Experiences and Language/Reading Development

Authors	Grades/ Levels	Language/Reading Variables	Types of Children	Types of Tests (when relevant)
Ayers & Ayers	K	Word Meaning, Listening Matching, Alphabet & Copying	Semi-urban Appalachian	Metropolitan Readiness Test (MRT)
Ayers & Mason	K	Word Meaning, Listening Matching, Alphabet & Copying	Urban	Metropolitan Readiness Test
Bybee & Hendricks	K	Language Development	Deaf Children	
Campbell	4-5-6	Comprehension		
Huff & Languis	K	Vocabulary Word Meaning Listening & Sentence Structure	Inner-City	
Linn & Thier	5th	Logical Thinking	Urban Suburban & Rural	
McGlathery	K-1	Language Development Vocabulary	Contrasting socio-economic	
Maxwell	K	Word Meaning, Listening & Verbal Expressions	Suburban lower to upper class	Metropolitan Readiness Test, Illinois Test of Psycholinguistic Abilities, The Marianne Frostig Developmental Test of Visual Perception
Neuman	K-1	Vocabulary Listening Alphabet Reading Achievement	Central-city Milwaukee	Metropolitan Readiness Test and Achievement Test
Olson	6th	Context Clues	Middle class urban	
Quinn	6th	Hypothesis Formation		
Quinn & Kessler	6th	Language Development	Upper class suburban	Batel
Renner et al	K	Word Meaning, Listening, Alphabet	Public city schools	Metropolitan Readiness Test
Renner et al	1	Word Meaning Listening Alphabet		SRA, Metropolitan Readiness Test
Renner et al	5	Paragraph Meaning		Stanford Achievement
Ritz	K	Visual Perception, Word Meaning Listening	City middle and upper class	Metropolitan Readiness Test, The Marianne Frostig Developmental Test of Visual Perception
Rowe	1-6	Language Development & Logical Thinking		
Wellman	1	Vocabulary Development and Word Size	Appalachian rural and suburban	

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Analyzing the Questioning Behaviors of Science Teachers

By

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> I use the Socratic method here. I ask a question - you answer it. I ask another question - you answer it. Now you may think that you have sufficiently answered the question but you are suffering a delusion. You will never completely answer it.
>
> "Law professor's" remarks,
> paraphrased from the movie The Paper Chase

INTRODUCTION

Since the time of Socrates, asking questions has been the hallmark of teachers. We use questions to help students review, to check comprehension, to control classroom activity, to promote creativity, to discourage inattentiveness, and for a variety of other reasons.

Questioning seems so natural that we seldom pause to consider exactly why we ask questions, what kinds of questions we ask, and how our questioning strategy is affecting the learners in our charge. Research suggests, however, that the content, context, and frequency of teachers' questions--even how long a teacher pauses after asking a question--can profoundly affect the learning process.

Probably the first empirical research on questioning-and-answering behavior was a 1912 study by Stevens (57), who found that teachers did 64 percent of the talking in high school classrooms, and that they asked questions at the astounding rate of two to four per minute, or about 395 questions per day. A school principal interviewed in the study asked, "When do they (students) think?"

Hyman suggests that a third of all classroom discourse consists of questions. (34) King, while analyzing a tape of a reading lesson she had given, was startled to find that she had asked so many questions (59 in 30 minutes). (35) Bellack documented that the teacher dominates the structuring, soliciting, and reacting moves (86 percent, 86 percent and 81 percent respectively). The student, on the other hand, reacts infrequently (19 percent), but dominates the responding move (88 percent). (5) The question-answer mode of teaching is evident in these studies.

What kinds of questions do teachers ask? Haynes analyzed questions asked in a sixth-grade history class and discovered that 77 percent called for factual answers. (32) Guszak's studies similarly showed that about 80 percent of questions asked required recall of facts (31), as did a study by Schreiber (53). In a pilot study done in 1970, Galloway and Mickelson verified that 70 to 80 percent of the questions asked by elementary teachers were of the memory variety. (27) And Gall estimates that about 60 percent of teachers' questions require recall; about 20 percent require students to think; and the rest are procedural. (24)

The research of Witkin and others suggests that the cognitive style of a teacher may influence his or her questioning patterns. (65) Evidence indicates that field-dependent teachers--that is, those who respond flexibly to changing classroom situations--favor teacher behavior that allows for interaction with students; while field-independent teachers (those who teach in a more structured way), favor more impersonal teaching situations, and are oriented toward the more cognitive aspects of teaching

Citing a study by Moore (43), in which a simulation game was devised to investigate differences in chemistry teachers' use of rules, examples, and questioning behaviors, Witkin relates that the "more field-dependent teachers tended to use questions to introduce topics and follow student answers, whereas the more field-independent teachers used questions primarily to check on student learning following instructions." (65)

Thus, the teacher begins to look, as Aschner (2) suggests, like a professional question-asker, who poses numerous questions which generally require only simple recall on the part of the students. This is not necessarily bad. Teachers should ask questions--and many of these questions will, of necessity, deal with information recall. But there are more creative ways to use questioning, which we shall explore in the remainder of this paper.

Types of Questions

In attempting to categorize the variety of questions asked by teachers, researchers have developed a number of different systems--many of which are built on the taxonomy developed by Bloom and his associates. (7) Sanders (50) used Bloom's taxonomy of educational objectives to develop a "taxonomy of questions" as follows (descriptions from Moriber (44):

1. Memory--a question requiring the student to recognize or recall information.
2. Translation--a question requiring the student to communicate an idea using his "own words."
3. Interpretation--the student is required to relate facts, generalization, definitions, values, and skills.
4. Application--questions that present problems and approximate the form and content in which they would be encountered in life. In addition to problem solving, application questions require the use of groups of ideas.
5. Analysis--questions requiring solutions of problems in the light of conscious knowledge of the parts and processes of learning.
6. Synthesis--questions which encourage students to engage in imaginative original thinking.
7. Evaluation--requires students to set up appropriate standards or values and then determine how closely the particular idea meets these standards or values.

Crump also does a nice job of organizing the various question classification systems. (15) Table 1 is basically hers, except that I have added columns for Blosser and Clegg.

Gagné has arranged human learning capabilities in a hierarchy, ranging from problem solving (highest) to stimulus-response (lowest).

Problem solving
(requiring prerequisites)
Rules
(requiring prerequisites)
Concepts
(requiring prerequisites)
Discrimination
(requiring prerequisites)
or Verbal association or other chains
(requiring prerequisites)
Stimulus-response connections

From Principles of Instructional Design by Gagné and Briggs (23, 37)

Table 1. Question Classification Systems (adapted from Claudia Crump—reference 14)

Minor (1966)	Fraenkel (1966)	Clements (1966)	Douglass (1967)	Gallagher (1964)	Guilford (1956)	Sanders (1966)	Bloom (1956)	Blosser (1973)	Clegg (1967)
				Evaluative thinking	Evaluative thinking	Evaluation	Evaluation		Evaluation
	What if questions	Questions with no answers	Problems to be discovered			Synthesis	Synthesis	Open	Synthesis
Real questions	Why questions			Divergent thinking	Divergent thinking	Analysis	Analysis		Analysis
		Questions with many acceptable answers	Problems in reasoning			Application Interpretation	Application	Closed	Application
				Convergent thinking	Convergent thinking	Translation	Comprehension	Rhetorical	Comprehension
Synthetic questions	Who what when questions	Questions with one acceptable answer	Problems of retrieval	Cognitive memory	Recall	Memory	Knowledge	Managerial	Memory
					Recognition				

Gagné and Briggs see questions as guiding the learner from one level of this hierarchy to another. Questions do not tell the learner the answer, but "suggest a line of thought which will presumably lead to the desired 'combining' of subordinate concepts and rules so as to form the new to-be-learned rule." (23, p.129)

If you have not previously worked with levels of questions, the various systems can be overwhelming. Blosser presents a rather simple system in the Question Category System for Science (QCSS). (9) Since this paper is geared toward the science teacher, the QCSS (shown below) might also be a good place to start.

Table 2. Major Types of Questions Teachers Ask (QCSS)

Question Type	Question Function
Managerial	To keep the classroom operations moving
Rhetorical	To emphasize a point, to reinforce an idea or statement
Closed	To check the retention of previously learned information, to focus thinking on a particular point or commonly-held set of ideas
Open	To promote discussion or student interaction; to stimulate student thinking; to allow freedom to hypothesize, speculate, share ideas about possible activities, etc.

Managerial questions are of a low cognitive level. Closed questions, also known as convergent questions, need not be of a low cognitive level, and can be phrased so as to encourage students to classify, make comparisons, use their judgment, or focus on a particular point. Open (or divergent) questions have a variety of "right" answers and generally lend themselves to a higher order of reasoning.

Effect of Levels of Questioning

Arnold has reported that memory-level questions tend to elicit memory-level responses, while questions above that level tend to elicit higher-level responses. (1) Other studies suggest that for elementary students, higher-level cognitive questions improve achievement on lower-level cognitive questions (11, 51), although Soar has shown that too high a frequency of high-level questions leads to poor achievement. (56)

In analyzing audio tapes of eight different teachers in grades 2-6, Cole found that cognitive level, length, and syntax of pupil response is highly contingent upon the cognitive level of the teacher's question. (14) A constant flow of low-level questions leads to low-level concepts, while a balance of low- and high-level questions leads to more learning.

Ward and Tikunoff caution that a teacher's use of higher cognitive questions may not necessarily lead to improved performance for all students, and that the context of the question is more important than how skillfully it is asked. (62) Student ability levels have much to do with responses to questions.

Bruce noted that curriculum may determine types of questions asked by teachers--he suggested, for example, that the use of Science Curriculum Improvement Study (SCIS) materials may cause the teacher to ask higher-level questions. (10) Kondo analyzed questioning behavior of teachers using the SCIS program to determine the effect that the structure of a particular content had on questioning techniques. (36) SCIS teaching strategies call for at least three different teaching styles. The exploratory lesson requires little teacher intervention, and is designed to give students an opportunity to manipulate materials. The invention lesson requires that the teacher "invent" concepts and labels that grow out of the exploratory phase. The discovery lesson gives students an opportunity to apply new concepts, and to transfer them to new content areas. It would seem that the invention lessons would call for memory, and for generally lower-level questioning, while the discovery lessons would require higher-level questions. Kondo found that teachers who use complex questioning patterns tend to use them regardless of the type of lesson.

A study by Sloan and Pate confirmed that the curriculum has much to do with teacher questioning behavior. (55) They found that School Mathematics Study Group (SMSG) teachers asked significantly more higher-level questions than "traditional" teachers. They attributed this difference to the fact that SMSG materials emphasized the objectives of inquiry. Bedwell reported a study that indicated that elementary teachers can be trained to classify, write, and ask questions according to cognitive level, and thereby raise the cognitive level of class discussions. (4) He reported, contrary to the findings of most studies that the different level of questioning did not seem to affect student achievement.

The proper mixture of higher- and lower-level questions seems to be about 50:50. Konya reported a study in which teachers controlled the percentages of higher-level questions, and concluded that the best balance of student response seems to be when teachers ask higher and lower order questions in equal amount. (37) Tisher found that students exposed to equal mixtures of higher- and lower-level questions achieved better than students exposed to mainly lower-level or higher-level questions. (59)

> Thus, to enhance student achievement in science, teachers should use more questions related to application, analysis, synthesis, evaluation, convergent production, and divergent production. Those relatively rare science teachers who ask mainly higher-level questions should probably concentrate on developing a balance between these and memory-recall questions.
>
> William G. Lamb (39)

Sanders (50) voices concern that teachers may become too proficient in asking higher-level questions, and lose interest in memory. He says of such teachers:

> They become so ir· 'gued with sending students through intellectual labyrinths that they neglect fundamental knowledge. They may tend to cater to the capacities of superior students. Simple questions designed for slow students are just as necessary as complex ones in all categories. Subjective questions are important and have a challenge of their own but should be mixed with a liberal number of objective ones. There is satisfaction in giving the one right answer to an objective question and being told the response is correct.
>
> Sanders (50)

Inquiry Teaching

Inquiry teaching is process-oriented, and is geared more toward student than teacher questions. (In most classrooms, as we have seen from previously cited studies, the teacher, not the student, is the questioner.) Victor (61) lists some characteristics of inquiry teaching and learning:

1. Inquiry lessons are carefully planned.
2. Inquiry lessons follow a general pattern.
3. Inquiry learning is highly process-oriented.
4. Teaching and learning are question-centered.
5. The teacher is the director of learning.
6. Children don't have answers in advance (and generally the teacher doesn't either).
7. Time is not of prime importance.

Victor lists advantages to learning by inquiry as: (a) the learner is a participant, not a spectator and, (b) inquiry-oriented classrooms teach children how to learn. Inquiry procedures are also in agreement with the theories of Piaget on how children develop intellectually, and they help children acquire Bruner's proposed four major benefits:

1. Increase in intellectual potency
2. Shift from extrinsic to intrinsic reward
3. Mastery of techniques of learning by discovery
4. Aid to memory processing.

(See Victor, ref. 61)

The Discrepant Event

Suchman developed a question training program for use with upper elementary and junior high school students called the Inquiry Development Program (IDP). (58) The basic model of IDP involves the introduction of a discrepant event (something not readily explainable by the students), using either films or a demonstration. In a process which is something like the party game "Twenty Questions," students ask questions which are structured so that they can be answered "yes" or "no" by the teacher. When the students offer theories to explain the phenomenon (in the form of questions), the teacher does not answer "yes" or "no," but notes that a theory is being proposed, and invites the student to "experiment" by asking additional questions. Suchman states that the introduction of a puzzling event, something contrary to the students' expectations, provides intrinsic motivation for learning the concept. Suchman also feels that "conceptual growth is stronger when it grows from inquiry." (58)

Some research with inquiry techniques has been done. Scott reported that Suchman's inquiry process had a persistent enough effect on the students' analytical behavior that they maintained a significant advantage over comparison students for a period of six years. (54)

Inquiry vs. Lecture Demonstration

Schlenker reported a study in which middle grade students of both inquiry-oriented teachers and lecture-demonstration teachers were tested on their understanding of science. (52) He concluded that students receiving inquiry training developed a significantly greater understanding of science, as well as greater fluency in inquiry and critical thinking, although no difference in content mastery or information retention was found.

Bills tested effect of the Inquiry Development Program on divergent thinking (creativity) of eighth-grade students, and found no significant results, other than that the students seemed to enjoy the inquiry sessions, and were motivated to seek outside help to find answers to questions raised in the open-ended discussions. (6)

Encouraging student questions

Wickless reported a study on the effectiveness of an in-service program for teachers, which centered on student questions. (64) Analyses showed a significant increase in the number of questions asked by students, as well as a greater variety of teacher questions, after the teacher training.

Sadker and Cooper suggest that childhood adages such as, "Children should be seen and not heard," "Silence is golden," and "Curiosity killed the cat," make children feel that they should not talk too much, or ask too many questions. (49) Indeed, this lesson seems to have been well learned. Sadker and Cooper wrote of some research studies which have demonstrated that students do ask few questions. For example, Houston found that junior high students in eleven classes asked less than one question per period. (33)

Floyd reported that only 3-5 percent of all questions asked in second- and third-grade classes in his sample were student-initiated. (19) And Dodd concluded that elementary school pupils simply do not ask questions, at least in the classes he observed. (17) Guczak (30) and Gallagher (26) suggest that not only are few questions asked by students, but those asked are generally low level (frequently they just check procedures or ask for information).

Sadker and Cooper conducted an experiment to test whether high-order questioning techniques could be taught to elementary school students. (49) Five types of higher-order questions were identified: (a) evaluation; (b) comparison; (c) problem solving; (d) cause and effect; and (e) divergent. A microteaching technique was used to teach a sample of four fifth-grade students a curriculum that was composed of (a) student-initiated, content-related questions, and (b) student-initiated, content-related, higher-order questions. The encouraging results indicate that trained students asked a maximum of about 1.3 higher-order questions per five-minute interval, while untrained students asked a maximum of about 0.10 questions per five-minute interval. So, students can be taught to ask increasingly sophisticated questions.

Wait Time, or the Pausing Principle

Teachers not only ask too many questions--they also tend to ask them far too rapidly. Stevens cautioned that the rapid pace of teacher questioning affects the educational outcome in classrooms:

> The larger number of questions suggests that whenever teachers, either individually or collectively, preserve such a pace for any length of time, the largest educational assets that can be reckoned are verbal memory and superficial judgment. It is quite obvious that with the rapid fire method of questioning there is no time allowed a pupil to go very far afield in his experience in order to recall or to associate ideas in fruitful ways. He is called upon merely to reflect somebody else--the author of his textbook generally--in small and carefully dissected portions, or to give forth snap judgments at the point of the bayonet.
>
> Stevens (57, pp.22-23)

Stevens further suggests that teachers, by dominating the classroom with a rapid-fire barrage of questions, prevent students from developing the "gentle art of expression." The rapid-questioning technique gives rise to short, incomplete responses by students.

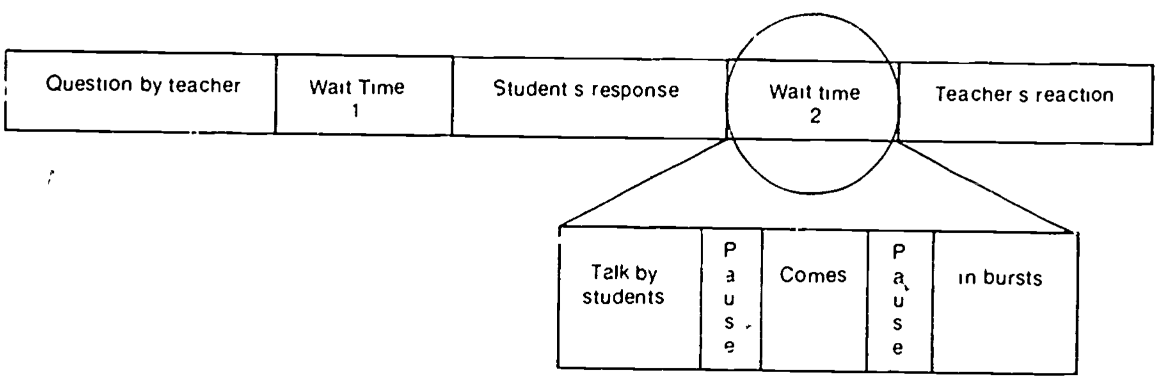
Rowe suggested that we might suffer from "question shock" if we sat all day long being bombarded with questions at the rate of 2-3 per minute, and were given less than a second to begin to answer. (47) She notes that current science programs depend heavily on intrinsic rather than extrinsic motivation, and that free conversation should be a mark of inquiry-centered programs.

> When "wait times" are short and reward schedules are high, payoff for students comes in doing only one thing-- focusing totally on the wants of the teacher.
>
> Rowe (47, p.243)

Rowe began her investigation of wait time when she found that only three of 200 classroom tapes exhibited instances of students questioning each other and the teacher. (48) The three teachers in whose classes this student questioning occurred, paused longer than the usual less-than-one-second.

While analyzing verbal activity, Rowe also became intrigued at how seldom classrooms are silent. (47) After a question is asked, teachers allow on average less than one second for a student to respond. If response does not begin within that time the teacher either prompts, calls on another student, or answers the question herself. Rowe diagrams the wait time as shown below.

Table 3. "Wait time" Patterns (from Rowe, Science as Continuous Inquiry, p. 244)



There are, in fact, two wait times that need attention:

1. The pause that follows a question by a teacher, and
2. The pause that follows a burst of talk by students.

Failing to pause at the first wait time produces the following predictable results:

1. Students generally give short responses;
2. Students give responses that call for memory rather than higher-level thinking;
3. Teachers allow relatively little flexibility in the responses they allow;
4. A few students dominate the answering of questions. "Slower" students don't participate;
5. "I don't know" answers increase, as well as no answers at all.

Rowe suggests that the second wait time is equally important (this is potentially available after a student concludes a response). By pausing after the student response, the teacher increases the probability that a student will add to his response, or that other students will "piggyback" on the initial response. (47)

The work of Rowe (47, 48), Garigliano (28), Lake (38), Blosser (9), and Fowler (20) (as well as that of Tobin (60), who worked with Australian students) indicates that if teachers can be trained to increase wait time, the following expectations exist:

1. The length of student responses increases;
2. The number of unsolicited appropriate responses increases;
3. Student confidence increases;
4. The incidence of speculative responses increases;
5. The incidence of evidence-inference statements increases;
6. The frequency of student questions increases;
7. The incidence of responses from "relatively slow" students increases;
8. The amount of student-to-student interaction increases;
9. Facilitation of more robust science inquiry occurs;
10. "I don't know" and failures to answer decrease;
11. The number of experiments proposed by students increases

Learning to incorporate the "pausing principle" or "wait time"--or what Crump (15) refers to as "reflection" silence--seems worthwhile, given the potential outcome. In addition to the changed student behaviors listed above, Rowe noted that at least three teacher behaviors change when wait times increase:

1. There is increased flexibility of teacher responses;
2. Teacher questioning patterns become more variable;
3. Teacher expectations for performance of students rated as "slow" may change.

An intriguing notion by Fowler is that perhaps we should train <u>students</u> to pause. (20)

Teachers Can Change

We need not only to change our questioning pace, but also to deliberately vary the kinds of questions we ask. Renner and Stafford (45) report on a 1969 study by Schmidt, in which 16 elementary science and social studies teachers, who were observed in their classrooms after having attended a summer institute: asked fewer recall and convergent questions, asked more higher level questions, and offered a greater number of learning activities in science.

Some aids exist to help the teacher. Lawson (1976) describes an instrument that helps teachers assess their "inquiry quotient," using four criteria: the lesson, student behavior, teacher behavior, and questioning techniques. (41) The section dealing with questioning techniques analyzes such points as:

1. Are most questions divergent or evaluative?
2. If questions are convergent do they focus on a particular problem area in an investigation?
3. Are questions phrased directly and simply?
4. Does the teacher call on an individual student <u>after</u> asking the question?
5. Does the teacher wait 4 to 5 seconds for a response?
6. Does the teacher accept all answers?
7. In answering student questions does the teacher respond by giving additional ideas and information which enables the student to continue thinking?

The Intermediate Science Curriculum Study (ISCS) offers suggestions and activities to train teachers help themselves to ask open-ended questions. Bass has developed a handbook on questioning and using pupil responses in teaching science. (3) The handbook was developed for use mainly with pre-service teachers, and was tested with 100 elementary teachers and 250 fourth- through sixth-grade students. The Washtenaw Intermediate School District in Ann Arbor, Michigan, reported a staff-development project in which project teachers succeeded in maintaining a 5:1 ratio of open to closed questions. (63) And Lamb describes a protocol model for training science teachers to ask a wide variety of questions. (40)

Implications for the Teacher

If you are interested in improving your questioning strategies, you must first know what you are presently doing--this means making some assessment of your current questioning technique. Tape record some of your lessons, or ask a colleague to help you evaluate your current teaching behavior as it relates to questioning strategy. Then choose a portion of the lesson to analyze. Research suggests that you should do the following:

1. Ask fewer questions. (Simply make a count of questions in a given unit of time, and if they seem excessive, strive to reduce that number.)
2. Ask a mixture of lower-order and higher-order questions. (It is, first of all, imperative that you learn to classify questions.) The analysis of your lessons will then show where work is needed. Learn the distinguishing characteristics of the various levels of questions in the category system you think will be best for you. Learn to construct questions of all the types in that category system. If you are like most teachers you ask mostly memory-type questions. This is OK, but you need to know when you also need to heed Suchman's warning not to ask vague, diffuse questions under the guise of inquiry.
3. Ask more open questions. Review again types of questions you ask, and be able to classify them as "open" (divergent) or "closed" (convergent). The persistent asking of closed questions encourages short student responses, and can squelch creativity.
4. Strive to foster an atmosphere of inquiry. You know you have succeeded when your students start asking questions. You may have to teach students to do this--try Suchman's inquiry technique--stage a "discrepant event" which will arouse student curiosity.
5. Learn not to set yourself up as the authority. Help children accept what they learn from interacting with their materials and with each other.
6. Value student questions, and encourage students to ask questions. See if there is some connection between the level of the question you ask and the levels of the questions asked by students.
7. Try to pause 4 to 5 seconds after asking a question. Learn, too, to pause after a student response. This use of silence will pay dividends in amount of student talk, number of student questions, and in other ways mentioned earlier.
8. Recognize that good questioning techniques are the hallmark of good teachers. Experiment with these techniques (and this goes, too, for other means of interacting with students--such as conversation.) Researchers know that half of the battle is over when they pose the question properly--shouldn't students know this, too?

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How Teaching Strategies Affect Students: Implications for Teaching Science

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INTRODUCTION

The number of ways in which students can differ, and the number of methods that can be employed in teaching, are as many as there are students and teachers. Teachers know that students are individuals -- that their learning performances vary with the subject and the learning situation --but there just simply isn't time for formal assessment of even a few learner traits. Consequently, teachers are forced to structure learning environments on the basis of informal assessments and observations of students.

But are there any research findings which suggest general methods for teaching science more successfully to certain types of students? Is it possible to individualize science instruction and still stay within the practical limits of the classroom (20 or more students small or non-existent budgets, limited preparation in science areas)? This paper will review some of the research studies which address these questions, and will consider their implications for teaching science.

Matching Learner to Subject

Broadly speaking, there are two things to consider in teaching science. the characteristics of the learners, and the distinctive elements of the subject itself. Ability as measured by conventional intelligence tests, although an important indicator of student performance, is not the only learner characteristic worth considering. Other learner traits may affect the way in which a student learns science--these include imagery skills, locus of control, anxiety level, and the student's self-image.

For example, studies of student anxiety levels appear to have significant implications for all kinds of learning. The overwhelming weight of research evidence indicates that a high anxiety level generally accompanies poor student performance, by all academic measures. (4) Furthermore, highly anxious students tend to lack self-confidence, curiosity, and adventurousness. These qualities are important in any learning situation, but are especially important for learning science, because the basis of science is exploration. Science is a "participant subject," requiring both physical and mental involvement--it is not a "spectator sport," in which the learner can remain passive and uninvolved. Science at the elementary level, for the most part, deals with concepts and phenomena which can be best understood through direct contact with, and manipulation of, concrete objects. Students who are short on self-confidence, curiosity, and adventurousness are not likely to take full advantage of the learning opportunities available in the science classroom. On the other hand, some level of anxiety is apparently helpful. That is, performance does seem to be related to moderate levels of anxiety. However, extreme anxiety can depress performance.

Are there methods that a teacher can use to reduce undue student anxiety in the classroom--or to compensate for it? Amidon and Flanders (2) found that highly anxious eighth-grade students tended to do better in student-centered, non-authoritarian classrooms, and that students with low anxiety levels tended to do better in classrooms where activities and discussions were dominated entirely by the teacher.

This study is particularly significant in that it produced strong evidence that student anxiety level and academic performance are related to different types of learning environments. Though it focuses on anxiety, the study has broad implications for teaching, and suggests a radical departure from the traditional practice of targeting instruction at the "average" student. Recognition of the fact that not all students learn equally well from the same mode of instruction suggests that perhaps the critical issue in planning instruction in science is not, "Should I use a textbook, an activity, a film loop, or a demonstration to teach this concept," but rather, "How can I create a learning environment in which students with different personality traits and learning aptitudes will function effectively and be successful, regardless of the instructional mode used?"

How Much Structure?

The anxiety study of Amidon and Flanders addresses another important issue in the science classroom: How much "structure" or teacher direction is needed during activities? Many science curricula developed in the last decade have placed a premium on laboratory activity. The amount of "open-endedness" or freedom to explore has varied from program to program--some explicitly describe all aspects of student involvement; others encourage free exploration of materials.

Many teachers have gravitated toward the more prescriptive curricula, claiming that "students need and want structure." The theory behind this statement is that highly structured activities keep students busy, productive, and out of trouble--especially the hyperactive, highly anxious child. Though this notion seems to appeal to common sense, recall that the Amidon-Flanders study suggests just the opposite--at least for students of junior high school age. The highly anxious students performed better in student-centered classrooms where there was less classroom structure, and less direction given by teachers.

This same reaction was observed by Allen (1) in a study of disruptive elementary school children. Allen found that the incidence of disruptive behavior among students labeled "troublemakers" was significantly reduced in a science classroom where the teacher assumed a non-directive, non-authoritarian role, and where student opportunity to select and explore alternatives was increased. On the other hand, a second group of disruptive students, who were exposed to a highly directive, authoritarian style of teaching, exhibited increased levels of disruptive behavior, much of which appeared in the form of open hostility toward the teacher and competition between students. The authoritarian strategy seemed to force students into a state of dependence on the teacher, as evidenced by an increase in calls on the teacher for help and directions. Allen suggested that hostility then arose from the teacher's inability to attend to the requests of the children quickly. It was also noted that total chaos in the authoritarian classroom was averted only through use by the teacher of an inordinate amount of reward and punishment (approximately 33 percent of the class time!). Clearly the Amidon and Flanders and Allen studies suggest that the notion that "students need and want structure" may contain some fatal flaws.

Research suggests that building student trust--both in themselves and in others--may reduce anxiety and promote better science teaching. (5) Increased levels of trust result in higher levels of inner confidence, and lower levels of anxiety. But how does one build trust? Trust is increased when the threat of failure is reduced. Reducing the threat of failure does not imply, however, that standards must be compromised or expectations lowered. Frequency of failure can be reduced by increasing the opportunity for success. For teachers of science, this means providing students with a variety of learning experiences, and accepting and respecting student performance regardless of the nature of the task. Planning science instruction so that students who are high in verbal skills can learn through reading or writing, while those weak in verbal skills can learn through manipulative, non-verbal channels, increases the chances that students will succeed at an activity matched to their interests and aptitudes.

The Flexible Classroom

In studies associated with Project Follow-Through, a project designed to test "planned variations" in instructional strategies in elementary school in terms of their effects on children's performance, Stallings (11) observed that "flexible classroom environments," which provide opportunities for children to manipulate and explore materials in non-directive situations and which give students learning options, contribute to: higher scores in nonverbal reasoning as measured by the Raven's Coloured Progressive Matrices; lower rates of student absence; and increased levels of independence in the learning activities. Here again, as with the Amidon-Flanders and Allen studies, increased opportunities to learn through optional and varied instructional modes seemed related to increased student success.

Support for such a "mixed-bag" of learning activities in the classroom can also be drawn from other studies relating personality variables to science learning. Using a questionnaire based on Jung's theory that differences in people's learning behavior are due to basic differences in the way people prefer to use their perceptions and judgments, and not to intelligence per se, McCaulley (6) studied the distribution of the various learning "types" among students and teachers at various school levels. He found that some students apparently prefer to learn by direct immersion in activities, followed by a period for contemplating the lessons from the activity more abstractly; others prefer to be given a picture of the place of the activity in the whole before plunging ahead; and still others prefer to go off in unexpected directions with activities, even at the cost of teacher disapproval. Though the data showed that some student types were more likely to pursue science studies or careers, McCaulley clearly pointed out that "so far as we know, all types can and do learn science"--the implication being that it would be premature to try to stereotype the learning styles of the successful or unsuccessful science student based on data collected thus far. In terms of the classroom the implications seem obvious--provide opportunities to accommodate all learning types.

The Importance of Teacher Behaviors

At this point a word of caution seems appropriate. There is a lot more to good teaching than putting out potentially interesting and thought-provoking materials, and letting the students "have at it"! The importance of the teacher is not diminished in a classroom where learning opportunities for individual students are expanded. On the contrary, teacher responsibilities are increased, and the impact of certain behaviors on student performance is magnified.

For example, the use of rewards and punishments in a science classroom can produce undesirable side effects on student behavior. Teachers who exhibit a high frequency of reinforcing behavior in the classroom not only run the risk of increasing anxiety levels in many students, and thereby lowering performance, they also tend to have a negative effect on the basic "sciencing behavior" of students. In studying the effects of reward schedules on risk-taking behaviors in a sample of elementary school students engaged in a hands-on science program, Rowe (8) found that students who were accustomed to a high frequency of overt rewards and punishments were not likely to explore alternative explanations for problems on their own without first checking with the teacher. These students were also less likely to engage other students in conversation about problems encountered. In short, they appeared to lack the inner confidence needed to delve into the activities and to extract meaning from the materials. Instead, they relied on the teacher for interpretations and answers.

The same dependency was observed in other studies of elementary school science. (7,9) In these studies, students who were exposed to highly directive patterns of teaching behavior, including a high frequency of reinforcing behaviors, were observed to become increasingly dependent on the teacher during "science time," as measured by increases in the incidence of "hand-waving" (to attract teacher attention), and decreases in the amount of time spent on independent activity and exploration. High dependency states were also revealed in student comments and anecdotal records. Students in the highly directive classroom were quoted as saying such things as:

"I try to do what . . . (the teacher) wants us to do."
"I follow directions and do what I should."
"I am behind everybody."
"I am ahead of everybody."

By way of contrast, students in the nondirective classroom said, for example:

"I am discovering new things all the time."
"I like to find out things on my own."
"Science is fun."

The Dangers of Au. .ty

That excessive and sometimes counterproductive student competition with peers, and high levels of dependence on the teacher, are produced by teachers who are highly directive and authoritarian, and who use rewards schedules frequently, is supported by the studies mentioned above. The Rowe study, especially, points out the adverse effects of high levels of reinforcing behaviors on students in elementary science classrooms. But the damage may extend beyond the immediate science activity.

Teacher behaviors which foster student dependence on "other" authority figures are potentially damaging from another standpoint. Creation of authority figures--the idea that there is a right answer for everything--can cause students to develop a distorted view of science. Evidence of this was revealed in a study of classroom structure and student performance in science, grades 1 to 5 (10). Students who were exposed to highly directive science activities and required to conform to the teacher's interpretations of right and wrong (that is, subjected to rigid directions regarding what activity to do and how to do it, and high levels of rewards and punishments), developed a system of "double standards" with regard to science. When they thought of science as something _they_ did, they saw it as a very neat and orderly collection of correct answers, not subject to any human interpretation or bias; they saw themselves as persons who simply seek existing truths. But they had an altogether different view of _scientists._ They saw _scientists_ as being very creative individuals who routinely "made up" knowledge and explanations for natural phenomena. Thus, the directive strategy appeared to have a distorting effect on children's views of science, producing a definite split in perceptions: science is one thing for scientists, another for students.

Classroom Implications

What can a classroom teacher do to maintain a learning environment in which student performance is kept at a maximum? Several tentative conclusions may be drawn. For one thing, since all students do not appear to perform equally well in classrooms where a single learning mode or teaching strategy is employed, a teacher might try to combine alternative modes of learning and multiple methods of teaching. Science is especially suited to the "alternatives" approach. Basic concepts of number, space, mass, time, distance, and so on can be learned through first-hand experience with concrete materials, as well as through written materials--students need not be restricted to one mode or the other.

The research on rewards schedules and student perceptions also carries important classroom implications. Classrooms in which the teacher assumes the role of "answer man," and makes extensive use of rewards and punishments, tend to produce students who depend heavily on authority figures for verification of ideas, rather than on their own experiences and interpretations. Dependency in learning is contrary to the nature of science, and inevitably leads to distortions and misunderstandings of science.

The Effect on Student Achievement

Up to this point, the studies discussed have dealt primarily with the relationship between classroom environment and student behavior and attitudes. But what about the "hard data measures" of student performance -- things like achievement scores and aptitude measures? How much science will students learn in a classroom where optional activities and multiple modes of learning are available? Though there are not an overwhelming amount of data which address that question directly, several studies of contrasting teaching methods in science have been conducted.

Three studies done in elementary school science classrooms revealed that students not only performed well in classrooms utilizing a multi-mode, optional-activities approach, but that certain groups (low-ability, underachieving, and disruptive students) actually out-performed counterpart groups in conventional single-mode classroom settings. (1,7,9) In two of these studies student performance was assessed in the areas of problem-solving skills and creativity development using the TAB Inventory of Science Processes and the Torrence Tests of Creative Thinking. The studies showed that students in a non-directive, multi-mode, optional-activities classroom scored at least as well in problem-solving skills and verbal creativity as students in highly directive classrooms. In terms of figural creativity, the students of non-directive teachers scored significantly higher than those of directive teachers. The studies also repeatedly showed that low-ability students (as measured by the California Test of Mental Maturity) reacted positively to the non-directive strategy -- that is, the performance of the low-ability students in the non-directive classroom (in terms of activity involvement, problem-solving skills, and creativity development) was disproportionately better than the performance of any other ability grouping, in either non-directive or directive classrooms.

Teaching Strategies

Bunderson (in Cronbach and Snow) (3) offers an interesting point of view on choosing the best instructional strategy, taking into account students' strengths and weaknesses. He suggests that when we find that a desirable educational outcome depends solely on one particular learner aptitude, "the task . . . be redesigned to eliminate the demand on that aptitude." He is not saying that learning can be made aptitude free -- that is, independent of learner skills -- but rather that performance in a learning task should be made equally dependent on <u>many</u> learning skills whenever possible, to provide success for students with various combinations of aptitudes.

The suggestion that individual students possess unique learning traits is hard to dispute, but difficult to apply to most learning situations. Science is an exception. At almost all levels, except the most advanced and theoretical, science is approachable from many different angles. Students can bring a variety of skills to bear on the subject, and can experience a certain degree of success in each. Science contains its own vocabulary, symbols, formulas, and concepts -- it is abstract. But science also contains many physical and experiential components -- it is also concrete. Students need not be required to deal with both aspects with equal skill, nor restricted to only one aspect.

For teachers of science, there is an opportunity to tailor instruction to students' individual needs, while avoiding the risks associated with forcing every student into the same learning mode. Consider surrendering to your students some of the difficult, if not impossible, decisions about which mode of instruction should be used. Rather than worry about making the correct decision on the use of highly verbal or non-verbal materials, structured or unstructured activities, open-ended or cookbook experiments, try making both options -- or several -- available.

Conclusion

Students differ in ways which have implications for how they may be helped to learn science. Highly anxious students do better if the teacher is less directive; students with low anxiety levels seem to respond better to stronger direction from the teacher.

The personality of students also gives a clue as to how they may prefer to learn. Some want to know what is expected in advance, others want to dive in and learn by doing.

Some students are highly dependent on teacher direction. Apparently, independence can be increased by reducing the amount of rewards (typically praise) teachers give. Students can help direct their own learning if they have some choices concerning the way they will learn -- from the teacher, from books, from labs, by projects. Can we vary our instruction in science enough to provide for these differences among students?

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Relating Student Feelings to Achievement in Science

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INTRODUCTION

Just how important is it for students to like what they study? Do their feelings about a subject influence how much they learn? Is the way a student and teacher feel toward one another important in the learning process? Are there specific attitudes and values for which we can successfully teach? The purpose of this paper is to examine these and other questions by looking at what educational, psychological, and sociological research has to say to the practicing teacher of science. From this analysis will emerge implications for possible new practices that will help students to more effectively attain the major goals of science education.

Attitudes, interests, motivation, appreciations, and values are all terms used to describe what educators call the "affective domain."

("Affective" or "affect" comes from the Latin word, affectus, meaning "feelings.") Affect is commonly expressed along a continuum of positive to negative. A person may either like or dislike something, or possess varying degrees of neutrality. It is this predisposition to respond positively or negatively that characterizes a person's interests, motivation, attitudes, or set of values.

On the first day of, let's say, a ninth-grade physical science course, students have varying feelings about the course. Some "love science," "want to make an A, and "can't wait to do an experiment in lab." Others enter with negative feelings; they "don't like science," "never do well in science," or find the subject "boring." These feelings may relate to school in general as well as to science. Furthermore, by the ninth grade, most students already have rather well-developed attitudes toward themselves, something called "academic self-concept" that probably relates to performance. One broad category that we shall examine in this paper is what research says about how the entering affective behaviors of students influence learning in the science classroom.

Many complex events occur in a classroom. The way students and teachers interact, the feelings exchanged between them, teaching methods, and management techniques are all part of what we call "classroom environment." The feelings students have toward this environment, toward their teachers, and toward major classroom events represent a screen through which intellectual activities are filtered. This will be another facet of the affective domain to be discussed.

ENTERING AFFECTIVE BEHAVIOR

Human Characteristics and School Learning

Benjamin Bloom presents numerous research findings from the United States and several foreign countries that relate "affective entry characteristics" to cognitive achievement. (5) In looking at how student interest in science related to achievement, Bloom found that the median correlation between these two factors was about +0.35 for the eighth grade and +0.52 for the twelfth grade. These findings suggest that interest generally accounted for between 20 and 25 percent of the variance in academic achievement in science Data from 17 countries in six different subject areas suggested that "attitudes" correlated higher with achievement in science than with achievement in other subject areas.

Another interesting observation made by Bloom was that relationships between affect and cognitive achievement increased as students advanced in grade level. In other words, student interest in science at the twelfth-grade level was more predictive of academic success than it was in elementary school grades.

It thus becomes evident that the amount of learning that takes place in a science classroom relates positively to the initial interest and attitudes brought to class by the students. This relationship, moreover, seems to be cumulative, suggesting that prior learning experiences n a subject area influenc future learning experiences in that area, and that attitude and achievement tend to become more closely related as students get older.

Many researchers believe that student attitudes toward specific subjects merely reflect their attitudes toward school. Rentz has hypothesized that a student who possesses strong interest in science probably also likes other subjects. (21) Research by the International Study of Educational Achievement (IEA)--as cited in Bloom (5)--correlated expressed feelings of students toward school with achievement tests for particular subjects. Correlations ranged from +0.25 in the middle grades to +0.45 in high school. As with interest in science, attitude toward school generally accounted for about 20 percent of the variance in achievement at the secondary vel.

The Importance of Self-Concept

Bloom has reported a series of individual research studies suggesting that even more central to academic performance than feelings toward science and school is attitude toward self, which is built up from experiences with tests, grades, teachers, and parents. Similarly, Brookover has developed a scale that measures what he calls "academic self-concept." (8) Research with this scale indicates that academic se'f-concept may account for more variance in academic achievement than the two previously discussed variables.

These findings suggest that as students move up through various grade levels, feelings toward themselves play an increasingly important role in how they do academically. These attitudes form gradually, are based on early experiences in school and at home, and (once formed) tend to be stable Success in junior high school science, and to a greater extent in high school science, is thus a product of a set of complex, cumulative feelings derived from earlier successes and failures.

Motivation

Another facet of entering affective behavior is motivation, which is associated with internal "drive" and based on fundamental human needs. A motivated person typically seeks success at particular goals. Several research students have examined motivation, and considered both its extrinsic and intrinsic features. Extrinsic motivation involves external rewards--such as good grades, praise from the teacher, or additional privileges from parents. Intrinsic motivation, on the other hand, involves internal rewards, such as increased self-esteem, personal satisfaction, or simply a good feeling toward oneself. Less mature learners usually rely more on extrinsic motivation and need here-and-now rewards. Mature, self-directed students act from intrinsic motivation, and aim for more long-term rewards.

While there is disagreement among psychologists on this topic, most believe that it is important for teachers to help students make a transition from external to internal sources of rewards. Rowe has found that when science teachers pause more after asking questions, and subsequently reduce their overt, verbal reinforcement, students not only demonstrate more desirable responses, but also seem to become less reliant on teacher and student approbation. (23, 24) A possible conclusion suggested by Rowe was that by deferring teacher (extrinsic) rewards, students are encouraged to become more thoroughly motivated by their own intrinsic interests. Thus, a teacher who is skilled in controlling reinforcement may be able to facilitate shifts among students from extrinsic to intrinsic motivation. Although research in this area is incomplete, several studies suggest that motivation may account for the ultimate success of a student in science--even more than intellectual ability.

Weiner and co-workers have determined that individuals attribute success or failure to four elements: (a) ability, (b) effort, (c) task difficulty, and (d) luck. (30) Kukla found that students who rank high in need for achievement (motivation) tend to attribute success to effort more than do students with intermediate or low need for achievement. (19) McClelland and Liberman have demonstrated that motivation may stem from both a need for success and a fear of failure. (20)

How to deal with students with low motivation for achievement is an educational problem most classroom teachers find perplexing. Steers has suggested that participation in goal setting is essential for such individuals. (27) Other research has shown that for low achievers, it is necessary to focus more on external rewards and that more time should be taken to help learners understand, as specifically as possible, the important factors associated with each educational objective. This would suggest that students should participate in selecting individual learning tasks; that the tasks should be carefully described to students by teachers in terms of concrete, realistic, and obtainable goals; and that students should be involved to some extent in evaluation of their own performance.

"Fate Control"

In conjunction with her studies of questioning behavior and wait-time, Rowe examined other variables that relate to motivation. One is called "fate control." (23, 24) Fate control is defined as the belief that events that happen to you are under your own control. Using metaphors from games, Rowe calls students who are high in fate control "bowlers." Those who are low in fate control are labeled "craps shooters." "Bowlers" believe that through skill and work they have some measure of control over the future. "Craps shooters," however, are oriented to the present and attribute most things to chance; they also believe that their future lies in the hands of powerful "others" who cannot be influenced.

Fate control is closely tied to another variable, called locus-of-control, which relates to the degree to which individuals believe that reinforcement is contingent upon their own behavior. In other words, some individuals believe that they (rather than someone or something in their environment) are largely responsible for what happens to them. Others, conversely, believe that rewards and punishments stem from luck, whim, or something other than themselves. In The Coleman Report of American High Schools, locus-of-control proved to be the single best predictor of achievement for non-whites and the second best predictor for whites.

Cultural Values

Students enter our science programs with cultural values and belief systems which influence strongly what and how they learn. A study by Spilka of 753 Sioux Indian and 455 white secondary-school pupils demonstrated, for example: (a) that political and economic realities override immediate school influences, and (b) that any school program in conflict with a student's cultural heritage may alienate that student. (26) If formal science instruction is not in harmony with the values of a given cultural group, students may reject science. And Spilka also found that the longer students stayed in school and the more they learned, the lower their alienation scores became. (This occurred in part because teachers come to understand that the cultural values of some students were different from their own, and that tolerance and flexibility were necessary.)

Kluckhohn, in discussing value orientations, has suggested that human beings relate to nature in three basic ways: "Man Subjugated to Nature," "Man in Nature," and "Man Over Nature." (18) The philosophy of "Man Subjugated to Nature" implies a fatalistic attitude, and is held by many Spanish-Americans. "If it is the Lord's will that I die, then I shall die" represents this position. The "Man in Nature" philosopny regards all natural elements, including humans, as parts of one harmonious whole; this attitude has been dominant in China in past centuries. "Man Over Nature" is characteristic of many Americans. In this view, natural forces are to be overcome and used for human purposes. In many Western civilizations, science and technology have been the primary tools for enacting this philosophy. It is obvious that science instruction for students from different cultural backgrounds needs to be planned with these different perspectives in mind.

O.J. Harvey found that beliefs of most adults fall into one of four systems. (15, 16) These belief systems influence the way people learn, develop new skills, cope with stress, and relate to others. System 1 people are characterized by their strong belief in supernaturalism, positive attitudes toward tradition and authority, and absolute adherence to rules and roles. They also tend to think in concrete terms and to view things as black or white, subject to little change. Members of this group generally are dogmatic, and hold fairly rigid beliefs about the world around them.

System 2 people are only slightly less dogmatic and inflexible than those of System 1. However, they tend to possess strong negative attitudes toward tradition and authority. System 2 people possess the lowest self-esteem, and the highest degree of cynicism. Paradoxically, they want and need to rely on other people, but fear a loss of personal control and power. When members of this belief system lack power, they denounce authority; but when they are in possession of it, they frequently abuse it.

System 3 reflects a strong emphasis on friendship, interpersonal harmony, and dependency relationships. Members of this system exhibit strong needs to help others, sometimes controlling others through the establishment of strong dependency bonds.

System 4 members are the most abstract and open-minded--they tend to be creative, flexible, pragmatic, and utilitarian in their problem-solving styles. They respond with moderation to rules and regulations, not seeming to need much structure or dependency for themselves, but recognizing that these frequently are necessary for others.

In studying these and other belief systems of students and educators, Harvey found that 75 percent of the elementary school teachers tested, and 90 percent of school superintendencs studied, belong to System 1. About 7 percent of all people tested ("This I believe Test" and Conceptual Systems Test) have been found to belong to System 4. While Harvey's research has not included children, he has suggested that science teachers should help System 1 children by initially providing needed structure, then gradually encouraging students to shift to a more independent style of observing, thinking, and problem solving. System 2 students need structure, coupled with warmth and fairness. Teachers should be sure that the rules and regulations of the classroom or school are explained reasonably and logically. System 3 students need external reinforcement (in order to meet their need for dependency), but should be encouraged to become more independent. Students who are members of System 4 have the greatest need for academic freedom and flexibility. Too many rules and regulations will stifle the creative individuals in this group. Adams and co-workers theorize that a child's ultimate belief system may be determined to a large extent by the freedom he or she has to explore values and to evolve and internalize rules on the basis of pragmatic outcomes. (1) Thus, teaching science as open-ended inquiry would appear to encourage more flexible behavior in children, but some students may need to be phased gradually into less structured teaching formats.

The Implications of Research

While we need to know much more about how attitudes influence learning, research indicates that students' initial attitudes toward science, school, and especially self, do serve as significant predictors of academic achievement at the secondary level. This finding supports the importance of children having positive experiences with science in elementary school. Yet Conant found, for example, that elementary school children in Portland received, on average, not more than one or two minutes of science per day. (12) And, in middle and junior high schools, where science normally is required, there still exist too few opportunities for youngsters to experience the joys of scientific investigation and discovery. Nationwide, it appears that many students never study much science until the seventh or eighth grade, at which time they are placed in courses where they are abruptly confronted with strange new vocabulary, difficult reading material, and some kind of laboratory experience. If their first course or two does not provide them with a positive experience, they quickly lose interest and end up disliking science.

Bridgman has reported that grading practices of physical science teachers appear more severe than those of other teachers, including mathematics teachers. (6, 7) He suggests that declining enrollments in the sciences, particularly the physical sciences, may be due in part to these grading practices. He also suggests that physical science teachers should try to make their offerings more inviting to all students.

It appears, then, that objectives and practices relating to the affective domain need to be more clearly delineated. Instruction needs to be designed and delivered so as to produce students with positive attitudes and values toward science. Evaluation systems should be designed to measure affective outcomes. The research by Bloom suggests that students who have successful experiences in science are likely to have repeated success with science-related endeavors--whether in school or the "real world."

THE CLASSROOM ENVIRONMENT

We have seen that students enter our science classrooms with a wide range of affective characteristics which predetermine to some extent how they will react to us and to our subject areas. The question is now, What can we as teachers do to increase the chance that students will leave our classes with more positive attitudes by the end of the year? How can we change negative feelings, capitalize on positive feelings, and increase motivation? In this section, we shall examine what researchers say about how teacher characteristics affect students' feelings toward science.

An enormously significant research study in this regard was conducted by Rosenthal and Jacobson. (22) These researchers randomly selected 20 percent of a large group of sixth graders who had recently taken an IQ test, and then told teachers that these students had high IQ's. The teachers were instructed to watch these students closely, since they were likely to "bloom" intellectually. Eight months later, the entire group of sixth graders was retested, and it was found that those students who had been (randomly) labeled "very bright" demonstrated significantly higher IQ's than did other students. Rosenthal and Jacobson conclud' that the teachers had apparently communicated their high expectations to the "bright" students, and that the students obliged their teachers by better achievement. Although Cronbach and Snow have challenged the statistical analysis (13), other studies reviewed by Rosenthal and Jacobson show similar results and raise the question of how much teacher expectation affects student achievement.

Recent studies by Adenkia and Berry (2) Altman and Snyder (3) and Clark (10) present evidence that teacher expectations for minority students are lower than for whites, which may influence the kind of instruction minority students receive and, ultimately, their self-concepts.

In a recent article entitled "Teachers Who Care," Rowe examined several research studies in light of teacher characteristics considered important by students, and found that caring was consistently ranked at the top. In fact, an analysis of a long list of studies of teacher attributes demonstrates that students prefer teachers who make them feel good about themselves. While there is little research on how student feelings toward their teachers directly influence achievement, Rowe cited personal interviews in which students volunteered that they worked harder for, and learned more from, teachers who cared about their feelings. This seems to agree with Bloom's analysis (discussed earlier), in which he suggests that self-concept is more predictive of academic success than is interest in science.

Robert Carkhuff has proposed an insightful model to explain the progressive development of effective human relations.(9) Working with Carl Rogers at the University of Wisconsin, Carkhuff and other investigators looked for common events that occur whenever someone like a teacher or counselor (a "helper") is successful in helping a student or client (a "helpee"). George Gazda and co-workers at the University of Georgia have modified the original Carkhuff model so that it is more appropriate for teacher-student relationships. (14)

The work of Carkhuff and Gazda suggests that before students will accept help, they must be convinced that the teacher really understands their feelings--in other words, that the teacher is truly empathetic. Empathy is the capacity to communicate to someone else that "you have been there too," and that you can accept the way he or she feels about something. (Closely related to empathy is the ability to be a good listener.) Gazda uses a one-to-four scale to illustrate different degrees of responses ranging from hurtful to helpful. For instance, if a student says to a teacher "I have been studying chemistry harder and harder, but my grades keep getting lower and lower," the lowest response

(Level 1) might be to say, "That's impossible. Anyone knows that the more you study, the more you learn." This response not only fails to respond to the student's feelings, but it is also judgmental and critical. A Level 3 or 4 response would be more like, "It must be very frustrating to feel as though you are studying harder while your grades are continuing to decline." Here the teacher gives the student a response that says "I understand how you feel."

Students sometimes perceive science as "hard," "tough," or "beyond me." By taking the time to understand these feelings, a teacher may be able to help a student over initial rough spots. By failing to understand them, the teacher increases the probability that some students will end up fearing and disliking the subject.

Another important dimension in this model is what Carkhuff calls "respect." After the helper listens empathetically, it becomes important that he communicate supportive feelings to the "helpee". "I know you will be capable of eventually solving your problems," or "I believe in you." To pity students is to show disrespect--to communicate that you do not think they are capable of handling things.

The third dimension in this model is "warmth." (This relates closely to what Rowe has called "caring.") By demonstrating warmth, a teacher communicates that he/she is willing to "make an investment" in a student's feelings or problems.

Each of these first three steps in the helping process is "facilitative," in that it helps the student to get in touch with his or her feelings and to express them. Before students can function effectively when the going gets difficult, their feelings of frustration and doubt need to be recognized.

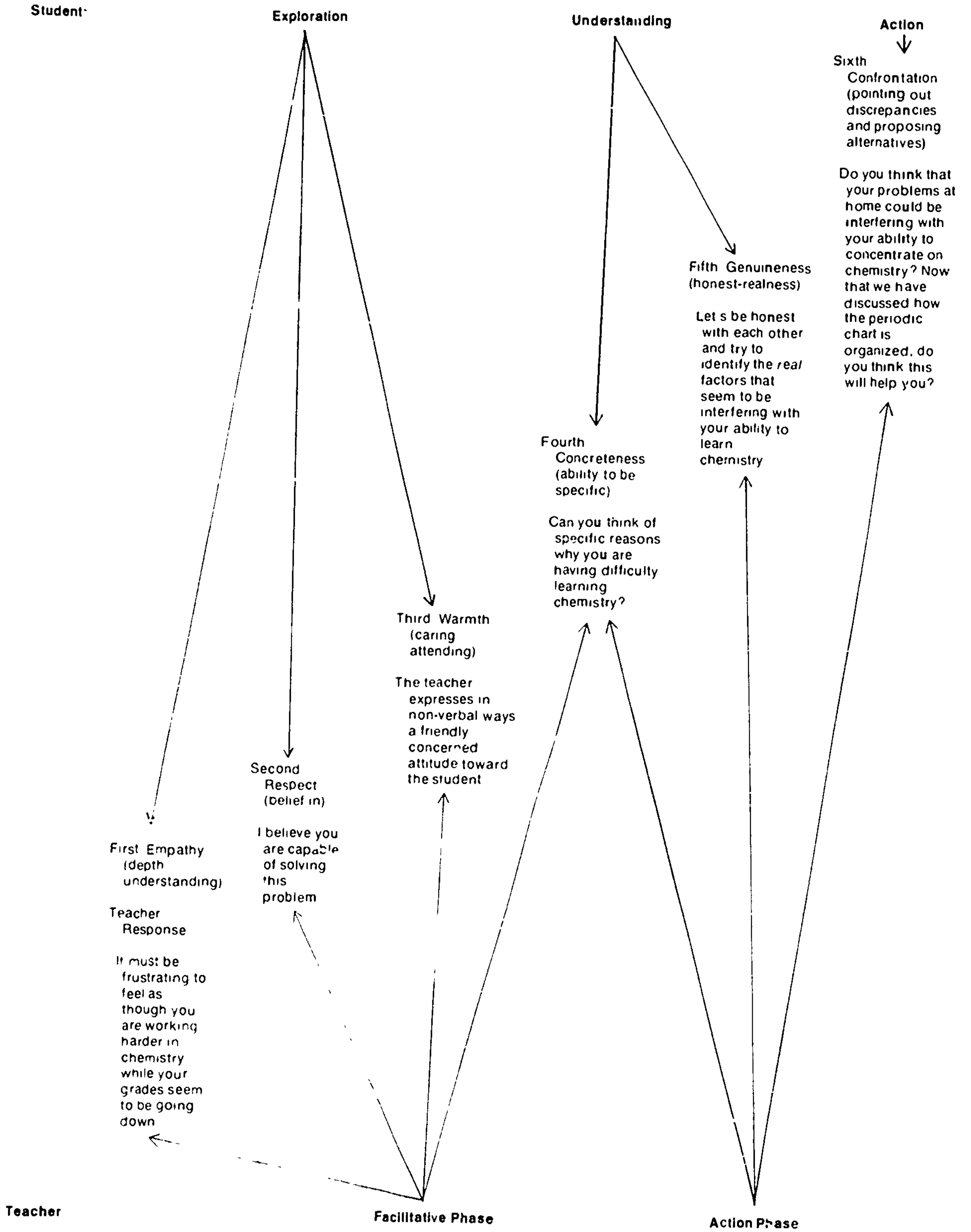
After a student-teacher relationship has progressed through these levels, it is possible to move to concreteness, a level where a more objective look at specific problems can occur. Here it becomes the teacher's role to help the student confront the problem by outlining and discussing alternative solutions. (Thus, this is where the facilitative phase of the helping process overlaps with the action phase.) While there are many other facets to the Carkhuff model (summarized in Figure 1), the important message of these studies is that unless teachers can get in touch with students' feelings, and communicate to students their understanding and concern, proper relationships will not develop, and student needs will not be met in the classroom.

The Classroom Climate

Anderson and Walberg investigated relationships between emotional climate and learning. (4) They studied twelfth-grade physics classes from all parts of the country, and found that classes where high gains in science understanding occurred were perceived by students as being

Figure 1. A Modification of the Helping Process Outlined in the Carkhuff Model

Student problem I ve been studying my chemistry harder and harder but my grades are getting lower and lower



well-organized and controlled by the teacher, yet allowing freedom to question and learn in a relatively informal atmosphere. In a more recent study, Walberg and his co-workers concluded that student perceptions of the learning environment accounted for substantial academic variance beyond that accounted for by IQ. (29) In other words, attitudes appear to be influenced by the climate teachers create. As a result, one sees changes in achievement.

A review of research by Yeany provides evidence that science teachers with a higher "indirect-direct" ratio (that is, those who are more student-centered in their teaching styles) produce students who learn more science. (28) The recent Lancaster Report from England, cited in Hechinger (17), says, on the other hand, that formal teaching methods tend to achieve superior results, not only in basic skills but also in creative areas. In commenting on the Lancaster Report, however, Hechinger observed that one lone "progressive" teacher produced results counter to the study's conclusion that traditional methods work best. (17) When asked what motivated her students to succeed in such an outstanding manner, this teacher replied, "They know I'll be pleased if they do well." In her classroom, individual freedom was not allowed to get in the way of the work ethic, an ethic she fostered from the first day of school. One general conclusion of the report was that a "clear link appears to emerge between work activity...and progress." (Note too that the teacher thought her expectations for performance were important.)

Hechinger's evidence is consistent with the other research cited above. When students are made to feel good about their work in science, and good about themselves, they try harder to repeat earlier successes. Teachers who demonstrate a love for science, who listen carefully to their students, and who give respect to the young people with whom they work (that is, have high expectations for them) are more effective in helping students learn. (While we are advising a supportive mode, we must caution against an inflated praise pattern in the name of improving self-concept.)

SUMMARY

Humans acquire attitudes and beliefs at an early age. These feelings are then later manifested in terms of interests, motivation, and increasingly complex value systems. As one experiences a school subject like science, success or failure tends to shape feelings toward the subject. These feelings then fuse with other affective experiences to form what is apparently a more generalized attitude toward school.

Eventually, students develop feelings about themselves, their abilities to accomplish specific tasks in school, and their overall self-worth. These attitudes appear to significantly influence learning in the secondary school classroom. The pre-formed incoming attitudes of students are further affected by the characteristics of their teachers. It is essential, then, that teachers be caring, concerned individuals, who demonstrate respect, warmth, and empathy. At this point, teachers then "earn the right" to help students.

Most science educators agree that affective outcomes should be given top priority when planning instruction. Students, they agree, should leave their classrooms with a love for learning, an appreciation of scientific methodology and logic, open-mindedness, an awareness of technological application, a concern for the world and its people, and a strong desire to cultivate life's many opportunities. These and other values are the very essence of science. Research strongly suggests that these affective outcomes are possible to attain. With well-defined goals, carefully selected teaching methods, and appropriate evaluation techniques, educational experiences can be designed to more completely incorporate affective behaviors. Additional research in this area is needed.

As we learn more about the nature of the objects to which science students attach value, and more about how these feelings are associated with the learning process, we shall no doubt be able to unlock many of the mysteries associated with the question we all have asked, "How can I motivate students to learn science?"

What does research suggest that we begin doing now? First of all, the mandate is clear concerning elementary school science instruction. Science needs to be taught to all students at all grade levels. It needs to be taught as an exciting, relevant quest for knowledge--a quest at which students from all backgrounds can be successful. In the earlier grades and through junior high school, science instruction should focus on creating interest, motivation, and appreciation for science. If students learn to feel good about science, they will be more confident and responsive in the higher grades.

Research also calls for an improvement in the state of the art of identifying objectives. <u>If affective goals are important, educators are going to have to identify them, teach for them, and evaluate for them.</u>

Perhaps the most concrete call for action by science teachers lies in the realm of human relations. The evidence appears overwhelming that the interaction between students and teacher represents one of the most significant variables in the education process. The classroom is a complex psycho-social environment. The teacher stands at the center of this environment--and, according to the research we have reviewed, is probably the most important factor in influencing the minds and feelings of students toward science.

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The Role of the Laboratory in Secondary School Science Programs

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Less than a decade ago, NSTA's Commission on Professional Standards and Practices thought the case for school science laboratories too obvious to need much argument:

> The time is surely past when science teachers must plead the case for school laboratories. It is now widely recognized that science is a process and an activity as much as it is an organized body of knowledge and that, therefore, it cannot be learned in any deep and meaningful way by reading and discussion alone.
>
> NSTA Commission on Professional Standards and Practices (47)

But times have changed. Money for education has become scarce, and educational priorities are being re-evaluated; the "case" for laboratories is no longer as self-evident as it once seemed. Like teachers from other curricular areas that require specialized materials--art, music, physical education, home economics, shop--science teachers are under some pressure to justify their "requirements" for facilities and equipment.

Can the research literature help? Do we know exactly what laboratory experiences contribute to student knowledge, understanding, and appreciation of science? Do youngsters get something from laboratory work that they can't get from lectures, films, or even demonstrations? And if our laboratory objectives are broader than teaching science content, can we articulate these objectives? Do we know how to design research studies to test for them? The purpose of this paper is to go beyond simple affirmation of the desirability of science laboratories by examining existing research for objective evidence concerning the contribution of laboratory experiences to student knowledge, understanding, and appreciation of science. It is useful to begin by briefly outlining some broad objectives for science instruction and relating these to the major curriculum improvement projects.

First, it is obviously desirable that students demonstrate familiarity with the basic body of organized knowledge associated with a discipline. Objectives at this level are largely verbal and can be conveniently addressed in conventional classroom settings. Students should also be able to operationalize this content by demonstrating modest skill in using common instruments to translate theory into practice. Specialized equipment and facilities are required to achieve these objectives. And finally, we hope that these experiences will help students to synthesize both the content and skills in a manner which makes the discipline a meaningful and relevant part of their adult daily lives. When viewed from this perspective, laboratory materials and equipment are as much an integral part of any program for general science education as is paint for the art class, violins for music, footballs for physical education, or wrenches for auto mechanics.

The focus and function of the laboratory has changed considerably during the past two decades. Older, so-called "cookbook" laboratories associated with traditional science courses, presented highly directed activities--students completed tables in their notebooks to verify results already presented in the text. The new science curricula (such as BSCS, PSSC, CHEM Study, and ESCP 1/)

1/ Biological Sciences Curriculum Study, Physical Science Study Committee, Chemical Education Material Study, and Earth Sciences Curriculum Project, respectively.

were largely developed during the 1960s, with considerable direction from the scientific community and generous funding from the National Science Foundation. They sought to create laboratory experiences that presented genuine problems for investigation. Emphasis shifted from what we know to how we know--that is, to the processes of science.

Importance was placed on increasing student abilities to think critically and on giving students some understanding of the nature of science. In the new curriculum projects, the laboratory frequently became the central vehicle for science learning.

Although these courses have had a major impact on the philosophy and rhetoric of science education, they have by no means fully met educators' hopes and expectations. There have been claims that most are really for the bright--that the courses are too abstract for the average student. They have failed, too, to stem the decline in science enrollments, especially in physics.

And, in spite of their aims, there are questions to be asked about exactly what processes and attitudes the laboratory activities do "teach." An analysis by Herron, for example, demonstrated that, in practice, the vast majority of PSSC and BSCS (Blue) laboratory exercises could be classified at the lowest levels of the discovery hierarchy. (23)

Let's look then at what research says on the question of whether laboratory experiences are critical to good science teaching. In doing so, we must pay particular attention to the outcomes that the research seeks to measure and the evaluation tools (or instruments) being used.

REVIEW OF SELECTED RESEARCH

Shulman and Tamir compiled an excellent review of research on teaching the natural sciences during the 1960s, which includes an overview of studies on the laboratory. (66) They examined several lists of laboratory objectives (7,8,21,38,44,46,56,78) and established five broad categories for classifying laboratory outcomes. These are:

1. Skills: for example, manipulative, inquiry, investigative, organizational, communicative;
2. Concepts: for example, hypothesis, theoretical model, taxonomic category;
3. Cognitive abilities: for example, critical thinking, problem solving, application, analysis, synthesis, evaluation, decision making, creativity;
4. Understanding the nature of science: for example, the scientific enterprise, scientists and how they work, multiplicity of scientific methods, interrelationship between science and technology and among the various disciplines of science;

5. Attitudes: for example, ıriosity, interest, risk taking, objectivity, precision, confidence, perseverance, satisfaction, responsibility, consensus and collaboration, liking science.

Given the central role of the laboratory in the new science curricula, Shulman and Tamir do not find it surprising that these objectives are similar to those suggested for science teaching in general. (7,49) However, they also note that the emphasis on laboratory was based more on the opinions of scientists and psychological theorists than upon empirical evidence.

The following studies are representative of recent research which has sought to isolate the impact of the laboratory on science teaching. The sample has been drawn from published research since 1960, and is divided between secondary school and college nonmajor populations. Shulman and Tamir's five major objectives will be used to summarize and discuss these studies.

Secondary School

Strehle compared the achievement of seventh-grade students taught by laboratory with that of students taught by enriched lecture-demonstration methods in a six-week summer program. (68) The lecture-demonstration method included programmed instruction, transparencies, films, filmstrips, models, and so forth. No significant differences were observed between the two groups when tested with the Reed General Science Test (pretest Form BM, posttest form AM); however, the investigator noted that the lecture-demonstration approach seemed especially effective among lower achievers, while the laboratory tended to produce greater variation in individual performance.

Oliver compared the results obtained using lecture-discussion, lecture-discussion with demonstrations, and lecture-discussion and demonstrations with laboratories. (48) Two classes of high school biology were included in each treatment. He found that the lecture-discussion with demonstrations was most effective ($p<0.05$) during the first semester for acquisition of biology information, as measured by the Indiana High School Biology Test, but its advantage over the other methods disappeared by the end of the second semester. No differences were observed among the three teaching methods for overall achievement in biology (Cooperative Biology Test), nor were there any significant differences on the Comprehensive Biology Test, designed by Oliver to measure students' ability to apply scientific principles.

Coulter worked with 75 ninth-grade biology students at the University of Minnesota High School. (16) One group performed inductive laboratory experiments, designed and conducted by students from questions raised in class discussion or proposed by the instructor. The inductive demonstration method was similar in that students designed the experiments and drew their own conclusions; however, the instructor performed the experiments as class demonstrations, using an overhead projector and microprojector. The deductive laboratory group performed a teacher-designed activity to test a concept which had already been thoroughly presented in class. A pre/posttest design was used which included measures of IQ (Lorge-Thorndike Intelligence Test), critical thinking (Watson-Glaser Critical Thinking Appraisal), and instruments constructed by Coulter to measure factual knowledge, scientific attitude, application of principles, and student reactions to the three teaching methods. There were no significant differences among the groups on knowledge of facts and principles, application of principles, critical thinking, or mental ability. However, students using inductive methods were superior on measures of scientific attitude, reactions to the teaching method, and ability to use selected laboratory techniques. Students who performed experiments were more positive toward instruction than were those who watched demonstrations.

Sorenson studied the changes in critical thinking between high-school students in laboratory-centered and lecture-demonstration-centered biology classes. (67) Twenty biology classes taught by 16 teachers were randomly selected from four high schools in the Salt Lake City School District. Ten classes were then randomly assigned to each of the two treatments, in which they studied the two BSCS lab blocks on Plant and Animal Growth and Development. A battery of instruments was administered in a pre/posttest design which included the Otis Quick Scoring Mental Ability Test, Gamma: Form AM, Watson-Glaser Critical Thinking Appraisal, Form YM, Cornell Critical Thinking Test, Form X, Dogmatism Scale, Form E, and the Test on Understanding Science, Form W. The lecture-demonstration group showed no significant changes on measures of critical thinking, understanding science, or dogmatism. The laboratory-centered group showed significant gains ($p<0.05$) in critical thinking, understanding science, and open-mindedness (indicated by a decrease in dogmatism scores).

Sherman and Pella taught the Introductory Physical Science (IPS) curriculum to average and high ability eighth-grade classes (N=100). (50) The experimental group viewed colored slides of 19 laboratory activities which were performed by students in the manipulative group. All other instructional factors were held constant. Although the gain in critical thinking of the manipulative group was significant ($p<0.01$), there were no significant differences between the two instructional methods for measures of: (a) critical thinking (Watson-Glaser Critical Thinking Appraisal, Form Zm), (b) understanding science (Test on Understanding Science, Form Jx), (c) academic achievement of knowledge and concepts presented in IPS (IPS Achievement Test), or (d) development and expression of interest in science (Kuder General Interest Survey, Form E). The manipulative method was significantly superior for development of laboratory skills (Lab Skill Test) ($p<0.01$).

Yager, Engen, and Snider conducted an exemplary study using a sample of 60 bright eighth-grade students (mean IQ=117) studying BSCS Blue Version biology, and taught by three exceptionally well prepared and experienced teachers. (79) There were three treatment groups. In the laboratory group students individually performed and discussed 50 of the 57 laboratories designed for the curriculum. The demonstration group completed each of the laboratories as a class demonstration (performed by the teacher or one of the students). In contrast to the laboratory group, the demonstration treatment produced a single set of data for analysis and discussion--although the teacher would introduce conflicting data from time to time for consideration. The discussion group neither did laboratories nor demonstrations, but were given results for each of the laboratories, which were then interpreted and discussed. All three groups were taught in an inquiry style within the limits of the treatments, and the three teachers rotated among the groups at approximately one month intervals to control for teacher effects. There were no significant differences among the three treatment groups in terms of: (a) critical thinking (Watson-Glaser Critical Thinking Appraisal, (b) understanding of science and scientists (Test on Understanding Science, Form W), (c) attitudes toward biology (Silance Attitude Scale and the Prouse Subject Preference Scale), and (d) student knowledge of science and achievement in biology (Reed General Science Test, Nelson Biology Test, and the BSCS Comprehensive Final Examination). However, students who performed demonstrations of numerous labs did develop more skills (p 0.05) as defined by a practical examination which included focusing a microscope, constructing and working with a manometer, and making coacervates.

A study by Babikian gives some results that appear to conflict with the investigations described thus far. (5) Babikian used three slightly different treatments with nine classes of approximately 250 eighth-grade students. The expository group received a verbal presentation in which the concept was stated, followed by examples and student discussion. No audiovisual materials other than a chalk board were used. In the laboratory group, the concept was stated and verification laboratory procedures were described by the teacher. Students were supplied with equipment and printed instructions for performing the experiments individually. Students in the discovery group were asked to discover an unstated concept individually, after receiving procedural instruction on the use of the laboratory equipment. Students received assistance from the teacher on procedural matters, but inquiries about the concept under investigation were given only "yes" and "no" answers. No significant differences were observed between the expository and laboratory methods, which were both superior to the discovery method (p 0.01) with respect to overall achievement, verbalization of concepts, recognition of concepts, and application of concepts to numerical problems as measured by an instrument developed by the instructor. We do not know how the groups would perform on the processes emphasized in laboratory activities, such as the design of experiments to gain new information.

Lunetta studied the effectiveness of computer simulations to parallel the PSSC inductive labs for Newton's Second Law of Motion. (39) Three teaching methods were used. The computer group viewed film loops and worked with computer interactive dialogues. The simulation group used the film loops, simulated data, problem sheets, and teacher interaction. The control group performed the PSSC laboratories and worked with the teacher in a standard presentation. The computer group achieved significantly higher scores on measures of content learning than did the simulation group, while both the computer and simulation groups were significantly superior to the control group. The control group also required 3.2 times longer to complete the unit than did the simulation group, and 8.3 times longer than the computer group. This investigation should be kept in mind as a possible indicator of future instructional technology. The question of cost effectiveness of the three strategies is especially relevant, and should be considered in any future investigations.

Ben-Zri, et al. reported a study in which tenth-grade Israeli students completed a chemistry laboratory course by working in the laboratory or viewing films of experiments. (6) Attitude tests showed that the laboratory was more effective than films in promoting interest in chemistry.

College

Dearden used a variety of treatments for the "laboratory" component of a one quarter college general biology course for non-majors. (18) All 924 students received the same lectures; however, different groups performed: (a) individual (conventional) laboratories, (b) demonstration laboratories, (c) workbook exercises, or (d) term papers related to biology. There were no significant differences among any of the groups on measures of biological knowledge, scientific thinking, or biological attitude. The investigator noted that the individual laboratory seemed to more consistently allow for differences in academic ability of students, which suggests that a wider spectrum of students may be successful when there are laboratory activities.

Bradley investigated the effects of lecture demonstration versus individualized laboratory work in a general education physical science sequence in college. (9) Both groups met for two one-hour lectures and a one-hour discussion section each week. The laboratory group performed a two-hour lab each week while the demonstration group observed the laboratory experiments demonstrated by the instructor with or without the help of a student. No differences on measures of content acquisition were observed between the two groups. There were no measures of outcomes that might relate directly to reasons for giving laboratory experiences.

Zingaro and Collette gave two different treatments to a subsample of 144 out of 793 sophomore students enrolled in six college physical science classes for non-majors. (82) The inductive group received no formal lectures, but rather "discovered" principles from analysis of data collected in the laboratory. Initially, problems and suggested procedures were provided; however, students received only a statement of the problem for the last exercise. Discussion periods following the laboratories served to formalize concepts and to apply them to practical problems. Once again it was noted that students required some experience to gain confidence in the method. The traditional group used the laboratory to verify principles already presented in the lecture. There were no observed significant effects between methods on measures of subject matter learned, general critical thinking (Watson-Glaser Critical Thinking Appraisal), or understanding of science (Test on Understanding Science), although differences were observed between instructors for general critical thinking (p 0.05), and both instructor and a method by instructor interaction was significant (p 0.05) on understanding science. In other words, some instructors worked more effectively with one method than the other. The inquiry group was significantly superior (p 0.05) on an investigator-designed measure of critical thinking in physical science.

Bybee investigated lecture-demonstration versus individualized laboratory methods for teaching general education earth science classes to 109 students at Colorado State College. (13) Many of the students had studied one of the new science curricula in high school (PSSC: 23 percent; CHEM Study: 32 percent; BSCS: 53 percent). The lecture-demonstration group met three times a week for a one-hour lecture supplemented with demonstrations and films. The experimental group met twice a week for a one-hour lecture, and once a week for a two-hour lab. The lab included a 30-minute inquiry into problems presented by the instructor; the remaining time was free for students to work individually or in groups, using laboratory or audiovisual materials. Initially, students in the experimental group were confused as to how to use this free time, but within a couple of weeks they gained confidence and self-direction. There were no significant differences in achievement between the two groups as measured by a Comprehensive Earth Science Examination; however, highly significant differences (p 0.001) favoring the individualized laboratory were reported for a number of affective measures related to the class. In short, the laboratory experience produced better attitudes.

DISCUSSION

Table 1 summarizes major findings of the studies reviewed. The results are in general agreement with previous research on the laboratory as summarized by Cunningham's review of 37 studies prior to 1945 (17), Watson's review of some 11 studies conducted during the 1950s (75), Ramsey and Howe's extensive review of instructional outcomes (which also included several unpublished doctoral dissertations) (52), and Shulman and Tamir's excellent summary of research on teaching in the natural sciences (66). It is noteworthy that for nearly two decades reviewers have commented with some concern that research on science instruction has focused primarily on content acquisition. For example, Ramsey and Howe observed that their sample of research included 97 studies in which knowledge of content was the prime outcome expected, while only 30 studies attempted to examine instructional aims from the cognitive, affective, and psychomotor domains. (52) Further, studies such as those reviewed in the last section have generally relied upon a handful of standard paper-and-pencil instruments of limited validity for assessing the potential outcomes of laboratory activities. This makes it difficult, if not impossible, to make many definitive statements about the role of the laboratory. Nonetheless, considerable information is available for consideration by thoughtful educators. We shall now turn to a discussion of the contributions of the laboratory to each of the five sets of objectives mentioned earlier.

Skills

As would be expected, providing students with laboratory experiences consistently results in improved skill in working with laboratory materials and equipment. Surprisingly, few investigators appear to value these results very highly. However, if we wish students to gain some modest competence in the ability not only to verbalize science content, but also to apply it to real phenomena, then skills for conducting both laboratory and informal experiments are essential for learning science. Fortunately, there have been some efforts to remedy this situation.

Jeffrey (27) proposed six major competencies for the chemistry laboratory, which included: (a) Communication--identification of laboratory equipment and operations; (b) Observation--recording of observations and detecting errors in technique; (c) Investigation--accurate recording of measurable properties of an unknown substance; (d) Reporting--maintenance of a suitable laboratory record; (e) Manipulation--skill in working with laboratory equipment; and (f) Discipline--maintenance of an orderly laboratory and observation of safety procedures. Jeffrey prepared a film and set of slides to measure the first three competencies. No tests were proposed for the last three.

Table 1 Summary of Selected Research on the Role of the Laboratory

	Skills	Concepts	Cognitive Abilities	Understanding the Nature of Science	Attitudes
High School Strehle (1964) Laboratory Lecture-demonstration (enriched)		equal			-
Oliver (1965) Lecture discussion Lecture · demonstrations Lect · demon · labs		equal	-		-
Coulter (1966) Inductive demonstrations Inductive Labs Deductive Labs	inductive methods deductive	equal	equal		labs demo
Sorenson (1966) Laboratory Lecture demonstration			lab lect demo	lab lect demo	lab lect demo
Pella & Sherman (1969) Laboratory Slides of lab	labs slides	equal	equal	equal	equal
Yager Engen Snider (1969) Laboratory Demonstration Discussion	lab demo disc (p 05)	equal	equal	equal	equal
Babikian (1971) Verification lab Discovery lab Expository		exp lab discov (p 01)	–		
Lunetta (1972) Computer dialog Simulated data Laboratory		comp sim lab			
Ben Zvi et al (1976) Laboratory Films of labs					lab films
College Dearden (1962) Laboratory Demonstration Workbook Term Papers		equal		–	equal
Bradley (1965) Laboratory Demonstration		equal		–	–
Zingaro & Collette (1968) Discovery Labs Verification Labs		equal	equal	equal	–
Bybee (1970) Lecture demonstration Laboratory		equal	-	-	lab lecture (p 001)

End tape 3
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Robinson reported an effort by teachers participating in a BSCS Blue-Version Test Center to develop a laboratory practical examination consisting of 20 items. (55) The test, which was administered to a sample of 390 students, included items related to measuring, identifying, selecting, and computing. The low correlation (0.33) between the laboratory practical and the end-of-semester paper-and-pencil test suggests that the two instruments are tapping significantly different aspects of student competence in the course.

Tamir and Glassman developed a laboratory practical examination which was administered to twelfth-grade Israeli students who had studied four years of biology based on the BSCS Yellow Version and portions of the BSCS second year course. (71,72) The examination included sections on plant identification (15 percent), an oral exam on plants and animals (35 percent), and a problem to be solved by experiment (50 percent). Scores on the practical examination sections showed low to moderate correlations with paper-and-pencil tests. A scoring grid was developed, which included scales for manipulation, self-reliance, observation, investigation, communication, and reasoning. The authors note that poor manipulative skills did not necessarily imply low investigative skills; however, reasoning skills appeared important to all areas of the scoring grid. In a comparison between BSCS students (N=142) and non-BSCS students (N=60), the BSCS students' total test scores were superior (p 0.01), with the major differences appearing on measures of reasoning and self-reliance.

These studies demonstrate that meaningful instruments can be devised to measure laboratory skills, and that content acquisition and laboratory performance appear sufficiently different to warrant separate evaluation. Shulman and Tamir (66) also note that work is progressing on sequential decision-making examinations (33) and sequential problem-solving aspects of science (12). Klopfer has proposed a Table of Specifics for evaluating science instruction. (32) Many of the objectives for the Process of Scientific Inquiry should prove valuable in guiding continued research on the effectiveness of the laboratory. The objectives for Observing and Measuring obviously requir laboratory experiences, as do objectives for designing appropriate procedures for performing experiments. It would also seem that objectives for Interpreting Data and Formulating Generalizations and for Building, Testing, and Revising a Theoretical Model would be rather meaningless exercises unless students have a feeling for the role of experimentation as one of the fundamental criteria for validating scientific concepts.

Concepts

Research studies on the role of the laboratory consistently report that laboratory experiences neither help nor hinder science content learning, as measured by conventional paper-and-pencil achievement tests. It would appear, at least at the present time, that good quality verbal instruction is sufficient for content mastery by students; however, this conclusion should be considered tentative pending results of current research on the effects of matching various teaching methods with student background and abilities. These issues will be further discussed.

Cognitive Abilities

The studies reviewed in the previous section generally found no significant differences between laboratory and nonlaboratory teaching methods on generalized measures of critical thinking. However, Zingaro and Collette reported that inductive laboratory experiences were superior to traditional verification laboratories on a measure of critical thinking designed specifically for the course. (82) There are several methodological problems which severely limit the validity of any conclusions which might be drawn from this data concerning the function of the laboratory in developing critical thinking skills. Perhaps the greatest concern is the almost exclusive use of a single general purpose instrument (The Watson-Glaser Critical Thinking Appraisal), which is not designed to measure specifically science-oriented capabilities. This concern has been strongly voiced by Shulman and Tamir (66), and by Bridgham (11), who caution that science instruction need not transfer broadly to nonscientific thinking processes. If the laboratories are inquiry oriented and not primarily for verification, and if there are enough of them, we might expect some impact on a general measure. However, it would be far more sensible to investigate specific science laboratory thinking objectives. Ramsey and Howe's (52) review of instructional outcomes associated with the national curriculum projects suggests that it is possible to design laboratory-centered instructional procedures which nurture critical-thinking ability; however, it is probably important that the laboratory experiences be oriented toward inquiry and problem solving and that the teacher be receptive and skilled in these teaching methods. Several recent studies support this position.

Scott reported a five-year longitudinal study on the effects of inquiry training on analytical thinking. (63) During late elementary and early junior high school, students received training in the inquiry strategy based on the method originally conceived by Suchman (69) and modified by Scott (60). In this strategy, the class is presented with an anomalous science demonstration which creates an interesting problem situation. Students must then explain how the phenomenon occurs by analyzing the situation into its component parts during a class session in which the teacher responds to student questions with only "yes" or "no". This format forces students to be precise about hypothesized relationships among variables. Students who received the training were significantly more analytical (Siegel Cognitive Style Test) than the control group, and the superiority persisted when remeasured at graduation, even though neither group had received specific inquiry training in high school. Studies such as this suggest that it is important to measure delayed effects. Moreover, experiments or training which goes on over one to several years, in contrast to short four- to eight-week studies, may produce more useful information about the impact of the laboratory. Persistent gains may require administration of specific inquiry training over several years. The three-year training program reported by Scott is much longer than the short intervals of a year or less which were used in nearly all the laboratory studies reviewed.

Some exciting work which may have far-reaching implications for inquiry training, as well as for the role of the laboratory in promoting cognitive abilities, focuses on the application of Piaget's Theory of Cognitive Development (26) to secondary school and introductory college science teaching. Since this work is quite recent and necessarily tentative, it will be discussed in the final section of this paper.

Understanding the Nature of Science

Efforts to assess students' understanding of the nature of science and scientists have become popular since the introduction of the Test on Understanding Science (TOUS). (15) Nearly all research in this dimension of science teaching has relied upon TOUS or the Science Process Inventory (SPI) developed by Welch. (76) These paper-and-pencil instruments measure students' knowledge about the nature of science, and, as is true of science content acquisition, the studies reviewed suggest that including standard laboratory experiences neither enhances nor detracts from student performance on these measures. However, Shulman and Tamir note a growing concern among science educators over the uncritical use of these instruments. (66) They suggest that the low correlations observed among these instruments and related abilities and attitudes such as the Vitrogan Attitude Scale (74) make questionable any use of an all-purpose test of understanding science.

Attitudes

Several new techniques are being explored for measuring attitudes; these include an adaptation of the semantic differential (19,57), development of a multi-attitudinal self-report inventory (42), and Klopfer's efforts to define objectives for evaluating the affective domain in science education (32). Even so, efforts to assess student attitudes suffer major methodological and instrumentation limitations. As Shulman and Tamir (66) note:

> It would require attitude measures far more sensitive than we currently possess to tap such laboratory-related attitudes as habits of accuracy, curiosity, readiness to experience and accept repeated failures, perseverance, the satisfaction and excitement of discovery, responsibility, collaboration and consensus, and reliance on the observables of experience rather than on the dogmas of textbooks.

It is disturbing that Lawrenz (35) cites several recent studies (1,28,40,50) which report declining interest in science following participation in science classes. Research by Anderson (2) and Lawrenz (35) suggests that attitudes such as student satisfaction with a class are highly correlated with several characteristics of the learning environment. Clearly stated goals and student involvement in class decisions are associated with greater student satisfaction. Teacher favoritism, disorganized teaching, and friction among students all reduce perceived satisfaction. It may be that general organizational patterns are central in determining student attitudes toward science programs. A laboratory program presents considerably more management problems than does a lecture/discussion course.

SUPPORT FOR THE LABORATORY

Three-quarters of a century of research with secondary-school and introductory-college nonmajor students has consistently shown that laboratory experiences neither help nor hinder student achievement--at least as measured by standard paper-and-pencil tests of subject matter. These findings are consistent across a wide range of objectives, including science concepts, understanding the nature of science and scientists, and critical thinking. This has led some science educators to conclusions such as those presented by Yager, Englen, and Snider (79):

1. Since desirable outcomes in science are obtained even though the laboratory is limited, the role of the laboratory as a central activity for individual students which characterizes all new curricula should be questioned.

2. For certain students and certain teachers a verbal nonlaboratory approach may be the best means of stimulating them to understand and appreciate science.

3. Some students (especially at advanced levels) may find the laboratory to be a waste of time, and merely a means of slowing their pursuit of new theories and concepts.

4. Structuring of some new courses that would de-emphasize the laboratory per se, while still emphasizing the nature of the scientific enterprise, may well be a worthwhile effort.

While these suggestions merit serious consideration and investigation, there seem to be compelling reasons to resist any widespread exclusion of the laboratory from general education secondary school science programs.

Support for continued and even increased emphasis on the laboratory comes primarily from three sources: (a) evaluation studies of modern curriculum projects in which the laboratory is a central focus; (b) emerging research which suggests the need to match teaching methods to student abilities, and (c) the exciting but as yet unestablished potential role of the laboratory in facilitating cognitive development.

Curriculum Evaluation Studies

The research studies on the role of the laboratory which were reviewed earlier sought to isolate the contribution of the laboratory to the teaching of science. It is also instructive to consider the impact of science curricula which include the laboratory as a central focus, such as the major national curriculum improvement projects.

Ramsey and Howe (52) conducted an extensive review of the effects of "traditional" science programs versus curriculum improvement projects such as BSCS, CHEM Study, CBA (the Chemical Bond Approach), PSSC, HPP (Harvard Project Physics), and ESCP. These "alphabet curricula" include extensive laboratory work as a central focus. The investigators summarized these studies in terms of knowledge acquisition, understanding the scientific enterprise, critical thinking, and the development of attitudes. The evidence presented strongly suggests:

1. Students participating in the new curricula demonstrate superior achievement on measures of content defined by the new curricula while performing equally well on traditional content tests as do students in conventional programs;
2. Multireference, laboratory-centered science teaching programs produce "greater student growth in understanding the scientific enterprise and in critical thinking ability," at least in studies where student and teacher background variables are held constant;

3. "An inductive, problem-solving, laboratory-centered approach can be expected to produce significant positive changes in student attitudes";

4. "Inductive, problem-solving, and laboratory-centered methods seem preferable to deductive-demonstration methods if outcomes other than knowledge are sought, and if retention of knowledge over time is felt to be important."

However, the authors also make clear that teacher characteristics are probably more critical than the particular curriculum materials used. It is most important that the background, philosophy, and instructional style of the teacher be congruent with the objectives and methods of the curriculum.

A recent study by Tamir and Jungwirth reinforces the need to look at long-term cumulative impact and perhaps to consider spacing instruction over several years. (73) Their study is especially instructive since some of their measures were specifically related to laboratory kinds of objectives (see especially number 4 below). The Israel BSCS Adaptation Project began in 1964 with a selected group of high school teachers, and by 1971 about half the high school classes in Israel were using the Hebrew adaptation of BSCS. All students studied biology in the ninth and tenth grades for three periods per week, and those who elected to major in biology continued with four or five periods per week during the eleventh and twelfth grades. The sample consisted of several hundred students who entered the ninth grade in 1965-67 and graduated in 1969-71. Care was taken to match comparison groups in terms of students, teachers, and schools. A comparison between BSCS and non-BSCS students suggested:

1. Although students were not meeting anticipated mean or gain scores at the end of the tenth grade, the BSCS students did perform significantly better on measures of biological knowledge.

2. Although both BSCS and non-BSCS students made small gains in the understanding of science by the end of the tenth grade, as measured by the Test on Understanding Science, the BSCS students demonstrated significantly higher understanding of the processes of science, as measured by the Science Process Inventory, which was administered at the end of the eleventh grade.

3. BSCS students outperformed non-BSCS students in most inquiry skills, especially in formulating hypothesis, suggesting relevant experiments, and designing proper controls, as measured by the Biology Process Test.

4. BSCS students also demonstrated superiority in solving open-ended problems which required the use of experimental procedures in the laboratory.

Matching Science Experiences to Student Characteristics

A second justification for continued emphasis on the laboratory in science teaching is based on the observation by Hunt (24) and others that a given teaching method may have dramatically divergent effects on different students. Instruction which is effective with one type of student may have little positive effect, or even a negative effect, when used with other students. Many of the "nonsignificant differences" observed when comparing teaching methods may occur because the conflicting effects on different students average to zero. In some of the studies reviewed, researchers reported that the effect of the laboratory was to produce greater variation in student performance than was the case for alternative procedures. The research on laboratory teaching reported earlier relied almost exclusively on common measures of IQ as the single differentiating characteristic among students. However, other variables such as past achievement, cognitive development, degree of structure in presentation, and group compatibility may need to be considered in the design, implementation, and evaluation of laboratory experiences.

Rowe, working with Hurd, conducted a fascinating study on group dynamics and productivity which demonstrates that teaching based on conventional wisdom may not always produce optimal student learning. (25) Rowe observed that 15 to 50 percent of the student groups in classrooms using the BSCS Laboratory Block program had sufficiently severe organizational problems to cause delay in completion of the group tasks. She hypothesized that more compatible groups as defined by the Control-scale of the FIRO-B should be more productive than incompatible groups. The ata suggest that this is true for college-bound students, but that noncollege-bound student group performance seems to increase with increasing incompatibility. This may be caused by differences in the methods which the two types of groups use to reduce tension. Individuals in the college-bound groups tended to reduce tension produced by differences of opinion by temporarily leaving the group or asking to work alone. Individuals in the noncollege-bound groups turned to task oriented behavior. Apparently they preferred not to disrupt the social peace.

Karplus has summarized the basic differences between concrete and formal reasoning patterns as shown in Table 2. (30) The importance of distinguishing between students using concrete and formal operational reasoning patterns, and perhaps structuring laboratory experiences for each, is illustrated by the following studies.

Lawson and Renner analyzed the concepts taught in the biology, chemistry, and physics classes of a large high school in a midwestern university town and found that a majority of them were formal. (36) Students in these classes were administered Piagetian tasks. Sixty-five percent of the biology students were classified as entirely or partially concrete. Ninety-two percent of the chemistry students were classified as transitional between fully concrete and fully formal. The physics students were also mostly transitional; however, 36 percent still exhibited some concrete operational characteristics. Only five percent of the entire sample of 134 students were judged to be fully formal. An analysis of student responses on the course subject matter exams showed that students classified as early concrete had no understanding of either concrete or formal test items. Transitional concrete and fully concrete students understood 30 percent of the concrete items, but no formal items. Students classified as early formal, transitional formal, and fully formal demonstrated understanding of both concrete and formal concepts. The authors concluded that formal thought apparently contributes to understanding of concrete concepts, and speculated that since the teaching style used in the classes was largely expository, without first-hand concrete experiences, the potentially concrete material was rendered abstract and required formal operational thought.

Sayre and Ball investigated the relationship between the cognitive development of students and their achievement in science. (58) A number of Piagetian tasks were used to classify 419 students in grades seven to twelve. The percent of students classified as formal operational increased consistently, from 9 percent for seventh graders to 81 percent for physics students. Significant positive correlations were observed between student achievement (as defined by course grade in eighth and ninth grade science, biology, and chemistry) and their overall performance on the Piagetian tasks. The authors suggest that the nonsignificant correlations for the seventh grade and physics students were probably due to the fact that most seventh graders (91 percent) were classified as nonformal while most physics students (81 percent) were classified as formal, i.e., there was no range on the variable.

This set of studies identifies some important limitations of past research on the laboratory, and suggests that much research is needed before criticism of the importance of the laboratory can be accepted with confidence. For example, the suggestion by Yager, Englen, and Snider (79) that "some students (especially at advanced levels) may find the laboratory to be a waste of time and merely a means of slowing their pursuit of new theories and concepts" may not be a valid criticism of the laboratory <u>per se</u>, but an indication of our failure to properly match appropriate laboratory experiences to the backgrounds and abilities of the students. One might speculate that secondary school students who elect advanced courses in science probably use formal operational reasoning patterns. These students would thus be able to work effectively with abstract symbols, and would enjoy thought experiments requiring deductive logic. They also would probably benefit from and enjoy low-structure situations which challenge their ability to creatively plan and implement complex experiments. On the other hand, students who use concrete reasoning patterns or who are unfamiliar with the material might only be

Table 2—Characteristics of Students Using Concrete and Formal Reasoning Patterns (Karplus, 1977a).

Concrete	Formal
I—Needs reference to familiar actions, objects, and observable properties	—Can reason with concepts relationships abstract properties axioms and theories uses symbols to express ideas
II—Uses reasoning patterns C1-C3, but not patterns F1-F5	—Uses reasoning patterns F1-F5 as well as C1 C3
C1—Applies classifications and generalizations based on observable criteria (e g consistently distinguishes between acids and bases according to the color of litmus paper, all dogs are animals, but not all animals are dogs)	*F1—Applies multiple classification conservation logic, serial ordering, and other reasoning patterns to concepts, abstract properties axioms, and theories (e g , distinguishes between oxidation and reduction reactions, uses the energy conservation principle, arranges lower and higher plants in an evolutionary sequence makes inferences from the theory according to which the earth s crust consists of rigid plates)*
C2—Applies conservation logic—a quantity remains the same if nothing is added or taken away, two equal quantities give equal results if they are subjected to equal changes (e g when all the water in a beaker is poured into an empty graduated cylinder, the amount originally in the beaker is equal to the amount ultimately in the cylinder)	*F2 Applies combinatorial reasoning considering all conceivable combinations (e g , systematically enumerates the genotypes and phenotypes with respect to characteristics governed by two or more genes)*
C3—Applies serial ordering and establishes a one-to-one correspondence between two observable sets (e g small animals have a fast heart beat while large animals have a slow heart beat)	*F3 States and interprets functional relationships in mathematical form (e g the rate of diffusion of a molecule through a semipermeable membrane is inversely proportional to the square root of its molecular weight)*
	F4 —Recognizes the necessity of an experimental design that controls all variables but the one being investigated (e g sets up the clover experiment)
	F5—Reflects upon his own reasoning to look for inconsistencies or contradictions with other known information
III—Needs step by step instructions in a lengthy procedure	Can plan a lengthy procedure given certain overall goals and resource.
IV Is not aware of his own reasoning inconsistencies among various statements he makes or contradictions with other known facts	Is aware and critical of this own reasoning actively seeks checks on the validity of his conclusions by appealing to other information

frustrated and unsuccessful if required to operate in this manner.

Promoting Cognitive Development

The final and most speculative reason for continuing to support laboratory activities is the suggestion that science programs might be specifically designed to facilitate student transition from concrete to formal reasoning patterns. Intellectual development is brought about through a process Piaget calls "equilibration." That is, when confronted with a situation which arouses interest and cannot be explained by existing reasoning patterns, a student reorganizes his or her explanatory system. In actively struggling to explain the anomalous phenomenon, the student develops new and more advanced intellectual structures.

Karplus and others have proposed a three-phase learning cycle to promote equilibration or, as Karplus calls it, self-regulation. (31) During the exploration phase, students engage in hands-on activities with concrete materials which familiarize them with the phenomena being studied. Students work with a minimum of guidance, and are not expected to produce specific results during this first phase, which is intended to interest and disequilibrate them. The exploration phase is followed by concept introduction, in which the teacher introduces a new concept relevant to the problem at hand. Students then concentrate on concept application, during which they apply the new concept to a variety of related but novel situations. Inquiry techniques such as those discussed earlier are most useful during this phase. Laboratory-type experiences are central to both the "exploration" and "concept application" components of this instructional strategy.

Summary

With the rising cost of instruction, and the press for efficiency in teaching, it is appropriate to ask whether laboratory experiences contribute anything unique and important enough to justify their expense and time. Tentative conclusions from the research reviewed are these:

1. Lecture, demonstration, and laboratory teaching methods appear equally effective in transmitting science content.
2. Laboratory experiences are superior for providing students skills in working with equipment.
3. Although most research has failed to assess outcomes that might be specific to the laboratory, meaningful laboratory measures can be developed; the laboratory appears to represent a significantly different area of science learning than content acquisition.
4. Some kinds of inquiry-oriented laboratory activities appear better than lecture/demonstration or verification labs for teaching the process of inquiry. However, teachers need to be skilled in inquiry

teaching methods; specific inquiry training should be provided over extended periods; and students need both time and guidance to become comfortable with the new methods and expectations.

5. Laboratories appear to have potential for nurturing positive student attitudes and for providing a wider variety of students with opportunities to be successful in science.

6. Recent and continuing research on the role of science teaching for nurturing cognitive development may, in the relatively near future, provide important new science teaching strategies in which properly designed laboratory activities will have a central role.

Teachers who believe that the laboratory accomplishes something special for their students would do well to consider carefully what those outcomes might be, and then to find ways to measure them. If it is nothing else, this paper is an invitation to systematic inquiry, for the answer has not yet been conclusively found: What does the laboratory accomplish that could not be accomplished as well by less expensive and less time-consuming alternatives?

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Learning Science from Planned Experiences

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INTRODUCTION

Psychologists from Rousseau to Piaget have emphasized that experiences form the basis of learning. Experiences may be casual (as in everyday living) or planned (as in the school laboratory, in museums, or on field trips). Although different in appearance, these three settings have the common purpose of stimulating learning. Furthermore, each setting can and inevitably does contribute to the full range of learnings: cognitive, affective, aesthetic, and skills.

This paper will consider, on the basis of available research, the interrelations between experiences in the different settings, the internalization of experience, and learning. Our attention will be restricted to those settings which offer, perhaps even require, an active role for the observer. All these settings allow the observer to have a personal, non-verbal experience with the things and behaviors of the world.

Numerous constraints and assumptions are inherent in this review. First is the recognition of major differences between individuals. Each brings his or her unique past experience to a new learning situation and builds on that prior background, which may or may not include familiarity with phenomena, vocabulary, and conceptual patterns. Also, each observes selectively; everyone notices different things. Although certain observations may be directed by a worksheet, students will be making many other observations on their own. While we tend to focus attention on what is seen, other senses, such as smelling, hearing, feeling, and perhaps even tasting, are constantly receiving impressions. These other senses often provide strong and significant input, which can help us in classifying and describing things and phenomena. Unfortunately, these other sensory inputs are often suppressed by our emphasis on verbal descriptions of visual images. Therefore, as we consider the learning potential of museums, field trips, and laboratories, we should be aware of the diversity of sensory experiences involved.

Teachers also know that students range from the rash to the timid. Some plunge ahead; others hesitate to explore. Some notice a wide variety of objects and events; others notice little. Given such a diversity of background experiences, and such a range of observer initiative and selectivity, what should be the central goals of experience-based learning?

Science from Experience

There is general agreement that science is man's endeavor to reduce the myriad of sensations of things and events to patterns which are consistent with experience. Increasing faith in these patterns develops when they serve as the basis for expectations (predictions) confirmed by new experience. ("See, it works.") Not only does our distilled experience help us to survive, it also gives us the satisfaction of knowing that we can cope ("Can do"). Furthermore, the confirmation of expectations helps to center control in the individual, rather than in "fate." Here, then, we have a rationale--differently phrased by different authors--for laboratory and field experiences.

Given this rationale, new experiences through field studies, museum visits and laboratory activities become the starting point for science studies. Perceptions of the environment gained from these experiences are the criteria against which we judge the appropriateness of our mental patternings. Thus, phenomena become the basis of all our mental operations of perceiving, naming, observing, classifying, measuring, ordering, patterning, and forming hypotheses.

Environmental Education

With its focus on the world within, around, and beyond the school, environmental education has within a few years grown to be a major component within science education. As it evolved from conservation education, environmental education has become more interdisciplinary. Consideration of the environment leads inevitably to discussions of the wise use of raw materials and handling of wastes. Thus, environmental education emphasizes not only the need to "know that," but also the need to consider "what to do."

Sufficient research in environmental education has already appeared to warrant two comprehensive summaries.(13,14) The studies considered in the first review include 94 references, up to 1971. Because environmental education was just emerging, these early studies dealt mainly with conservation and camping activities. The second review, covering 1972-76, included 100 citations, and concluded that the field was still embryonic. (14) A major difference of opinion endures between those contending that emphasis should be on knowledge, and those contending that comparable emphasis must be upon affective objectives.

Much of research on environmental education appears to describe courses featuring short-term instruction (often only a few weeks), small groups, and a narrow definition of environmentalism. In the second review, Roth concludes that there appears to be a small positive relation between increases in knowledge and attitudes of concern for environmental protection. As Sherman had concluded in 1950, concern for environmental protection arises from many factors, of which increased knowledge is only one. (17)

Both Roth (13,14) and Doran (4) have concluded that the devices and procedures for evaluating learning in environmental education are low in reliability and in validity. Doran comments that: "the development of a pool of valid and reliable instruments for any field is a complex and difficult task, but is essential to the stability and maturity of the discipline." Such a state of confusion in an embryonic field is to be expected, especially when general agreement is lacking on the types of objectives to be sought. However, the self-consciousness of those involved in environmental education, as they seek acceptable objectives and means of evaluating their instruction, stands in laudable contrast to the lack of such concern described by Bates (2) for evaluating science laboratory activities.

Museums

The directors of museums (another type of learning laboratory) are collectively beginning to explore the dimensions of their educative role through their Association of Science-Technology Centers. Also, they are attempting to evaluate the effects of museum visits. (3) As with environmental education, establishment of a frame of reference and criteria for appraising such effectiveness is difficult but essential.

In an internal working paper for the Boston Museum of Science, Richard King, Director of the Education Division, has turned to learning theory to consider the difference between a perception and an observation. Within the sensory field are many perceptions. On the basis of past experience and current set, some of these are selected to become observations, while the remainder are supressed.

Every teacher daily sees the differences between students who "see" different aspects of common experiences. How and why these differences arise is not clear, but is worth some speculation and subsequent research. Presumably those students who look but do not see (at least not what we wanted them to) lack a basis for selecting a few important particulars and excluding the remainder. Museum directors are concerned about the extent to which they are involved in teaching through directed observations in contrast to having students discover on their own.

It does seem that an observation begins with pre-existing concepts resulting from previous experience. The completely naive observer may have difficulty in selecting aspects to consider. We have all experienced the confusion of being presented with some completely novel device or behavior, and finding that we had difficulty in selecting aspects for our attention. Perhaps your first viewing of a cell through a high-powered microscope produced a sense of confusion. Without cueing, you probably did not notice many of the cell's subsytems. A student who asks "What should I see?" is on the right track--he or she is at least indicating a need for some sort of selection system.

A more experienced student "zeros in" on a few aspects which are important to him. Some may be novel, others may confirm previous observations. Such selective perception has been learned through experience and tutelage. Development of selective perception (knowing what is important) is then one purpose for planned experiences, whether in the laboratory, field, or museum.

Many musuem directors are now beginning to explore the possibilities of "interactive" or "hands-on" exhibits, often for the very young. It may seem more appropriate to restrict such hands-on experience to the very young, but we are all naive about novel experiences. Adults as well as children may experience a surprise when, for example, they place their hands on sheets of wood, plastic, and metal--all at room temperature--and find that the metal "feels colder." "Hands-on" need not be reserved for the young.

While the interactive mode offers many opportunities for personal experience, it does have limitations. Some sorts of things may not be practical for hands-on experiences. And, without some cueing, there is the possibility that the experience will not progress beyond merely "messing around." Furthermore, what we consider to be the important attributes may be the action or reaction of the materials, which may not be readily accessible to the viewer (how does a transistor function?).

Museums often exhibit "the real thing," such as a large complex working engine, a diorama of a natural environment, or the skeleton of a prehistoric animal. Without prior experience with simpler things, cueing questions, or "exploded views" centering on particular aspects of the display, the visitor has little basis on which to observe niceties. The visitor's reaction may be only "Wow, that's big (complex, whatever)." Museums seem to avoid a pedagogical procedure, commonly used by teachers, in which simple components are introduced first, then compounded into larger wholes. The use of such developmental approaches introduces questions about the role of a museum--whether for education, culture, or entertainment. (These purposes need not be mutually exclusive.)

Museums have the same concerns as do educators, but the brief time given museums by casual and short-term visitors accentuates the importance of gaining and holding attention. If the museum could focus attention on selected aspects of the display with various cues, it could become a complex teaching machine. This approach has the hazard of controlling the visitor's observations, and may also inhibit the excitement of personal discovery. If attention is not focused, however, the visitors fall back upon their diverse previous experiences as the basis for their selective perceptions. Actually, most museums present exhibits which range from the strongly focused to the unstructured, with a majority having some degree of simplification and structure. Perhaps such a mixture provides adequate experiences, given the diversity of musuem visitors.

As a place for research, museums offer rather different possibilities from those occurring in schools or environmental centers. Borun has investigated some aspects of the effectiveness of the Franklin Institute in terms of the relation between what people learned, how long they were in the building, and the number of exhibits they considered. (3) (Those in her sample were, unlike a school sample, ordinary people not expecting to be tested, but were cooperative.) Sh noted Lakota's study at the National Museum of Natural History in which he concluded: "People aren't receptive to information if they are feeling lost." (8) The lostness may be either spatial (resulting from a huge establishment) or mental (resulting from the overwhelming diversity of novel things). This is consistent with our earlier comments about "naive " observers who lack sufficient background to feel at home with an exhibit. Many of Borun's conclusions are related to the peculiarities of the Franklin Institute. She notes that upon entering, people tend to turn to the right.They also tend to seek verbal confirmation from guards of information on printed statements.

Another recent study by Marsh at the National Collection of Fine Arts involved training docents (volunteer tour guides on the floor) to ask questions relating to meaning and to wait before responding to questions from visitors. (9) (This was an application of Rowe's (15) wait-time relationship.) The number of visitors' questions in search of understanding increased remarkably, from around 2 per tour to 17, showing that relationships first noted in schools have more general applicability.

A Distant View

Let us attempt to stand off from the particulars of research and consider some of the dimensions that we might expect to influence student learning and subsequent behavior. We shall first explore some of the significant factors influencing learning, and then propose a new model for research. The novelty of the research model is its dependence upon classroom observations by teachers as the source of questions to be later examined empirically with larger samples. Teachers can initiate the researches and later apply them.

In an effort to re-center investigations of learning from museums, laboratory, and field experiences, we may posit two major dimensions. First is the "knowing" (conceptual or logical) component, on which there will be large ranges among individual learners both initially and subsequently. Second is the social/psychological dimension, involving values, attitudes, self-image, risk-taking, fate-control, and so on--this is strongly mediated by the past and present social environment of the learner in school, in the home, and among peers. Suspected social or psychological causes of behavior (that is, suspected precursors) are less likely to be effective predictors of future behavior than are the student's present characteristics. Even so, a knowledge of these social precursors may be important if major social intervention is contemplated.

For schooling and teachers, the student here and now is of central concern. Teachers differ considerably in their emphases, rewards to students, and attention to creative learning by students- this results in a wide range of classroom learning environments, which in turn result in many different kinds of learnings by students. Munby's (10) conclusion that most secondary school teachers present science in the classroom as essentially a closed system (using a dogmatic, this-is-the-answer approach), suggests that "questing" for acceptable conclusions is not common in classrooms. Surely, the ways by which teachers mediate instruction, both by verbal and non-verbal signals, must be included in the description of any intervention program.

Students differ in many factors influencing both their perceptions and their interpretation of perceptions. If these differences are genetic, little can be done to modify them, but different instructional patterns and appraisals could be designed to accommodate differences. If the differences are learned, then a worthy line of investigation would be the timing, nature, and extent of procedures by which the differences might be lessened--if that seemed desirable.

Increasing evidence indicates that early home environment tends to set a child's appraisal of himself and the nature of the world before he enters school. If that conclusion is sustained, schooling can be expected to make only modest changes. Clarification of the risk-taking capacity and self-image of children entering school could be the basis for long-term growth studies. The home is also influential in shaping the self-image, ego-strength, and risk-taking level of the student. At present, we have little knowledge about how those attributes influence the learning of science and the internalization of experience. While the social-economic status of the family is often used in sociological research as a mediator, for science learning a description of the philosophical attributes of the home may be more important.

Risk-taking and fate-control are probably associated. Whether this would be a positive or a negative association is unclear. Those who feel in command of their futures might take greater risks. But then again, those whose "fate is sealed" have little to lose by taking risks. If we seek ingenuity, imagination, and creativity we should look more carefully at the role of risk-taking and fate-control. Some research on this subject has been recently reported by Rowe. (15)

Self-concept, self-perception, and gender have also been central in the studies of Shymansky, Penick, Matthews, and Good(18) and of Krockover and Malcolm (7). Shymansky, et al. found that some elementary-school children were hesitant to participate in an activity-centered program, and therefore to capitalize on problem-solving situations. As Bates noted, Atwood--and probably many teachers--had previously reached a similar conclusion. With a relatively small number of students, taught with SCIS materials for only four and half months, Krockover and Malcolm found some differences related to gender and method of instruction. These and other studies are beginning to include a multiplicity of parameters, such as student gender and self-esteem, in addition to academic criteria.

If we consider science as an attempt to create order and predictability among perceived phenomena, the laboratory, field trips, and other experiences are the starting point--but only the starting point. From personal experience we know only the specifics of what we, individually, perceived. By discussion we can compare our perceptions with those of others, and gain a wider data base. However, the organization of experience into patterns is an individual mental operation. Students need aid in becoming more competent in such patterning. Discussions among themselves, questions, perhaps even cueing from the teacher, also aid students in this patterning process.

Most of the research involving a pre-post design has avoided the details of the inputs and struggles by which students "make sense." Teachers, who are "on the scene" and are participants, can provide the descriptive and diagnostic data. This places the teacher's observation in a crucial position and opens up new possibilities for clinical research in this area.

A Small Map of Research Possibilities

Quarterly Report #8 of Project City Science (11), includes an interesting map of the possible dimensions for research:

Figure 1. A Small Map of Research Possibilities.

Obtrusive

Participation	Intervention
Action Research	Empirical
Counselling	Testing
Clinical	Measurements

Natural Experiments

Observations	Counting
Case Studies	Surveys

Unobtrusive

The vertical axis divides research possibilities into those involving numbers and those involving word descriptions. The horizontal axis divides the possibilities on the basis of the presence or absence of direct intervention. Thus, the "obtrusive" quadrants include all those arrangements introduced by the experimenter in which he may or may not play an obvious role. The "unobtrusive" quadrants include all the "natural experiments" which occur without arrangement. Here the investigator observes, records, and ponders "what is." An example might be a record of who works with whom in the laboratory, and the questions include "why those groupings?" and "to what end?".

The four quadrants differentiate the types of information accessible and the role of the investigator in each. The upper right quadrant includes typical empirical research involving deliberate intervention, comparison groups, and testing--usually pre-post. Inherent in the design of such experiments are many decisions: what populations to include, what factors may be cancelled by randomization (and how well randomization can actually be done), what range of characteristics to consider (gender, social-economic status of the family), duration of the intervention, validity of the tests to be used, correspondence of the actual input with that anticipated, and so on. As we have seen, some recent studies are beginning to include a wider range of characteristics and more complex procedures of analysis. But inherent in such types of experiments are the choice of attributes to be included. Often decisions are made on hunches, limited experience, time available, and financial resources. Therefore, more attention should be given to careful clinical observation, especially by the teacher, as a precursor to selection of parameters for empirical studies, which are necessarily expensive in time and finances.

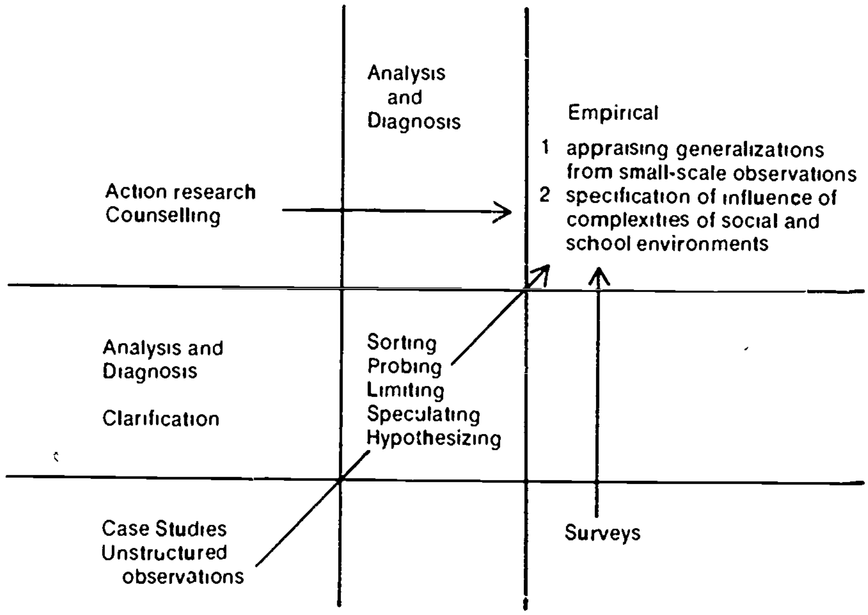
The lower right quadrant--quantitative but "unobtrusive" studies--offers possibilities not often used. Here are some of the "natural experiments," which occur without intervention, as described by Webb, et al. (19) For example, teachers and administrators are often concerned about students' "motivation." Direct measures (testing) of "student motivation" appear to be difficult, and subject to faking. Perhaps a relevant and valid unobtrusive descriptor exists in notations of students' daily attendance. No intervention or special conditions are required. Yet, an argument could be made that voluntary class attendance is a valid description of "motivation." This would be most applicable with student populations whose school attendance was less than perfect. Teachers who already have a sense of student interest might, and probably do, choose to intervene with those most frequently absent by some form of counseling (upper left quadrant).

The upper left quadrant includes those non-numerical activities in which the investigator is actively involved. Here are "participant research," action research, and counseling. Not only is the investigator attempting to describe and analyze the situation, but he or she is also intervening to produce change. The types of information sought, the diagnosis of possible effective intervention, rationale for action and what was done, plus the outcomes--successes and failures--may lead to a clarification of parameters useful to more extensive empirical investigations. Examples of such involvement are reported by Kohl (6) in "36 Children" and by Radosh (12) in "Debs."

The lower left quadrant corresponds to the "fly on the wall" approach. One watches, presumably with a minimum of preconceived expectations. This is a mode advocated by Atkin in an effort to generate potentially useful descriptions of the actual dynamics of behavior. (1) Here, for example, would be the Erlwanger's long series of interviews with Benny about image of arithmetic which produced his revealing comment that "fractions have over a hundred rules." (5) Similarly, attention to the significance of wait-time in teachers' questioning grew out of Rowe's clinical observations in classrooms.

Figure 1 is a map of research styles, but it is essentially static. Figure 2 presents a more dynamic model--an intervening layer of analysis and diagnosis has been added. While it is difficult to observe without reaching conclusions, careful descriptions in the anthropological sense may permit others to consider a range of interpretations and prescriptions for action through planned intervention, resulting from diagnosis of the kinds and intensities of factors bringing about the observed behaviors. A variety of criteria may be involved in this diagnosis--including relevant aspects from psychology, sociology, philosophy, anthropology, and perhaps economics. These would be the "glasses" through which the behavior was examined. Hopefully, more than one approach would be used simultaneously on one set of data.

Figure 2. An Active Model.



Classroom teachers have much knowledge and wisdom which rarely is presented in the literature of educational research. Busy with their many responsibilities, they have little time for major empirical research. However, their observations and experience can contribute significant results. Hopefully, teachers as individuals or small groups will realize the importance of contacts with students as the basis for research. Through clinical interventions, various forms of unobtrusive data-gathering, and descriptions of clinical interventions, teachers can orient and contribute to the research about how children shape experiences into reliable conceptual patterns, and in so doing gain confidence in their own teaching capabilities.

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