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ABSTRACT

This volume was conceived as a review of basic research in science education and as a discussion of what the research findings mean for K-12 science teachers. The eight reports presented represent different dimensions of science education. Each provides a review of a given dimension and/or a goal of science teaching and suggests ways that current knowledge might affect practice. Reports focus on: (1) a review of some major studies in instruction, with suggestions for applications to science/mathematics curricula (J. Stallings); (2) information-processing psychology and a brief description of a science project using its methodology (J. Larkin); (3) role of instruction in the development of problem-solving skills in science (R. Ronning and D. McCurdy); (4) developing creativity as a result of science instruction (J. Penick); (5) deriving classroom applications from Piaget's model of intellectual development (D. Phillips); (6) the development of an attentive public for science: implications for science teaching (A. Voelker); (7) factors affecting minority participation and success in science (J. Kahle); and (8) status of graduate science education: implications for science teachers (J. Gallagher and R. Yager). Brief summaries of each report and background information are provided in an introduction. A list of six actions by educators that would serve to implement the research findings and set new directions for science education is presented in an epilogue. (Author/JN)

WHAT RESEARCH SAYS TO THE SCIENCE TEACHER

Volume 4

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PROLOGUE: USING RESEARCH FINDINGS TO DEFINE AND ASSESS NEW GOALS FOR SCIENCE TEACHING

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The 1980s are years for reassessing the basic goals of science education. Advocacy groups in the past have urged science education in certain new directions, but the thrust of these directions usually entailed little more than revising and updating science course content and usually met with relatively little resistance. After all, who could oppose dealing with "current" content in school science?

For over fifty years "science processes" have been emphasized in school science programs. Such processes presumably focus on how new science content is produced or on what procedures are followed by scientists. During the past quarter of a century this dimension or goal of science teaching has been popularly referred to as "inquiry." Many have argued that content and process should receive equal treatment in individual science course structures and throughout the entire K-12 science curriculum.

Although this argument continues today, researchers generally agree that such an argument is simplistic. Science content and process are but two dimensions of the the discipline we call science. Science is a multidimensional enterprise and the dimensions of it appropriate to K-12 students and the general public are matters of great concern and current debate. In some respects the traditional content and process dimensions of science may be the dimensions least important and appropriate to us in planning for the year 2000.

Project Synthesis (the focus of What Research Says to the Science Teacher, Volume 3) and the NSTA Analysis of the Current Accomplishments and Needs of Science Education (ERIC, 1980) were major studies available in 1981 providing a basis for current thinking, research, and practice. Both of these efforts focused on reformulating goals for science education and developing a rationale for the discipline of science education, concerns identified by science education leaders as two of the most critical needs now confronting the discipline and the society. These new goals and rationale must, ideally, reflect the nature of science, the nature of society and culture, the expectations of education, and the needs of individuals. The support necessary to mount such an effort, however, has not been forthcoming.

Just as these issues were being discussed following careful analysis of current data, federally supported science education activities were curtailed. Recommended for extinction early in 1981 was the Science Education Directorate of the National Science Foundation, the government agency largely responsible for direct support of science education. NSF had only begun a focus on research in science education late in the 1970s, and reports from several significant studies, some co-sponsored by the National Institute of Education (NIE), are only now becoming available.

This volume was conceived as a review of some of this basic research in science education and as a discussion of what the research findings mean for K-12 science teachers. Some of the reports included here represent extensions of NIE or NSF projects; others are reviews of several studies; and some are direct reports of the recipients of single large grants awarded to investigate critical problems in science education. The set of eight reports included represent areas of study which outline broader goals and definitions for science education. These particular reports were selected on the basis of their implications for classroom teachers, and the NSTA Publications Committee approved the selection. Some problems worthy of note as this volume was developed include the lack of relevant results for classroom practice from some national projects that were funded; the large focus on college level science in a number of instances; the incompleteness of some efforts at the present time; and the inability and/or unwillingness of some investigators to consider making such a report for practitioners.

Many educators over the past five years have identified the split between research and practice in science education to be a major problem of our time. This volume is dedicated to narrowing the split and offers interpretation of research designed to affect practice. The monograph series, What Research Says to the Science Teacher, represents a major commitment by NSTA to developing a research base for practice, reducing barriers between researchers and teachers, and improving science teaching practices based on the results of research.

The eight reports here represent different dimensions of science education. Each provides a review of a given dimension and/or goal of science teaching and suggests ways that our current knowledge might affect practice. Other dimensions, of course, exist. An entire monograph could be devoted to the science/society dimension and definition of science education; a series could deal with science and career awareness; and values, ethics and science comprise another dimension not adequately addressed. An additional dimension critical to science education is its relationship to the arena of public decision making. How can science be used to affect daily living, survival, our future? Unfortunately, definitive research ready to review and discuss in each of these areas is not currently available. The choice of research areas in this monograph was governed not only by their importance, but partly because these research reports were available, the projects were funded early enough to permit analysis and discussion at this time, and the eight investigators agreed to provide manuscripts without honoraria or other reward.

The first research review is that of Jane Stallings concerning her extensive studies of instruction. She observes classrooms as they are; i.e., she is not an advocate of new goals and/or new materials. She studies what teachers do and how their actions affect student learning--that learning traditionally used to assess success. Stallings' work is concerned with improving science given the basic two dimensional view of science: content and process.

Stallings reviews some of the major studies of instruction and shows how some of the techniques and suggestions developed in these studies have been applied to mathematics and science curricula. She suggests the most important variable to emerge from these studies is the "Use of Time." Examples of mathematics and science classrooms are presented and examined to discover how learning environments affect teacher and student behaviors. Findings regarding the length of a school day, academic time, time allocated to activities, and student time-on-task are examined to uncover their implications for instruction. Contrasts between general and advanced instruction are discovered in both mathematics and science classrooms. The same teachers who teach calculus in an active way also teach general mathematics in a non-active way. Teaching suggestions emerging from these studies are presented to help mathematics and science teachers continue to provide quality instruction to all students in the face of decreasing support and budget cutbacks.

The second research review deals with studies of problem solving and what their results suggest for the classroom. Jill Larkin has been involved with several research projects and has been instrumental in expanding the focus on problem solving in mathematics to embrace other curriculum areas including science. Many express interest in problem solving; a recent Gallup Poll indicates that the public ranks it second only to reading in importance as a goal for schooling. (Interestingly, science, although recognized as important, receives a priority ranking next to the bottom when compared with 18 other important functions of a school.) Science teachers give some lip service to the importance of problem-solving skills in science but seldom plan activities designed to foster or develop such skills. Although science educators are often generally concerned with teaching students to think, a major gap exists between research in science teaching and those methodologies from cognitive psychology most directly concerned with elucidating the processes through which people reason.

Larkin describes a research approach, commonly called information-processing psychology, in which human intelligence is viewed as the ability to take in and process information. Work in this area is characterized by the collection of detailed data, usually from individual subjects, and by the use of computers to construct precise yet powerful models of human performance. Larkin argues that the rules of thinking discovered through this research are particularly relevant to the design of science instruction. She illustrates this kind of research approach using an example from the physics classroom.

The next research review is that of Royce Ronning and Donald McCurdy who deal with student cognitive styles and problem solving in science. Although a definition of cognitive style remains controversial among some investigators, Ronning and McCurdy use such terms to identify different personal traits among students in a given class. These researchers affirm the importance of developing problem solving methods and seem, at times, to relate them to scientific "processes." Their research provides an interesting link between that of Stallings and Larkin and is positioned after both of their reviews to permit such analysis.

Current research in problem solving is primarily concerned with problem solving methods and the degree of knowledge acquired through their application. A brief argument is advanced that this conceptualization is incomplete because of its failure to consider individual differences among problem solvers beyond their problem solving methods and extent of knowledge. Ronning and McCurdy maintain that a viable theory of problem solving instruction must take these differences into account. Evidence for the argument is presented in the form of data on the problem solving abilities of junior high school students who have extreme scores on Witkin's field independence-field dependence measure of cognitive style. Results indicate that junior high students have difficulty solving problems, particularly problems involving proportional reasoning or the control and separation of variables. The study also demonstrates that "field independent" students solve significantly more problems than do "field dependent" students.

The fourth review by John Penick is concerned with a definiton of creativity and its importance in science. Developing creative minds capable of new thoughts, new hypotheses, new approaches, and new insights is a vital dimension of science, yet most of what is done in science classrooms (as shown by the NSF Status Studies and the Actual State of Science Teaching described by Project Synthesis) is designed to thwart creativity. Means must be found to develop scientific creativity in more students. Penick's review of research in this area is full of implications for K-12 teachers and science classrooms.

Penick's review clearly shows that creativity does not have to be left to chance. A person's creativity, creative potential, and ability to use creative processes are readily influenced by the classroom environment--the teacher, the room, the materials, and peers. Although a minimal I.Q. seems to be necessary for individual creativity, Penick identifies many studies which have shown that most students can benefit from definite strategies aimed at improving scores on creativity tests. These strategies usually involve reducing the amount of restriction placed on the student. Penick suggests that this reduction might be brought about by giving students more opportunities to make decisions, initiate learning, and evaluate their own ideas, actions, and products. Creative students demonstrate increased achievement, more flexibility, better attitudes and socialization, increased sensitivity and self-sufficiency, and better overall social adjustment. Although creativity has been shown to be worth promoting in science classrooms, few science teachers set goals of developing more creative students; few consider creativity an essential dimension of science.

Another dimension of science dealt with here is concerned with the level of understanding possible given the "mental structures" that have developed in an individual. Many of the curriculum efforts of the past two decades have been described as Piaget-based and yet Piaget never developed a curriculum and never classified information or concepts. He was concerned with understanding how humans develop intellectually and used certain tasks--many of them related to science content--to study such development. Darrell Phillips has worked extensively to replicate Piaget's studies and relate the findings to science classrooms.

Even though the work of Piaget has provided the basis for a large number of research efforts, relatively few attempts have been made to point out and explain direct and practical classroom applications. For example, many books and programs provide extensive written material about Piaget's developmental stages; some even provide examples of interview protocols and suggestions for classroom activities. But these attempts, even though commendable, provide very little specific direction in terms of what a teacher does, day by day, in an actual classroom.

Phillips asks us to consider the enterprising teacher who invests the time and energy to conduct interviews with many of his or her students. The data are collected and students are labeled (often incorrectly) either "concrete" or "formal." Now what? How are these data used? What bearing do these data have upon the science topics being taught in that classroom? All too often these questions remain unanswered; the teacher typically has no recourse other than to continue teaching the same science topics in the same way.

Phillips provides an easily understood review of Piaget's work suggesting how textbook authors, curriculum developers, and even researchers have misused the research. Phillips uses Piaget's framework of structures as a means by which teachers and other curriculum planners may select and sequence content topics. This is significant work since most text series, curriculum teams and others often assume that the content they present and the order in which they present it are appropriate. In fact, great pressure is often exerted at the state level and in professional societies such as NSTA to develop content and skills continua which emerge based on little other than expert or committee opinion. Phillips' review provides new criteria that have been clarified only recently.

The sixth review by Alan Voelker deals with developing a scientifically literate citizenry, a preeminent goal of science teaching today. Many report that the general

American public is basically illiterate with respect to dealing with science and technology. This is true even though we have the most educated public in the world, a public that can read and do basic arithmetic and that can succeed in the world of work. In investigating an "attentive" public for science, Voelker and his colleagues have discovered much about attaining a more scientifically literate populace able to understand and resolve the major scientific and technological issues of our day.

Voelker's research involves a survey of high school and college students designed to determine the proportion of students that may be considered part of an "attentive public" for science and technology. First, each of the components of attentiveness is discussed: interest, knowledge, and information acquisition. Voelker follows this discussion with an analysis of the group called the attentive public. Much of this discussion centers on the proportion of young adults meeting the criteria for membership in the attentive public. The discussion then considers the characteristics of members of the attentive public for science and technology. These characteristics are associated with family, peers, school, and other groups. In examining these characteristics and their relationship to scientific literacy, implications for schools and science teaching emerge and are emphasized. Next, Voelker considers the consequences of being a member of the attentive public. He addresses questions about how attentives react to societal issues, what careers they select, and similar concerns. He ends with a discussion about developing more attentives and working and communicating with those who are attentive.

The work offers new procedures for meeting an oft-stated goal that has rarely been approached by science teachers in any meaningful way--the goal of promoting a scientifically literate public.

A seventh area of science education considered here deals with factors affecting minority participation and success in science instruction. Project Synthesis and the Analysis of the Current Accomplishments and Needs of Science Education both identified the need for and importance of attracting more underrepresented populations into science. The small number of females and members of minority groups in science and science education is a serious problem in need of attention. Handicapped people are also underrepresented in scientific studies and careers. As attention is directed toward achieving greater scientific literacy for all citizens, specific attention will be needed for special populations. Remediation for these groups should include not only science training but also overt efforts to augment the professional involvement of women, minorities, and the handicapped in the disciplines of science and science education.

Kahle's impressive and extensive work with black students was selected to illustrate here the need for studies on underrepresented groups and the need to better utilize what information is already available.

Kahle observed students at five predominantly black colleges to discover the personal and academic characteristics of undergraduates enrolled in introductory biology and mathematics classes. Kahle analyzes these data to extract factors influencing minority participation and achievement in science. Furthermore, she identifies attitudes and conditions adversely affecting minority enrollments in secondary school science. Kahle recommends to secondary school science teachers, guidance counselors, and principals strategies for increasing minority participation in the sciences. She suggests specific changes including the adoption of appropriate curricular materials, teaching styles, and counseling activities to augment opportunities in science for black students. Kahle's work begins to illustrate the extent of what must be done as we work toward solving a major social (and scientific) problem of today.

The last review is one conducted by Gallagher, concerning the status of science education in research centers. Teachers and school personnel are often critical of universities, research facilities, and college faculties in education, dismissing them as members of an "ivory tower" society. And yet if we are to be a discipline, if we are to have a research base on which to build, to improve, to make decisions, we must work cooperatively as a team. Another major need identified by Project Synthesis and the Analysis of the Current Accomplishments and Needs of Science Education is the need to involve people from all dimensions of science education--i.e., teachers, supervisors, administrators, consultants, teacher educators, and researchers--in resolving the problems confronting science education.

Gallagher reports on major threats to the ability to address such problems as university budgets tighten, enrollments decline, and public support (both attitudinal and financial) decreases. He finds that little attention has been paid to goals for the discipline and that few attempts have been made to redefine science education. Gallagher reports a high level of professional isolation in the discipline of science education. Few examples of cooperative research and all too few mechanisms for promoting professional dialogue can be identified.

These trends in graduate centers are emphasized and traced to their effects on science classrooms across the nation. If future decisions affecting science education are to depend upon a data base, means must be found to correct the crisis condition existing at graduate research centers today.

As mentioned earlier, more dimensions of science are worthy of research, analysis, and discussion than are represented here, but the current format has already been stretched to its limits by these researchers who have reviewed their work and discussed implications for classroom practice. Each has included references for interested readers. Most will welcome the chance for further dialogue about the critical research findings and their implications for the future of our profession. It is left to future volumes of What Research Says to the Science Teacher to introduce new research findings, to elaborate upon still more dimensions of science, to extend the influence of research findings upon practice.

APPLICATIONS OF CLASSROOM RESEARCH OF THE 1970s TO MATHEMATICS AND SCIENCE INSTRUCTION

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Developments in mathematics and science instruction in the 1980s can be guided by findings from research studies conducted in the 1970s. This paper will review some of the major studies in instruction and offer suggestions for applications to the math and science curricula.

For several years following the announcement of the Soviet Sputnik, policymakers provided funds for and educators focused considerable effort on improving science and mathematics education. A number of experimental science and new-math programs funded by the National Science Foundation in the early 1960s were developed and implemented all over the country. Some of these programs thrived and continued to be funded into the 1970s; others did not. The goal of many of these programs was to help students develop problem-solving skills, see relationships, generate and test hypotheses, and make generalizations from their findings to new situations. These abilities, however, were difficult to examine through standardized achievement tests and the value of these programs was hard for funding agents, educators, or researchers to estimate without concrete evidence of student learning.

During the 1960s, other social forces were affecting school curricula and instruction. The civil rights movement had made the general populace painfully aware that our schools were not serving the needs of low-income children. To meet this responsibility, vast sums of money were channeled into educational programs designed to serve the educationally handicapped. The primary focus of these programs was to improve basic reading and mathematics skills. Because this meant a reallocation of school time and resources, time for science in elementary schools was reduced or eliminated in many cases.

Having invested so much money in these remedial programs, the federal government wanted to know whether the programs were having a positive effect on student learning. A large survey study of school-level variables by Coleman (1966) revealed few consistent relationships with positive student outcomes. The conclusion of Coleman and others who reanalyzed the data (Mosteller and Moynihan, 1972; Jencks, 1972) was that improved school services and facilities did not make significant improvements in student learning.

Given this forewarning, it came as no great surprise that students' test scores did not increase nationwide. It was shocking to learn, however, that in 1965 standardized test scores above the third grade level started to decline (see Figure 1, over), as did scores of college-bound seniors (Figure 2). These findings forced a reevaluation of all school curricula and awakened an interest in identifying programs that enhanced student learning.

Early in the 1970s the federal government funded researchers in several parts of the country to study effective classroom instruction (Brophy and Good, 1970; Soar, 1973; McDonald and Elias, 1976; Stallings and Kaskowitz, 1974). They focused on instructional processes rather than on more global school variables such as special student services, curricular materials, and the physical plant. These researchers created observation instruments and collected objective, low-inference data which

FIGURE 1

Trends in Third- Through Eighth-Grade Student ITBS Reading Test Scores (Expressed in 1965 Base-Year Grade Equivalents on the Iowa Reading Subtest)

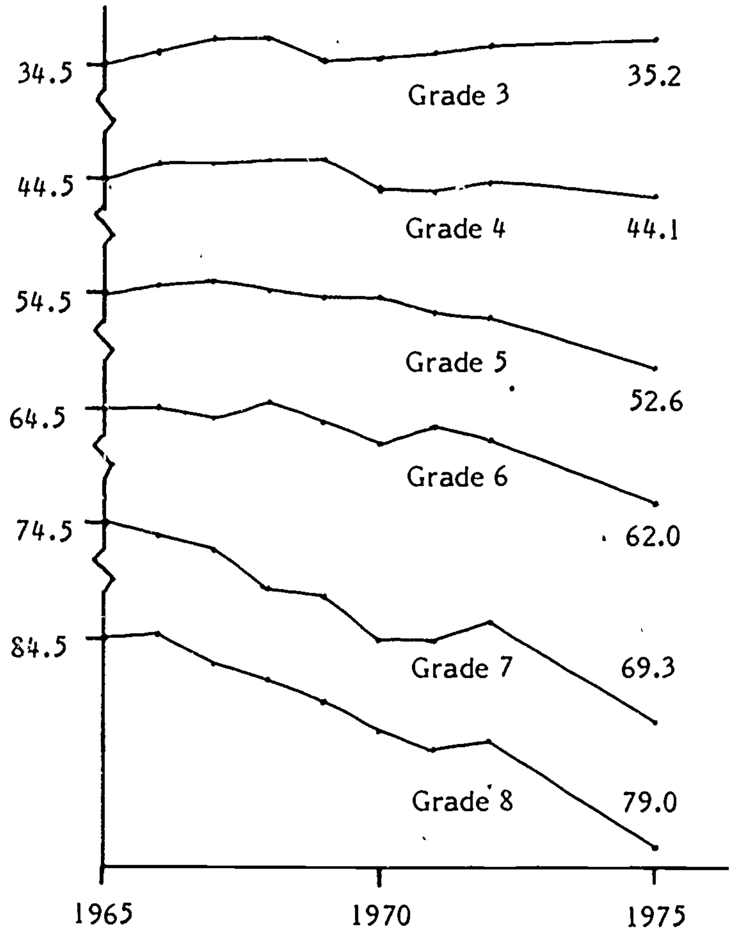
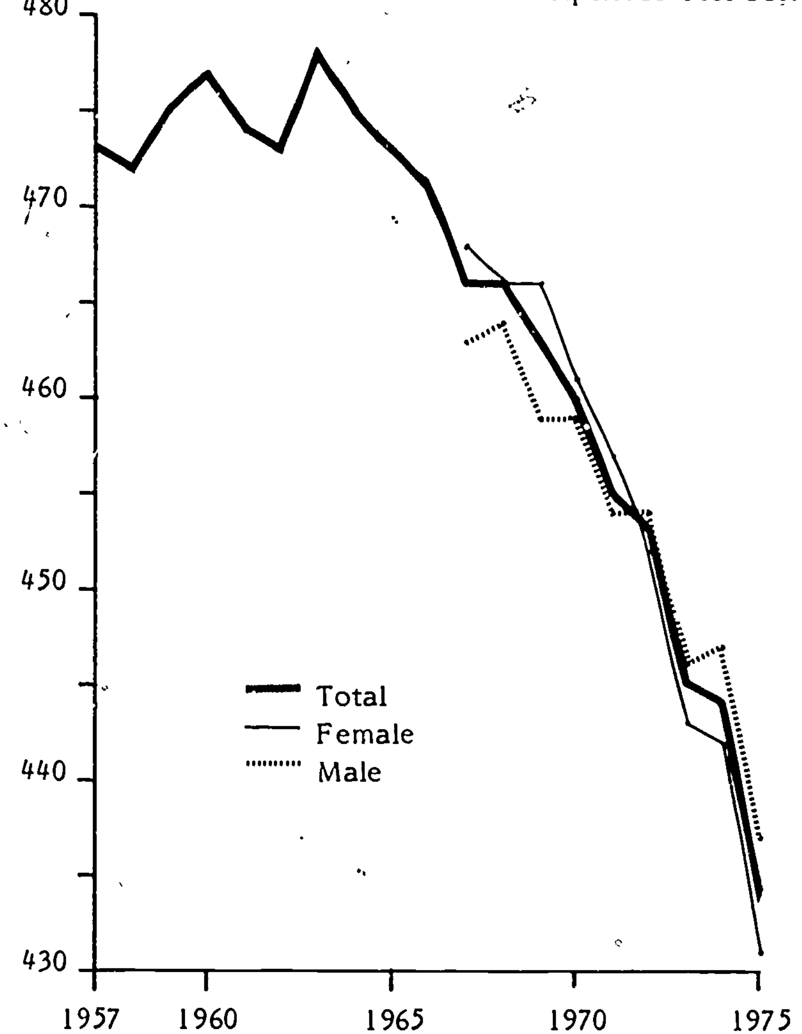


FIGURE 2

Mean Verbal Scholastic Aptitude Test Scores



Reproduced with permission from Achievement Test Score Decline: Do We Need to Worry? by Annegret Harnischfeger and David E. Wiley. St. Louis: CEMREL, Inc., 1976, pp. 11; 53.

were correlated with student gains on standardized tests. Identifying what teachers were doing in classrooms where students were improving in reading and mathematics then became possible. Since the main purpose of this research was to evaluate how well the compensatory education programs succeeded in teaching basic skills, most of it took place in remedial reading and mathematics classes.

This review reports the major findings from research in the 1970s and suggests how these findings might guide mathematics and science instruction in the 1980s.

RESEARCH ON TEACHING BASIC MATHEMATICS AND READING

Student "time-on-task" is one of the most potentially useful variables to emerge from this research. Many educators are now convinced that if student time-on-task is increased, there will ultimately be an increase in student achievement. This belief is based on considerable research that focused on the length of school days, actual class time, time allocated to academic subjects, and engaged student time.

LENGTH OF SCHOOL DAY

The length of a school day in elementary school or the length of a class period in secondary school defines the maximum amount of time available for instruction. Harnischfeger and Wiley (1978) found that the length of school days in two second grade classrooms in the same district varied by 45 minutes. The time spent in class on actual instruction, however, varied by only eight minutes. First grade class days in the National Follow Through Observation Study (Stallings, 1975) varied in length as much as 1½ hours while secondary class periods for remedial reading varied in length as much as 15 minutes, ranging from 40 to 55 minutes per period in one school day (Stallings, Needels and Stayrook, 1979). Findings from these studies indicate that academic achievement does not depend on the length of a school day or class period alone. How the available time is used is much more important to student learning than the amount of time available for instruction.

ACADEMIC LEARNING TIME

Researchers at Far West Laboratories initiated the idea of Academic Learning Time (ALT) in the Beginning Teacher Evaluation Study (BTES) (Fisher, Berliner, et al., 1978). ALT had three basic components: the time available for academic work; the students' time-on-task; and the error rate or the appropriateness of the seatwork, computed primarily from the errors students made in homework or seatwork.

Data from the BTES (Powell and Dishaw, 1978) indicated that the actual time allocated to academic studies for second graders ranged from 62 minutes to 123 minutes per day, and for fifth graders from 49 to 105 minutes per day. The study found variable degrees of correlation between allocated learning time and achievement from one test to another. In the Follow Through Observation Study (Stallings, 1975), however, time spent in mathematics, reading, and academic verbal interaction was related to achievement. Time spent working with textbooks (as opposed to time spent with puzzles, games and toys) was related to achievement in reading and math. Time spent in small groups (as opposed to one-to-one instruction) was also associated with student academic gain. Conversely, time spent in more exploratory activities (e.g., activities that allow students to take things apart and put them back together) was positively related to scores on a nonverbal problem-solving test and to a lower student absence rate. Similar relationships were also found in a study of California third grade Early Childhood Education classes (Stallings, Cory, Fairweather, and Needels, 1978).

The percentage of time allocated to academic subjects actually used by students to engage in academic work is another interesting measure. The BTES study reported that the engaged time of second grade students ranged from 38 minutes to 98 minutes, and that of fifth grade students from 45 to 92 minutes. Engaged student time was positively associated with student achievement in all tests and at both grade levels. Summative findings reported by Berliner and Rosenshine (1977) suggested that the more Academic Learning Time students accumulate, the higher their scores will be on criterion tests.

ACHIEVEMENT LEVELS AND ACADEMIC TIME

Variation in the amount of engaged student time by achievement groups was reported by Evertson (1980). On the average, low achieving junior high students were engaged 40% of the time in academic activities compared with 85% engaged time for high-achieving students. Low-achieving students experienced less variation in the activities that occurred during the class period and had more "dead time" (time in which nothing happened) than did the high achievers.

Even though high-achieving students are more inclined to be engaged in academic tasks, working with low achievers who may not be so inclined is very important and requires the allocation of sufficient time and effort. Stallings (1975) reported that low-achieving third graders in Follow Through prospered more from increased time in reading and math than did the high-achieving students. For all students, however, there is a point at which more time ceases to produce more learning, a phenomenon reported by Soar (1978).

CLARITY OF FIRST DAY ORGANIZATION AND PLANNING

Work by Evertson and Emmer (1980) focused upon a sample of 102 junior high school English and math classrooms. Effective teacher-managers were distinguished by several characteristics. Fewer student behavior problems and more student progress occurred throughout the year in classrooms characterized by the following:

- Teachers made rules, consequences, and procedures clear on the first day. This included teachers monitoring the students and following through with consequences for those who did not comply.
- Teachers established a system of student responsibility and accountability for work on the first day.
- Teachers were skillful in organizing several instructional activities.

TIME DISTRIBUTED ACROSS ACTIVITIES

A study by Stallings, Cory, Fairweather and Needels (1978) identified strategies for teaching basic reading skills in secondary schools. These include distributing time among different activities, instructing interactively, and shifting the focus of instruction. In classrooms where teachers were efficient in making assignments and allocating materials, more time was available for instruction and students gained more in reading. In addition to the importance of beginning class on time and continuing to the end of the allotted class period, the distribution of time among several activities during the class period also emerged as an effective strategy for keeping students on task. Effective teachers in three studies of secondary schools distributed time in the following ways:

Organization/Management Activities (15%)

- Take role
- Make announcements
- Make clear expectations for quality and quantity of work
- Clarify behavioral expectations
- Pass out/in papers or books

Interactive On-Task Activities (50%)

- Review/discuss previous work
- Inform/instruct (demonstrate/give examples)
- Question/check for understanding
- Reteach small group (if necessary)
- Read aloud/develop concepts

Non-Interactive On-Task Activities (35%)

- Written work
- Silent reading
- Teacher monitoring/guiding

The percentage of time allocated to each of these activities varied among classrooms according to the achievement level of students. For instance, oral reading was helpful to low achievers but was not so important for students achieving above the 4th grade level. Since reading comprehension scores for secondary students are often lower than vocabulary scores, the oral reading was conducted through lessons in which vocabulary had been carefully developed and in which teachers helped students develop word concepts in small groups of students with similar, low-level reading skills. Those who operated at this level needed to hear and say the words to reinforce reading and writing them. These students were usually successful in pronouncing and sounding words out but often did not understand words in the context of a story. Oral reading allows a teacher to hear students' reading problems, ask clarifying questions, provide explanations to help students comprehend new words, and link their meanings to students' prior experience or knowlege.

Minimal gain was made by students who spent more time on written assignments (28%) and in silent reading (21%) than on interactive instruction, discussion/review, and drill/practice. Some of these students were assigned to spend entire periods working in workbooks with very little instruction from the teacher. Such classrooms often registered more behavior problems, possibly because students with reading problems are likely to have short attention spans. The opportunity to be involved in several activities during one class period is likely to help these students stay on-task.

Although science and math class time might be differently distributed than remedial reading class time, direct teacher-student interaction and instruction are similarly important. Offering two or three different activities during the class period seems to be an effective strategy, especially if these activities include opportunities to learn orally and visually (see Figure 3).

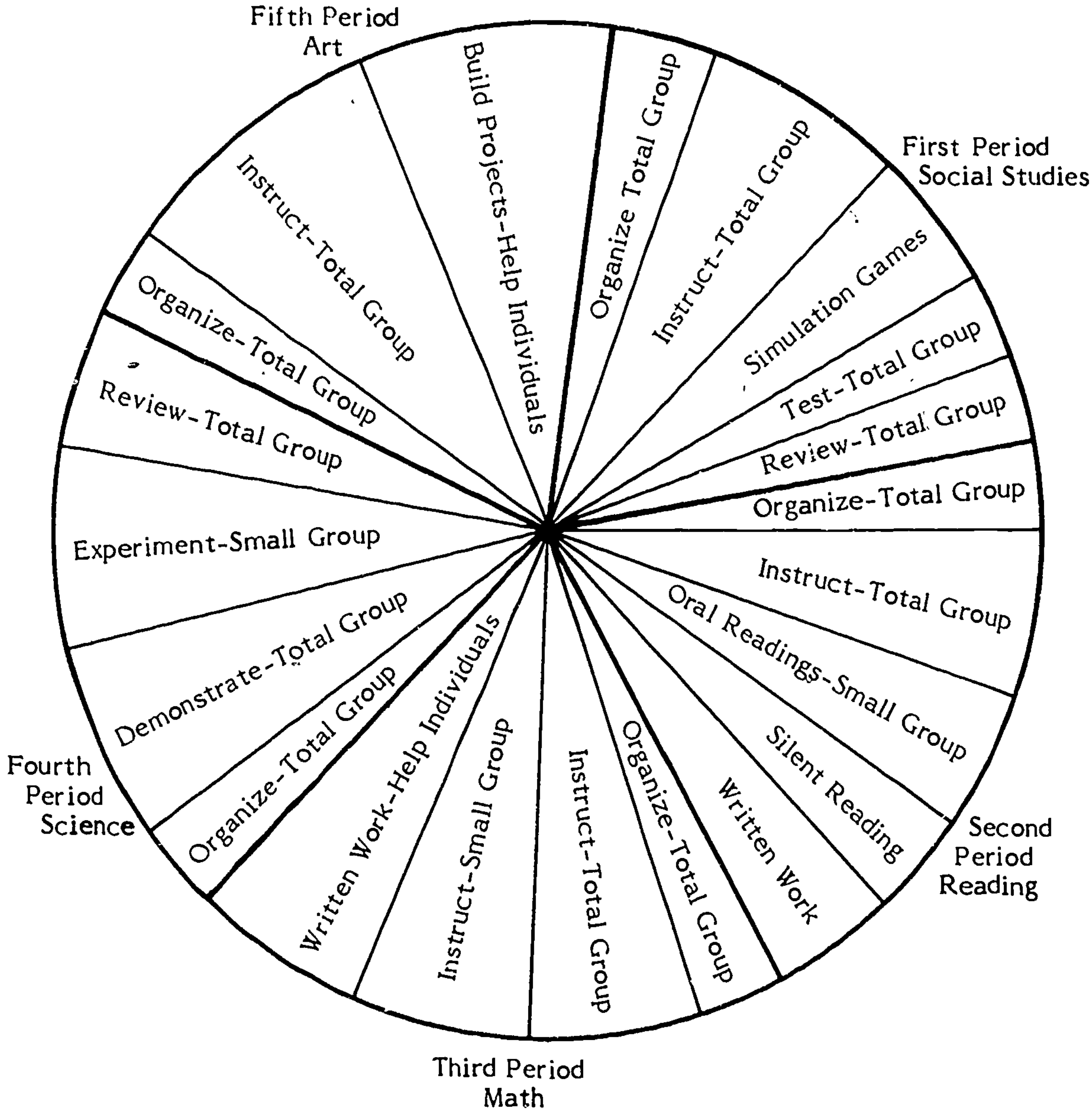


FIGURE 3

School Day Available Time
By Periods and Activities

FOCUS OF INSTRUCTION

Should teachers focus their instruction on individuals, small groups, or the total group? During the last decade, considerable effort has been expended to develop individualized programs. Federal, state, and local funds have been spent to develop programmed reading, mathematics, and science books, many of which include activities in which students progress at their own rates. Learning was supposed to be enhanced by allowing students to pace themselves through a series of sequential exercises, a method that worked for some students but not for others. In general, educators have become greatly disillusioned with this kind of individualized instruction. Some students learn best as part of a small group of students confronting new information together at a similar pace (Stallings, 1975; Stallings, Needels and Stayrook, 1979). For these students, learning is more likely to occur as they read aloud, hear others ask questions, and respond. Hearing and speaking as well as reading and writing help students integrate and retain information in a way that individualized programs based almost totally on workbooks do not.

At a conference on instructional dimensions sponsored by the National Institute of Education, sixty teachers discussed their experiences with and attitudes toward individualized instruction. In most individualized programs teachers reported feeling relegated to being record keepers. Teachers also felt unable to integrate the students' learning when workbooks were the main instructional vehicle (Amarel and Stallings, 1978). Flexibility is the main advantage of small group instruction over this kind of individualized instruction: a teacher can develop concepts with a group and can change examples or illustrations to coincide with the group's background experience. If students do not understand, the teacher can find yet another example. Books or machines can provide opportunities to practice and reinforce what teachers are teaching, but research suggests they do not provide the interactive instruction that students need (Stallings, 1975).

The distribution of teacher time among the total group, small groups, or individuals should depend upon the purpose of the lesson. Recent research in secondary remedial classrooms suggests that teachers spend approximately 50% of their time with the total group or small groups providing active instruction; 15% of their time making assignments and getting activities organized with the total group; and 35% of the time monitoring individual students' work (Stallings and Mohlman, 1981).

INTERACTIVE SUPPORTIVE INSTRUCTION

During the study of how teachers allocated time to various classroom activities, teachers who were interactive in their teaching style were found to have students who achieved more in reading. This interaction included oral instruction for new work, discussion and review of completed work, drill and practice, questioning, and acknowledgement of right or wrong responses.

Effective teachers try to include all students in classroom discussions and review sessions by not calling on volunteers, but by selecting students and calling on them by name. When calling on a student who has not volunteered, effective teachers ask a question at a level where the student is most likely to be successful. If the student gives an incorrect response, however, the effective instructor will stay with that student and rephrase the question or give a clue so that the student can ultimately give a correct answer. A wrong answer can provide an opportunity for the teacher to clarify and reteach, if necessary. Research on secondary remedial classrooms signals the importance of handling wrong responses in a supportive manner since the students involved are particularly sensitive to demeaning experiences of failure.

MATHEMATICS AND SCIENCE INSTRUCTION

The interactive type of instruction is important when teaching subjects other than remedial reading. Tom Good (1980) discovered that junior high school students learned more mathematics in classrooms where teachers were active in their instruction. These teachers made assignments, provided clear information, asked appropriate questions, and provided immediate feedback to student responses. Unfortunately, many general math teachers are not active in their teaching styles. In a study of math classes in 11 schools, Stallings and Robertson (1979) found that teachers more often assigned general math students to do written workbook assignments in class and less often gave them instruction or reviewed seatwork than students in geometry or calculus classes. More achievement was found to occur in classrooms where students are more involved. Students in general mathematics or pre-algebra classes were found to be off-task significantly more often than were students in algebra II, geometry, or calculus classes.

Observations of eleven of the teachers in the study were made in both lower and advanced math classes. When these observations were compared, the same teacher found to be active with advanced classes was discovered to be not active with lower level classes. In the advanced classes, teachers were more likely to ask clarifying questions, e.g., "Do you understand?" Advanced students were found to receive active instruction 30% of the time and review of work 23% of the time (see Table 1).

TABLE I

Percentage of Student Time Spent in Activities for Three Types of Mathematics Classes*

Variables	Type I	Type II	Type III
Instruction	14.0%	25.0%	30.0%
Review	8.0%	21.0%	23.0%
Written Assignments	34.0%	15.0%	11.0%
Teacher Management/ No Students	24.0%	20.0%	15.0%
Social Interactions	11.0%	13.0%	13.0%
Students Uninvolved	11.0%	6.0%	4.0%
Discipline	4.0%	.2%	.05%

Type I--General Math or Pre-Algebra
Type II--Algebra I, Geometry
Type III--Algebra II, Trigonometry, Calculus

*Some activities overlap and the columns will not sum to 100%.

In most cases, programmed workbooks were used in general math classes and other instructional methods with advanced students. These general math students worked at their own pace while the teacher graded papers or monitored the class. Only 14% of the time was spent in providing instruction or explanation to Type I classes, and they received review only 8% of the time (see Table I). Students raised their hands to receive help, and while some students were acknowledged, others waited a long time or gave up. To make achievement gains, students need to receive consistent instruction and feedback from a teacher. The most important finding of this research is that teachers need to teach actively about 50% of the total class time. Under these conditions, students stay on task and achieve more.

Relationships similar to those described in mathematics classes were found in general science and physics classes: the advanced classes experienced active instruction, demonstrations, and student experiments, while students in general science classes received workbook assignments and seldom interacted with materials or observed demonstrations. Research indicates that these trends result in ineffective instruction, especially for low-achieving students. Since general science may be the only science class that many students take in high school, science teachers are in an instrumental position to inform students about societal and ethical problems--such as depletion of natural resources, land use, energy, nuclear waste, and population control--which may not be addressed by any other discipline. The urgency and immediacy of these issues increase the importance of teaching general science in an interactive and hands-on manner.

FINDINGS ON BEHAVIOR CHANGES OF SCIENCE AND MATHEMATICS TEACHERS

In a recent study of eight schools in the San Francisco Bay area (Stallings and Mohlman, 1981), the Teaching and Learning Institute (TALI) conducted workshops with 32 teachers after observing their teaching styles. These workshops focused on making specific recommendations to the teachers for changing their teaching methods to enhance student learning and other classroom dynamics.

Three of the math teachers were in a school district bound to an individualized programmed curriculum in which students worked through sequenced materials and were tested at the end of units. Table II summarizes the observations of their instruction made over the course of an academic year. (See over.)

At the beginning of the year, these math teachers did not provide examples on the chalkboard or group instruction, but monitored the students as they worked, answered questions when students raised their hands, gave tests, kept records, and tried to maintain order. Asked if the students could read and understand the written instruction, these teachers assumed the students could. A Cloze Test which measures text readability (Taylor, 1953) indicated, however, that this was not true for many of the students. Given the restrictions of the required curriculum, these teachers were generally unable to implement Effective Use of Time strategies which require interactive group instruction for 50% of the time. Because of the overall structure of the program, a number of students could be expected to be off-task as they waited for the teacher's assistance and were. Student absence rates were significantly higher in these classrooms than in classrooms where the teachers were more interactive in their instruction and offered several activities during the class period. As Table II illustrates, little change in math teacher A's behavior occurred during the year and an extremely high frequency of non-interactive and individually-focused activities persisted. These general observations suggest questions that might be asked by schools and school districts about the programmed curriculum concept and its limitation on student-teacher interactions.

TABLE II

A Comparison of Three Teachers' Behavior Change

Activities	Teacher A Fall	Teacher A Spring	Teacher B Fall	Teacher B Spring	Teacher C Fall	Teacher C Spring
Interactive	18%	29%	20%	85%	55%	48%
Non-Interactive	59%	50%	55%	39%	10%	21%
Not Involved	23%	17%	27%	13%	21%	5%
Students Off-Task*	49%	46%	55%	27%	19%	35%
Interactions**						
Organizing	63	65	140	20	47	61
Teacher to Individual	150	158	70	82	70	114
Teacher to Everyone	5	4	120	155	130	30
Teacher asks Questions	10	12	2	55	45	15
Student Responses	8	10	0	52	40	12
Praise and Support	15	14	3	15	15	6
Behavior Statements	20	33	54	20	13	19
Monitoring	172	167	0	12	38	160
Task Statements	31	35	126	237	159	70

* Some students, but not necessarily the same students, were off-task 49% of the time in the fall for Teacher A.

** Statistics indicate number of times each variable occurred out of a total 300 interactions per class period.

Specific observations suggest even more questions and recommendations. Teacher B on Table II was one of the least effective teachers the investigator observed. This teacher lectured and harangued the students for not doing homework. The instruction for the lesson was barren: the teacher did not explain key vocabulary or key concepts, but simply read from the text; there were no concrete materials or charts available to clarify the explanations; the students were argumentative and the teacher was demeaning. Many of the interactions were about misbehavior and many students were excused from the class for disciplinary reasons; during one class period alone four students were ordered from the classroom. The teacher's expressed opinion was that these kids were too slow and lacked enough ambition to learn.

At the end of the first workshop, the teacher was asked to examine the readability of the text and to compare that to the students' reading scores. Six of the 30 students read below the 4th grade level and only five read at or above the 10th grade level, the level of the book. The teacher was surprised and concluded that those mischief makers able to read the text could be expected to do the work, but that those unable to read the text required another approach. This teacher started planning different instructional activities including more experiments and demonstrations and fewer lectures. The teacher explained key concepts and checked for student understanding. This lead to students being on-task more frequently. As the teacher became more supportive of good behavior there were fewer discipline problems. These changes happened slowly over a school year and required considerable coaching and support of the teacher as well as the provision of good models. The teacher visited other schools with similar student populations. Enough growth and change occurred to suggest that this very poor teacher could become a good one with continued support and encouragement. The principal was very supportive in providing the resources required to effect the changes.

Another science teacher, Teacher C in Table II, was assigned four remedial general science classes at the beginning of the school term. He made a gallant effort to bypass the textbook and teach by demonstrations, student experiments, and models even though this required a great deal of daily preparation. By January, he felt worn out and discouraged, partly because he received very little acknowledgement from his academically-oriented community for teaching slower students to love science. The administration suggested a programmed science workbook and the teacher started using these workbooks to reduce the burden of preparing non-textbook lessons each day. In addition, he withdrew to the position of simply monitoring student work instead of actively providing instruction. Students stopped asking questions and the teacher stopped giving examples and demonstrations. Efforts to help the teacher continue with interactive instruction were not supported by the administration whose primary interest seemed to be test scores rather than developing attitudes of scientific inquiry and an appreciation for the surrounding world.

TEACHING FOR UNDERSTANDING

Educators and researchers have been concerned for some time about whether students really "master" the work they do. Mastery must include understanding as well as getting the right answer on the test. Paul Hurd (1970), a notable science educator, suggests that teaching only the factual findings of science in effect teaches an illusion of scientific knowledge. In a monograph, <u>Improving Reading on Science</u> (1976), Thelen emphasizes the need to link new knowledge to students' existing cognitive structure:

> If a student is forced before he masters the necessary backlog of experience for the concept of energy, he may become frustrated and resort to memorization of definitions and trivia. Student preparation is an important and a neglected area of teaching.

She reports high school students who can sound out words, pronounce them, and even fill in the blank in a workbook correctly but who do not comprehend the material. Students have learned to memorize the right answers but not to understand relationships. In this case, they have memorized to forget.

Anderson (1981), in an observation study of elementary school children, asked individuals such questions as, "How did you get this answer? What are you learning when you do this page?" Many of the children were not able to give a specific response. The low-achieving students had strategies for finishing the page, such as asking someone for the answer, but displayed little understanding of the material.

During the observations of science classrooms, effective teachers systematically checked with students to ascertain their understanding. These teachers would provide information and/or give demonstrations and/or allow students to experiment. They would then ask students to explain what was happening in their own words or to give an example of a similar phenomenon. If the students did not understand, the teacher would reteach the concept giving different examples.

High school students need to receive instruction that will enable them to see relationships and transfer information from short- to long-term memory. Students who merely drill and practice for tests will not transfer information to long-term memory from which it can be retrieved. Teachers need to assist students in organizing new information and linking it to other information already in the long-term memory. According to Ausubel (1968), "The most important single factor influencing learning is what the learner already knows." Research is needed to find methods to help students learn strategies for creating structures and linking new information to what is already known.

WHERE TO FROM HERE?

Conferees at the Exeter Conference on Secondary School Science Education (1980) listed the following phenomena as problems that threaten the welfare of the nation:

A. There is growing evidence that the United States is falling behind other nations in the areas of science, technology, and science education.

B. There is a decline in enrollment in science courses which is expected to result in an inadequate supply of scientists and engineers as well as an inadequate scientific literacy among the voting population.

C. Lack of confidence in scientific solutions is leading to an increased reliance upon mysticism.

D. The disparity between the scientifically literate and the rest of the population is increasing in our society.

E. There is a decline, in real dollars, of financial support for research and innovation and for education in the sciences.

F. The use of "hands-on" activities in science instruction is growing ever more restricted by budgetary and other constraints.

G. The time allotted to science in the lower grades is diminishing.

Items E and G suggest that funding agencies and the public are placing less value on science instruction, possibly because what is being taught in science classes is not relevant to today's problems and/or because of the manner in which science is being taught. Observations of science classrooms reported here suggest that the situation described by item F is becoming increasingly entrenched. Many science teachers are using very few "hands-on" activities, especially for low-achieving students. As a result, interest in science may decline, and the disparity between the general population and the scientifically literate may thus increase as item D suggests.

Conferees suggested solutions to these problems that involved infusing present courses with current and relevant topics (clean air, energy sources, atomic waste, etc.) rather than creating new courses. The changes required, however, are extensive and would be difficult for science teachers to actually implement. Most science teachers now teaching were trained in the 1950s and 1960s and many continue to teach as they did in the Sputnik era. Keeping abreast of the developments in this profession and organizing new resource materials are not easy tasks for these teachers.

In the face of tightening budgets, teachers need to produce low-cost apparatus and to locate free or inexpensive tapes, films, slides and lectures from local industries and/or universities. To assist teachers in this effort, conferees proposed a national network of Science Resource Centers which would distribute materials to teachers regionally and provide short term training courses and personnel services as requested by schools, teachers, and students.

These suggested solutions are attempts to infuse science education with new life, but they focus primarily on curriculum content. Every teaching episode has both a curriculum and a delivery system. The delivery system is the process--how the curriculum is taught. Curriculum and process are mutually dependent key elements in effective instruction. The most elaborate apparatus money can buy will not compensate for an ineffective instructional mode.

Findings from the research on teaching conducted in the 1970s can be useful to the instruction of general math and science classes of the 1980s. Such findings suggest the following elements must be provided: several different activities during a class period, interactive instruction, and a supportive environment. More research is needed to assess, on a broader scale, the processes of good teaching in advanced math and science classes.

Of all school subjects, science has a great opportunity to capture students' attention and awaken curiosity and wonder. Science classes can also develop problem-solving skills while sharpening and promoting the application of reading and math skills. Through good science instruction, students can learn how to build frameworks for categorizing information and sorting out logical and illogical conclusions, structures that will serve them in other disciplines and endeavors. The connection between the specific and general implications of science education was cogently illuminated by the Exeter conferees:

> ... unless the science teacher addresses the social and ethical aspects of science, no one else will, and the majority of Americans will continue to base judgements that shape the future on intuition, short-term self interest, and political expediency.

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STUDYING HOW PEOPLE THINK: AN APPLICATION IN THE SCIENCE CLASSROOM

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A primary need from research in science teaching is knowledge that would guide us in better educating our students to think. Because we understand so little about the process of thinking, our current efforts to teach it are at worst haphazard and unreliable, and at best based on the idiosyncratic personal talents of individual teachers. This paper describes and illustrates a methodology called "information-processing psychology." It has not traditionally been applied to problems in science education, but is particularly suited to producing knowledge about how individuals think. This paper will provide an overview of the methodology. Then a research project in basic science that illustrates its utility will be described very briefly.

INFORMATION-PROCESSING PSYCHOLOGY

Information-processing psychology views all thinking as taking in information, processing it, storing it, and using it to generate new information. This basic view of human intellectual functioning is well described in a paper by Simon (1979). During the last 20 years the information-processing viewpoint has formed the basis for a growing and productive stream of research.

What are the virtures of this viewpoint for research in science teaching? First, the tasks addressed are sometimes directly relevant. Early work, including that described in the classic volume by Newell & Simon (1972), often concerned how people solved puzzles or played games. These tasks require a substantial amount of information-processing, but are sufficiently structured and constrained to have provided a fruitful arena for early studies of human abilities, just as E Coli provided a simple and fruitful arena for the early study of genetic structure. As we have learned more about human information-processing, the focus of research has shifted to questions of how people perform more complex tasks of direct interest to science educators. Many of the tasks studied are, in fact, specific components of science education, e.g., solving problems in basic physics (Larkin, McDermott, Simon, and Simon, 1980); constructing proofs in geometry (Anderson, 1981); solving equations in algebra (Lewis, 1981); and using analogies to understand scientific situations (Gentner, 1980).

Second, information-processing psychology is concerned with performance on tasks that are usually considered to require intelligence, such as problem solving, learning, and reasoning. These tasks go beyond mere rote performance or utilization of memory. For example, recent studies address how people understand and store information from simple stories (Rumelhart, 1975); how people plan the execution of tasks such as performing a set of errands (Hayes-Roth, 1981); and how people understand and use spatial knowledge of buildings, cities, and maps (Chase and Chi, 1980; Thorndyke and Stasz, 1980). Thus, information-processing psychology is concerned with the same basic phenomena that concern science educators--the acquisition and use of intelligent behavior.

Finally, information-processing psychology is concerned with elucidating and specifying mechanisms that people use to perform tasks requiring intelligence. Thus, a typical study might determine some of the rules followed by skilled (or less skilled) individuals in solving a physics or chemistry problem. Knowing more about such mechanisms could help us teach science better. The processes of skilled individuals can suggest strategies to be taught to students, while the processes of less skilled individuals can help diagnose the difficulties of students and indicate what form of instruction might be helpful.

DATA

Because information-processing psychology is concerned with mechanisms of performance, its research methodology must provide a means to observe and model in a detailed way the steps through which various processes are implemented.

To meet this need, a common experimental methodology employed is the collection of "protocols." An individual performing a task is asked to speak aloud freely, reporting as completely as possible everything that is thought and done. These comments are tape-recorded and transcribed, and the resulting transcript, along with any written work, forms the body of data used in further analysis. Hayes (1981) provides a readable discussion of protocol analysis, as well as of many other topics in cognitive psychology.

These protocol data are very rich compared to more traditional data such as written responses to structured questions. To manage this wealth, the transcript must be coded according to the type of information-processing represented by each segment. The long transcripts are thus ultimately reduced to a list of steps. This process is time-consuming and difficult, and care must be taken that it is done in a disciplined and consistent manner. Good research in more traditional modes also requires a large amount of effort and exploratory experimentation to produce good measurement instruments and experimental designs. These structures serve to drastically reduce the kind of information that is collected. In contrast, protocols allow very free collection of data, but these data must afterwards be structured and reduced. Thus, the amount of effort expended on traditional research approximates that required in protocol analysis, but the timing and distribution of effort are variable.

Protocols are particularly valuable in studying information-processing mechanisms that are not well understood. The free collection avoids closing off potentially interesting data that the experimenter has not expected. When a process or mechanism is understood, the data collected can be more rigorously limited in effort to enhance the efficiency of research. Since we understand very little about how individuals learn and think in science, however, the use of protocols is particularly appropriate in this area at this time.

THEORY

Detailed observation and the capacity to build models as complex as the situations they emulate are both essential to identifying the information-processing mechanisms involved in addressing complex tasks. Past research has been hampered because the associated models of performance either have concerned only the most trivial aspects of performance (e.g., rote learning) or they have been too general to be systematically tested and revised. The latter difficulties are well illustrated in the field of science education by the theories of Ausubel and the uniformly inconsistent set of experimental results concerning these theories (Anderson, Spiro and Anderson, 1978).

The basic difficulty constraining much of this past work is the inadequacy of closed-form mathematics for building models of human cognition. Thus researchers have faced the unappealing choice either of limiting their studies to reflect theories that can be expressed in traditional mathematics, or of trying to work with theories that are vaguely expressed in the language of philosophy. The situation has changed dramatically in the last 20 years with the advent of the computer. A computer language is a mathematics with sufficient power and flexibility to begin to be adequate to express models reflecting human intelligence.

Appreciating the role of computers in information-processing psychology requires knowing something about the kinds of computer systems used as models. Almost everyone has written a program in FORTRAN or ALGOL, or at least can imagine the kind of program that might be required to produce, for instance, a bank statement. The operations of these programs seem very different from the work of a human being solving a problem. Computer programs that perform "intelligently" almost always use some form of what is called a "production system." A production system consists of a relatively small, unstructured "working memory" that contains elements specifying the information the computer program is currently attending to. The remainder of the program consists of a large unstructured list of "productions" each having a set of conditions and a set of associated actions. A condition is a pattern that can be matched (or fail to be matched) by the current contents of working memory. The actions add, modify, or delete elements in working memory. The program operates by attempting to match the conditions of each and every production to the contents of working memory. Ordinarily the conditions of at least one production are found to match, and then the actions associated with these conditions are executed. These actions change the contents of working memory; the conditions of some new production are thereby satisfied; and then its actions are executed. This recognize-act cycle repeats over and over again as the computer program flexibly responds to a developing body of knowledge in its working memory. Production systems have a responsive performance that is very different from the algorithmic performance of programs written in FORTRAN-like languages, and they have repeatedly proved fruitful as tools for modeling psychological performance (McDermott, 1978, Newell and Simon, 1972).

As an illustration of the need for a precise language that can handle complexity, consider Piaget's efforts to capture the richness of human cognition (c.f. Inhelder and Piaget, 1958). Those who study Piaget all struggle with this complexity and often fail to comprehend it fully. As Groen (1978) points out, in educational work we have often settled for "naive applications of stage theory more or less in isolation." In context, stages are mental structures that underlie observable behaviors in complex and ambiguous ways. Perhaps because Piaget did not have a good language for expressing this complexity, his work is often simplified and misinterpreted.

In summary, the study of human information-processing requires both detailed observation and detailed models. This has led to the use of protocols as a means for collecting data, and the use of computers as a mathematics with sufficient power to express precisely the complex models required. None of this says that human beings are like computers, but merely that computers are incredibly useful tools for building models that help us understand how human beings process information.

The psychology of information-processing begins to provide a theoretical basis for designing specific components of science education such as laboratories, course formats, and exercises. Science education may be able to move from being basically a cottage industry, in which talented individuals produce the best products available, to being a theoretically-based applied science in which a variety of individuals can reliably produce consistently good quality instruction. Good instruction can be based on theoretical knowledge, rather than idiosyncratic talents and intuitions.

The psychology of information-processing is oriented toward individual mechanisms of performance. In this respect it fills in theoretical gaps left by more traditional research in science teaching which has often focused on global changes produced by a large module of instruction (e.g., between a pre- and post-test). Such research results are useful in deciding whether or not to use a particular module, but are often difficult to interpret if one wants to know what made the module effective, or how successful mechanisms might be used in alternative settings.

Finally, the psychology of information-processing provides a methodology for modeling human performance in a fashion that is neither vague nor trivial. Such direct approaches to understanding the complexity of cognition are promising moves toward creating psychological models that might helpfully influence education.

The remainder of this paper will describe briefly an information-processing study that deals directly with the subject matter of basic science. It concerns the kind of knowledge a student must have in order to understand and use the material in a chapter of physics (mechanics). Much of this required knowledge involves the ability to make "common sense" spatial inferences.

SPATIAL REASONING IN PHYSICS

The goal of the study described here is to identify the kind of knowledge that a learner must have in order to use the material presented in a physics textbook. The subject matter used was a six page section of text describing fluid statics (Halliday & Resnick, 1970), together with three problems as follows: 1) A simple U-tube contains mercury. When 13.6 cm of water is poured into the right arm, how high does the mercury rise in the left arm from its initial level? 2) What fraction of a person's body (density equal to that of fresh water) is submerged when floating in sea water? 3) A 0.001-m^3 lump of metal is submerged in fresh water ($0^{o}C$) and suspended by a string that exerts an upward force of 4.9 Newtons. What is the density of the metal? Each of 12 subjects, working individually, was told to imagine that the text and problems had been given as an assignment in a physics course, and that due to unforeseen circumstances they had only 1½ hours to complete the assignment. In this imagined situation, they were asked to work to finish the assignment in whatever way they chose, but to talk aloud as much as possible. The resulting protocols were typed in full, and together with the subjects' written work formed the student data for this study.

Consider the following excerpts from the statements of three solvers made as they began work on the U-tube problem.

Subject 1

Let's call the initial level of the mercury A, it's an arbitrary A. Ok, when you pour water into the right arm, 13.6 cm, the mercury will rise to a level, let's call it B. How original! Mercury is more dense. It will rise to a level B. And the water, ok. Wait, I'd like to define a point C.

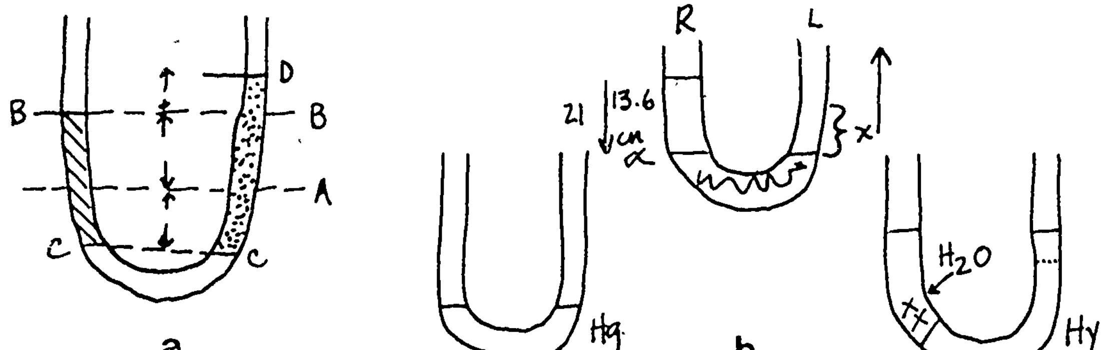
Subject 2

Ok, let me draw this better. This is the U-tube filled with mercury. Put the water in. Let's see, it's going to go down 2x and up on x. Ok, and there's going to be 13.6 of water.

Subject 3

Turn to the section describing problems with U-tubes. Look up some information about mercury and its density. And it is given as 1.4×10^4 kg/m^3. I'm rereading section 15-3 on the variation of pressure in a fluid at rest. I believe that you would have to use the equation $p=p_0 + \rho g x$.

The diagrams drawn by these subjects are shown in Figure 1.



a b

These excerpts come from the first substantive work each subject did on problem 1. They show very different amounts of spatial reasoning. The first subject speaks accurately and completely about the relations in the problem, and ultimately constructs the well integrated diagram shown in Figure 1a. The second subject, although making extensive efforts to visualize the situation spatially, is very confused about what is happening, and ultimately produces the incorrect and disintegrated diagram shown in Figure 1b. The third subject never makes any effort to comprehend the problem spatially, but immediately plunges into algebraic equations.

How can we account for these differences in the use of spatial inferences, and what effect does this ability, or the lack of it, have on success in solving physics problems? Answering these questions depends on understanding the potentially complex relationship between a theoretical knowledge of physics and general spatial knowledge. The power of the computer to model these two kinds of knowledge and to study their interaction makes it an appropriate and valuable tool to use in this instance.

The model used in this study is a computer-implemented model that applies theoretical knowledge from a textbook (Halliday & Resnick, 1970) together with clearly separated spatial knowledge. To solve the three physics problems, the computer model produced a series of steps comprising its "reasoning" for each problem. The model was then purposely and seriously impaired by removing much of its spatial knowledge, after which it produced a collection of erroneous solutions for the same problems. This study examines the correspondence between the verbal statements made by human solvers and the "statements" made by the spatially based computer model, and the correspondence between the errors made by human solvers and the errors made by the spatially degraded computer model. A more complete description of this study is given elsewhere (Larkin, 1981; Larkin and Simon, 1981).

The computer model is implemented as a production system. The working memory initially contains elements that are very close in content to the verbal phrases in the original problem statement. For example, corresponding to the phrase, "A simple U-tube contains mercury," in problem 1, three elements are put into the working memory, one representing the mercury, one representing the U-tube, and one representing the containment relationship. After all the initial elements have been entered into the working memory, the model begins its work on the problem, using the production rules described earlier. In this computer model, the production rules are separated into two groups: rules of spatial inference and rules of theoretical inference. The rules are summary rules; each one ordinarily corresponds to two or three productions in the computer implementation.

The spatial rules correspond to kinds of inferences that might be made by any careful observer of a real physical situation. Some are rules about spatial relations among parts of a real world situation (here a U-tube) that could be seen if the real situation were before one. Others allow the model to notice a particular location by marking it with a point. Still others concern geometric relations between points and lines, and in fact correspond directly to theorems in geometry. The final group concerns quantities that can quite easily be seen to be equal. Although there are underlying physics reasons for these equalities, most are not stated in physics texts, and the ability to use these rules may depend on an ability to envision a situation, not on a formal knowledge of physics.

The rules of theoretical inference correspond closely to the text section (Halliday & Resnick, 1970). As each rule is executed during a problem solution, the computer writes a statement describing what has been done. Some statements made by a few production rules act only to interpret entities from the problem statement (e.g., height risen, fraction submerged) into terms of the entities in the spatially-oriented representation of the problem. Since the rules are summary rules, with each English statement commonly corresponding to two or more detailed rules in the computer program, a single rule can sometimes generate two separate statements.

What happens if this computer model tries to solve problems without using its spatial knowledge? To explore this issue, all of the rules of spatial inference were removed from the model. This action alone totally crippled the model because many of the rules of theoretical inference have as part of their conditions spatial relations. The elements referring to spatial relations were, therefore, removed from the conditions of the theoretical rules. Thus the impaired computer model neither makes spatial inferences nor requires spatial relations for the application of theoretical rules. The resulting model produced a variety of erroneous algebraic statements for the three problems. The computer output statements were matched against the various statements from subject protocols, and Tables 1 and 2 summarize the results.

TABLE 1
(Correct Responses)

Subject	Number of Matching Computer (Unimpaired) Statements	Diagram
Student 14	13	integrated
Student 8	13	integrated
Student 19	8	unintegrated
Student 1	15	integrated
Student 18	12	integrated
Student 6	12	integrated

TABLE 2
(Incorrect Responses)

Subject	Number of Matching Computer (Unimpaired) Statements	Number of Matching Computer (Impaired) Statements	Diagram
Student 16	8	2, 3	unintegrated
Student 17	4	3	unintegrated
Student 12'	7	3, 1	unintegrated
Student 12	0	4	none
Student 15	2	atypical error	unintegrated
Student 2	0	2	unintegrated

Diagrams shown in the problem-solving process were coded as integrated or unintegrated depending on whether or not they clearly showed all the spatial relations essential to solving the problem. Integrated diagrams for the U-tube problem showed the levels of mercury both before and after the water was added, and showed relations between fluid levels on the two sides of the tube.

Tables 1 and 2 show a consistent picture of related abilities. Subjects able to achieve correct solutions to the problem do so by a process that involves many spatial statements analogous to those produced by the spatially oriented computer model. These subjects have correct solutions, high spatial scores, no erroneous algebraic statements, and they tend to draw integrated diagrams. Conversely, subjects who fail to achieve a correct solution make some of the same kinds of errors made by the model when its spatial knowledge is removed. They show relatively few spatial statements (have low spatial scores) and their diagrams are unintegrated.

What implications for instruction might be drawn from this study? First, we must recognize that much of what is required to solve problems in physics (e.g., rules of spatial inference) is not knowledge of the principles of physics, but is instead an awareness of and insight into the conditions under which these principles operate. This awareness might be called "common sense spatial knowledge." It is usually not explicitly taught or particularly emphasized. This study, however, certainly suggests that the source of many students' difficulties may be a failure to use such knowledge.

What could be done about this situation? Certainly we could try in all areas of our teaching to be more explicit about spatial reasoning when we encounter it, recognizing that this is not an easy or automatic process for many of our students.

SUMMARY

This physics study provides a picture of the beginning science student as an information processor who acts in a lawful and reasonable manner, but who lacks certain basic capabilities such as the ability to make spatial inferences. Knowledge of these limitations should affect our teaching. We may need to develop ways of directly teaching these capabilities. We many need to develop instruction that depends less heavily on them. The physics study illustrates the application of information-processing methodology to questions of interest to science educators. It is based upon detailed observations of subjects' free performance on an intellectually demanding task. It also illustrates the use of the computer to formulate explicit models able to perform a task in such a way as to aid in understanding human performance on the same task. In addition, the research approach illustrated here offers a promising way to address directly the questions of how people think, and how they can be helped to think better.

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THE ROLE OF INSTRUCTION IN THE DEVELOPMENT OF PROBLEM SOLVING SKILLS IN SCIENCE

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INTRODUCTION

In a paper presented at Carnegie-Mellon University Conference in 1978, James Greeno (1980) concluded that: "The kind of process used in solving a kind of problem depends both on the characteristics of the problem and on the knowledge of the problem solver." His conclusion sums up the now rather widely held view that general problem solving methods are of value most often in situations in which the problem solvers' knowledge is very limited. Consequently the direction of recent problem solving research has been the study of solving problems in specific knowledge domains such as physics and mathematics in which the domain information necessary for problem solving can be rather well specified. Larkin's (1977) work in expert and novice performance in solving physics problems exemplifies such research.

Productive as such research has been, severe instructional difficulties still exist when attempting to teach problem solving in even a specific domain. Domain specific knowledge must be acquired by the learner/problem solver in an organized and meaningful manner. Relatively little is known, however, about the nature of the organization and meaningfulness of a given body of knowledge for a novice learner. Furthermore, based upon psychology's long involvement with the study of human individual differences, no single "organization" or "meaning" is likely to be appropriate to all prospective learners. Differences in intelligence, cognitive style, developmental level, and prior experience are only a few of the differences which may make effective instruction for a group of individuals difficult to carry out.

The purpose of this paper is thus twofold: (1) to present a brief argument that the current emphasis on general knowledge and general problem solving methods leads to an incomplete model for problem solving instruction; and (2) to show how one kind of individual difference, a cognitive style dimension, affects performance on problem solving tasks in a specific domain.

The many possible components of cognitive style cannot all be considered in a single study. Instead, a single, well-researched variable of cognitive style, field independence-field dependence (Witkin, et al., 1977), has been used to illustrate how individual differences can influence the process of solving problems. The investigators contend that recent studies illustrate, in at least a preliminary way, the need to take into account individual learner differences when providing instruction. Apparently the search for an appropriate organization of knowledge and a set of general problem solving methods is an inadequate base for instruction. Effective problem solving techniques in any domain seem to involve specific adaptation to the individual problem solver (perhaps in the form of an individual coach as in the work of Burton and Brown, 1979, or with computer coaching as in Goldstein, 1980).

STUDY DESIGN

This report is based upon: A. a study of problem solving processes of 150 junior high school students, B. the results of a problem solving processes training program for junior high school students, and C. a comparison with the first two groups of the problem solving skills and processes of a senior high school group composed of students aspiring to science related careers.

Each of the students in the three samples described above was given a set of six problems selected to resemble problems found in biology or physical science sections of typical junior high school science textbooks. Before attempting the problem set, junior high school students in group B were exposed to a four-hour general problem solving program which attempted to develop (through an intensive practice program) general skills in defining, attacking and solving science problems. Control group A, comprised of students in the same school, tackled the criterion problems without the problem solving program. Group C, the senior high school group, was evaluated in an attempt to assess the extent to which the problems (difficult for junior high school students) would be readily solved by students who had elected heavy course emphases in science and mathematics, usually to prepare to enter college with a science related major.

In addition to producing "think aloud" audiotapes, the more than 200 students solving the six problems all completed measures of attitude toward science, internal/external locus of control, and analytical skill as assessed by the Embedded Figures Test. Each student also granted the investigators access to permanent school records of achievement test performance in science and mathematics and intelligence test scores. Since records were not always complete on all students, some analyses involving these variables are based on less than the total sample.

This report summarizes the major findings of the study and offers suggestions for teaching consistent with the research findings. The discussion of findings will proceed from (1) problem solving performance by grade and sex; (2) problem intercorrelations; (3) analyses of covariance; (4) variables of individual difference; (5) attitude data; (6) within problem differences; (7) comparison to secondary "science committed" students; (8) developmental level; to (9) protocol analysis.

METHOD AND POPULATION

In the five junior high schools from which our largest population (N=150) was selected, students were required to take a minimum of one semester of physical, biological or earth science. Course patterns suggested that most of the students met this requirement in the 7th grade with either a one- or two-semester science course. All but about 10% of the students in the study were enrolled in a science course at the time of the study. Students were selected randomly (though stratified by sex) from the existing enrollments. The data collection consisted of two sessions: a 40 to 50 minute group session during which students took the attitude and "learning style" tests, followed by an hour long individual session (usually conducted after school) during which students were trained on a "think aloud" problem sample and then audiotaped while solving the six test problems. (Two of the problems were presented in variations discussed below.) The problems are briefly described in an appendix. Each student received an honorarium of $5.00 for participating.

FINDINGS

General Findings

Each student's responses were scored on a scale ranging from 0 (unable or unwilling to attempt the problem) to complete success (scored either 4 for five problems or 5 for a sixth problem). Then a problem solving mean score (ranging from 0 to 4.2) was computed for each student. To assess reliability of scoring, a 20% sample (chosen from across the three grades) was scored twice by two independent raters. Inter-rater reliability (.92) was satisfactorily high. The grand problem solving mean across all of the main population was 2.52. Table I presents means and standard deviations by grade and sex.

Table I

Problem Solving Means by Sex and Grade

Grade	Male	Female	Combined
7th	2.42 ± 0.66 (27)	2.20 ± 0.72 (24)	2.32 ± 0.69 (51)
8th	2.73 ± 0.66 (23)	2.45 ± 0.72 (24)	2.59 ± 0.70 (47)
9th	2.67 ± 0.90 (26)	2.50 ± 0.74 (25)	2.59 ± 0.82 (51)
Combined	2.70 ± 0.75 (76)	2.38 ± 0.73 (73)	2.49 ± 0.75 (149)

(Numbers given are problem solving means ± the standard deviation with sample size in parentheses.)

No grade differences appeared, although a non-significant trend toward better performance at higher grades did appear. Although male performance at all grade levels slightly exceeded that of females, the difference was not significant. These findings, not surprising in the context of a single required one-semester science course, show little growth in science problem solving performance from the seventh through the ninth grade. The study was cross-sectional in nature, so that different students were tested at each grade level.

Problem Intercorrelations

Inspecting patterns of student performance across problems resulted in a decision to construct an intercorrelation matrix among five of the six problems. (Complexities of the sixth problem, the "mealworm" problem, deferred the analysis of that task.) A pattern of low and generally non-significant problem intercorrelations emerges from this matrix.

Table II

Problem Intercorrelations

	Lake	Radioactivity	Pendulum	Water Fountain	Frog
Lake		.36	.14	.13	.35
Radioactivity			.14	.12	.39
Pendulum				.23	.21
Water Fountain					.22
Frog					

Correlations are Pearson Product Moment Correlations.
Circled correlations are significant at .05 level.

Only "frog" problem performance correlated consistently with the remaining problems. The surprising lack of problem correlation suggests the absence of a general "problem solving" skill, at least on these problems. This issue will be discussed more fully later in the report.

Perhaps because of the lack of intercorrelations among problems, attempts to predict a problem solving mean (PSM) for the five problems were quite unsuccessful. A multiple correlation of .58 (R^2 = .34) was obtained using IQ, vocabulary, math concept score, math application score, math comprehension score, attitude toward science, Embedded Figures Test score, locus of control and science achievement test scores as predictors. Only IQ, Embedded Figures Test score, vocabulary, and math applications made significant contributions to the multiple R. IQ correlated .53 with the PSM while the Embedded Figures Test score entered the regression equation second with a zero order correlation of .46, and raised the multiple R to .56.

Analyses of Covariance (ANCOVA)

The analysis of variance conducted on the problem solving mean reported above suggests that grade or sex differences may be masked by systematic differences in the population despite its random selection. Consequently, a series of analyses of covariance 'as carried out using the PSM as the criterion and keeping various predictors ␣onstant" by the ANCOVA technique. Using a composite mathematics achievement score as a covariant, the analysis revealed a significant effect for both grade (later grades outperformed earlier) and sex (males outperformed females), with no significant interactions. Similar analyses revealed the following: with IQ as the covariant, significant effects for both grade and sex appear, consistent with those for mathematics achievement; using attitude toward science as the covariant, significant differences appeared favoring males; when science achievement was covaried, a similar difference appeared for males. No other covariance analyses resulted in significant findings.

The Embedded Figure's Test (EFT)

Witkin and his associates have noted that using the EFT as a predictor frequently requires an "extreme groups" analysis; that is, using very high and very low scores on the test as the base of an examination of differences. For the junior high school population, the mean EFT score was 9.5, with a standard deviation of 4.7. Scores on the measure may range from 0 to 18 (perfect score). A series of analyses comparing the performance of high EFT students (EFT $\geq$ 14) with low EFT students (EFT $\leq$ 6) revealed significant differences favoring high EFT students on each of the five problems. Although girls' scores on the EFT were generally lower than those of boys, sex differences in the PSM disappear when students are matched on EFT. This finding suggests that the frequently discovered sex differences (see ANCOVAs above) may reflect differences in the analytical skill required for successful performance on the EFT. As a point of comparison, the EFT score of the secondary school "science committed" population averaged 14.7, a full standard deviation higher than that of the junior high school general population.

Attitude Data

The attitude scale consisted of 20 items scored on a five point Likert scale ranging from negative attitudes toward science to attitudes favoring science, with 100 points the maximum favorable score. The mean for the junior high populations was 64.2. With the exception of 7th grade males, little between-grade or sex variations appeared, with all cells having means falling between 63 and 67. Only 7th grade males, with a mean score of 59.8, seemed to vary much from the grand mean. Table III shows the items with the highest (most favorable toward science) and lowest (most unfavorable) means.

Table III

Items on Science Interest Inventory With Highest and Lowest Ratings

HIGHEST RATING	MEAN RATING	STANDARD DEVIATION
Science is an interesting subject.	3.79	1.10
Science is a subject everyone should take.	3.71	1.05
Science is an exciting subject.	3.69	1.02
Science knowledge is useful in everyday life.	3.69	.91
Science is important for solving world problems.	3.61	.975
LOWEST RATING		
Science requires hard work.	2.26	1.04
Science requires a lot of memorization.	2.27	.96
Science tends to be complicated.	2.55	1.14
Science needs quite a lot of imagination.	2.75	1.12
Science facts and ideas are hard to understand.	2.99	.80
Most students enjoy science courses.	3.03	.77

(Items were rated on a scale of 1-5. A neutral rating = 3.)

The cluster of favorable items suggests a generally approving attitude toward science as interesting and necessary. At the same time, the more negative items suggest that science is regarded as difficult, unimaginative, hard to understand, and requiring much memorization. Informal student comments from the audiotapes verified these findings. Noteworthy too is the fact that the senior high group (as one would expect) had a mean score of 70.5.

Within Problem Differences

The water fountain problem (see appendix for description) was presented in two forms. In the first, the actual apparatus was set up for the student, and the "fountain" was put into operation. In the second, a diagram of the problem was presented and explained. This difference was statistically significant; in fact, of 74 solutions to this problem only 19 emerged from the "picture" form of the problem. While only suggestive, this finding is consistent with the viewpoint that values hands-on science instruction. The live presentation also stimulated increased animation and duration of the audiotaped student comments and discussion.

No data discussed thus far have addressed the sixth problem on the problem solving test, the mealworm problem. It was presented in three forms on a continuum ranging from "open-ended and unstructured" to "highly structured." (See appendix for the different forms of the problem.) The general intent of the problem was to permit students to perform the way scientists do in going about the difficult business of generating hypotheses and designing adequate tests for them. Using a lenient scoring criterion for both generating and testing hypotheses, only a sex trend (favoring males) appeared. A non-significant trend favoring the more structured problem also appeared. On the other hand, an analysis of variance using the EFT extreme group analysis revealed that more analytical students were uniformly more successful on all three forms of the problem, with the greatest difference in mean scores on the most "open" form.

Comparison to Secondary "Science Committed" Students

The senior high school students used as a comparison group in this study were <u>not</u> randomly selected. Rather, systematic efforts were made to secure a sample of students whose commitment to science was evidenced by enrollment in elective science and mathematics courses. These high school students were all drawn from a single high school which, in turn, drew from two junior high schools in the major sample. As already noted, the high school students have significantly higher EFT scores, attitude toward science scores, and IQs than the junior high students tested. All are certain they will attend college and expect to take additional science in college. Many were drawn from a pre-calculus class and had already taken high school physics and chemistry.

Of some interest is the fact that in spite of the rather extraordinary abilities and achievements of these students, the frog and pendulum problems were difficult for them. Thus their additional age and science experience had not brought all of them to "formal operational" thought in science. Several of the students experiencing difficulty with the two problems reported that they had encountered similar (or identical) problems in mathematics or physics, and were quite confident that their responses were adequate.

These difficulties aside, the high school students differ from the junior high sample in qualitative ways as well as quantitatively. The secondary school students have a more complex, correct and complete science vocabulary and their approach to the problems (even when incorrect) tends to be more thoughtful and systematic. Longer pauses in their solution processes may indicate more non-verbal consideration of the tasks.

Developmental Level

A developmental level score ranging from 0 (consolidated concrete) to 3 (formal operational) was computed for each student using the responses to three of the six problems (mealworm, pendulum, frog). Five scores were obtained from these problems and then averaged to compute the developmental level for each student. An analysis of variance revealed no significant differences for grade or sex although scores for eighth and ninth grade males slightly exceeded those of females. The mean for the sample junior high population (N = 143) was 1.86 with a standard deviation of 0.76.

A new problem solving mean score (PSM3) was computed (0 to 4.33) using the three problems not scored for developmental level (lake, radioactivity, water fountain). Using the PSM3 as the criterion, a multiple regression analysis was performed and included developmental level scores as well as the nine predictor variables we have discussed. A multiple correlation (N = 123) of .61 (R^2 = .38) was obtained. Only math application and developmental level made significant contributions to the explained variance. Math application correlated best with the PSM3 (r = .53) and developmental level was the second predictor to enter the multiple regression equation, raising the multiple R to .59. Math application and IQ were highly correlated (r = .80) and eliminating the math predictor would cause IQ to enter the equation first.

Extreme group analysis comparing high developmental students (DL 2.50) with low developmental students (DL 1.20) revealed significant differences in the PSM3 favoring the high developmental level students. No significant sex differences appeared in this analysis.

These data suggest that teachers be aware of developmental differences and attempt to incorporate problem solving methods which take these differences into account.

Protocol Analysis

The "think aloud" approach enabled greater insight into the thinking processes students used in attempting the six problems in the study. The audiotapes generate a great amount of data about individual problem solving efforts, and reducing these data to a brief report is difficult. The following observations summarize the most frequent or prominent characteristics of student problem solvers.

Even casual examination of the protocols revealed striking gaps in the basic "knowledge" of science. The six problems selected were chosen, in part, because they did not require large amounts of specific information. Simple errors of common science terms were frequent. Differences in vocabulary were particularly noticeable when contrasting junior high with senior high students, with the latter group showing substantial vocabulary growth and language flexibility. As a specific instance, in the "water fountain" problem many students had difficulty finding words for the concept of differential pressure. Consequently, making sense of the process causing the water to flow was extremely difficult. The students' lack of vocabulary specific to the tasks may have led to the rather low problem intercorrelations.

In addition, the junior high school students evidenced not even rudimentary general problem attack skills. While the secondary students frequently mentioned the strategy of "looking for the constants and the variables" before attempting to solve a problem, this was never verbalized by the junior high students. This approach had evidently been taught, probably in the high school physics course.

The EFT extreme groups data revealed frequent response pattern differences. The high EFT students (more analytical) showed not only higher vocabulary levels, but also more frequent hypothesis generation skills--searching for ways to restate problems in hypothesis-testing ways. The analytical high school students were particularly careful to define and understand problems before attempting to solve them. Low EFT (global) students commonly made statements that tended to avoid the problems. For instance, one 9th grader with an EFT score of 2 responded to the frog problem by asserting, "I'm not a biologist. I don't even like frogs. Why would I want to find how many?" Such avoidance was frequent and seems predictable. Why would students who are unsuccessful in science approach science problems eagerly and positively?

All in all, the protocols suggest that science problem solving is difficult for these junior high students because they do not have adequate knowledge or viable attack skills. If this is true of students in general, real problems are posed for junior high school teachers. On the one hand, students might be pressed to attain more "science facts." Yet our attitude data provide considerable evidence that students already see science as difficult, requiring much memorization, hard to understand, etc. Thus a response which focuses on fact acquisition is likely to make science even more unattractive to many students. At the same time many junior high school curricula include the four or five step "scientific method" in effort to provide students with a problem attack strategy. The evidence from our short-term intervention to teach such a process suggests that 7th graders are perhaps developmentally unable to profit from such a general strategy. The problem solving skills of more analytical (high EFT) students were generally better at all age levels. These conclusions, coupled with the rather fragmentary information available to us about methods of presenting problems (from the water fountain problem), suggest that a "hands-on" approach to teaching science using tasks which pique curiosity may help students approach problems more skillfully and then solve them successfully. Given current teaching loads and limited curricular and laboratory materials, such a proposal would put severe stress on many junior high school science departments.

IMPLICATIONS

Implications of this study for junior high science instruction include:

1. Determining student analytical ability using an instrument such as the Embedded Figures Test, by Witkin, et al., could help teachers predict where problem-solving difficulties lie.

2. Problems should be carefully chosen based on appropriate developmental levels and analytical abilities of the students. Problems that are too difficult will frustrate students and contribute to creating a negative attitude toward science.

3. Whenever possible, problems should be presented by concrete demonstration as opposed to purely verbal instruction.

4. Care should be taken to insure that all concepts prerequisite to solving problems are understood by students confronting the problems.

5. Teachers should introduce and regularly reinforce problem attack skills such as looking for the constants and variables, generating and testing hypotheses, etc.

6. Teachers should take advantage of the many naturally-occurring problems and curiosities of science to create a motivation to learn. Discrepant events (events that appear to be contrary to what would normally be expected) can be particularly inspiring.

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APPENDIX

PROBLEM DESCRIPTIONS

Lake Problem

The lake problem presents two pictures of a deep lake. One picture shows summer temperatures at the surface, the bottom and mid-depth of the lake while the other picture shows comparable information for winter temperatures. Information is given below the pictures which points out that the bottom of the lake is coldest in summer and warmest (relative to surface and mid-depth temperatures) in the winter. Information is also given about differential weight of water at 39^o and 37^o and 72^o. Subjects are then asked to use that information to explain why the lake bottom is coldest in summer and warmest in winter.

Radioactivity Problem

In its entirety the problem is as follows: Some elements are naturally radioactive. That is, they give off invisible particles that can only be detected with a special device called a Geiger counter. Even when these elements combine with other elements to form compounds, they continue to be radioactive. Four elements, A, B, C, and D, can be combined to form various compounds. Read these statements carefully: (1) The compound formed by mixing A and D is radioactive. (2) The compound formed by mixing B and D is also radioactive. (3) The compound formed by mixing C and D is not radioactive. What can you conclude about these four elements, A, B, C, and D?

The Pendulum Problem

This familar problem was presented to the students in such a way that, with the aid of the experimenter as time keeper, students could gather data on any of three string lengths and two weight difference combinations to discover the factor(s) which affect the rate of pendulum oscillation.

The Water Fountain Problem

This problem, given either with a drawing or "live," is as follows: Observe that two jars, A and B, are connected by a rubber hose. Jar A contains water and sits higher than Jar B, which contains no water. Notice that a long glass tube begins deep in the water in Jar A and stops above a glass funnel fitted into the top of Jar B. If I pour water into the funnel on top of Jar B, what would happen? Be sure to say <u>why</u> it would happen.

The Frog Problem

In its entirety the problem is as follows: A biologist did an experiment to find out how many frogs lived in a pond. He did not have enough time to catch and count all the frogs. The first day he caught 55 frogs and put a band on one of the legs of each frog. He waited a week to give the banded frogs a chance to spread themselves evenly throughout the pond. He than caught 72 frogs, and 12 of them had bands on one leg.

Using all of this information, how could the biologist figure out about how many frogs are in the pond?

Mealworm Problem

Form I. Imagine yourself in a biology class. The teacher wants you to make up experiments using 100 mealworms (small worms that eat wheat flour and other grains). You are free to use whatever equipment or materials you might need. What experiments will you do?

Form II. Imagine yourself in a biology class. The teacher wants you to make up an experiment using 100 mealworms (small worms that eat wheat flour and other grains). Your experiment must answer the question: How do mealworms react to light? How will you set up your experiment to answer this question?

Form III. Imagine yourself in a biology class. The teacher wants you to make up an experiment using 100 mealworms (small worms that eat wheat flour and other grains). Your experiment must answer the question: How do mealworms react to both light and moisture? How will you set up your experiment to answer this question?

DEVELOPING CREATIVITY AS A RESULT OF SCIENCE INSTRUCTION

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WHAT IS CREATIVITY?

Although creativity has been an area of legitimate concern and interest to educators since the time of the Greek philosophers, little has been done directly to encourage creativity in the science classroom. Research into creative process and product has been reported since 1950 but has had only a meager effect on the literature of education and almost no impact on curriculum development in science. Although creativity may be readily identified as a by-product of many recent curriculum developments, widely published activities indicating creativity as a primary goal are difficult to find.

One possible reason that creativity has not been included directly in the science curriculum is disagreement about what creativity is, its relationship to science, and the nature of its products and processes. Much early thought correlated creativity with intelligence. As might be expected with two mental functions, there is a degree of correlation between IQ and scores on creativity measures. Various researchers (Mackinnon, 1966; Torrance, 1966; Yamamoto, 1965) have shown, however, that the correlation decreases with increasing IQ and becomes almost negligible above an IQ of about 115. Thus, there appears to be an IQ threshold for creativity. Beyond this threshold, the old assumption that giftedness in intelligence is synonymous with giftedness in creativity has been effectively refuted by a number of studies (Getzels and Jackson, 1962; Torrance and Myers, 1970).

Even though a number of talented investigators have researched questions of creativity, it is still an area in need of additional research. Researchers in the field of creativity have difficulty defining creativity and are in only reasonably close agreement when considering the processes of creativity. Some scholars, such as Rhodes (1961), define creativity as a creative product. Others (Rogers, 1961) speak of novel relationships or the capacity to find new connections (Kubie, 1958). Others have mentioned insights (Gerard, 1961) or insist that the product is creative only if it did not exist previously in the same form (Stein, 1953). Stewart (1950) feels that the criterion should be newness to the individual even though the idea may have been produced many times before. Thurstone (1952) shares this idea by maintaining that a creative act has occurred when the individual reaches a solution that is new to the individual.

Others have emphasized the creative process rather than the product. Thus, Bartlett (1958) and Ferren (1953) speak of stepping into the unknown, breaking away from the main track, and following one's own instincts. Ghiselin (1952) emphasizes the process of psychic change in the individual culminating in a creative product. Golovin (1963) feels that a creative contribution "transcends prior experience and, to some extent, contains a revolt against it." (page 16)

Several investigators (Crutchfield, 1962; Wilson, 1956) have examined both product and process and define creativity by contrasting it to conformity or to doing that which is expected or usual. Also combining product and process, Guilford (1956) conceptualizes creativity in terms of the mental processes and abilities necessary for creative achievement. From this conceptualization he created the divergent thinking portion of his structure of the intellect model. Within this portion he has developed tests that demonstrate the existence of factors he identifies as fluency, flexibility, originality, and elaboration.

Although we need not assume universal meaning for the word creativity, we should have some common understandings. Sprecher (1963) proposes that "we study the variety of meanings which in practice are assigned to the term rather than ... attempt to discover some ultimate meaning." Perhaps this is what Torrance (1974) was attempting to do when he wrote that creativity is:

> ... a process of becoming sensitive to problems, deficiencies, gaps in knowledge, missing elements, disharmonies, and so on: identifying the difficulty; searching for solutions, making guesses, or formulating hypotheses about the deficiencies; testing and retesting these hypotheses and possibly modifying and retesting them; and finally communicating the results. (page 8)

The emphasis here is on direct, primary experience--experience in which individuals use their own senses to perceive reality freshly and spontaneously. In this light, creativity might be thought of as looking at one thing and seeing another.

Such a definition is perhaps more applicable to the science classroom than other arenas since it speaks of processes and worries little about the product; rationally parallels the well agreed upon processes of science; and involves observable activity on the part of the participating individual. This definition is also appropriate in that it forms the basis for the Torrance Tests of Creative Thinking, a research tool which, since 1966, has been used in more than 1000 classroom studies.

CREATIVITY HELPS TEACHERS AS WELL AS STUDENTS

Enhancing creativity yields many long range benefits to both the individual and the society, for creative activity is involved in the development of new knowledge; the production of music, art, and literature; and in the pleasures and benefits of generally imaginative thinking and living. More immediately, creativity can be useful in the classroom. Individuals have been shown to benefit in a variety of ways from their own creativity and that of others. Studies have shown that creative people are more flexible in new surroundings (Rubin, 1963), more observant (Barron, 1963), and more self-confident (Maw and Maw, 1965) than less creative people. Creative people have also been shown to be more adaptable and sensitive to their surroundings and to others (Rogers, 1962). Creative boys have been shown to demonstrate more sociability than less creative boys (Maw and Maw, 1965). In a study which has been replicated several times, Getzels and Jackson (1962) found that when a group of highly creative, lower IQ students were compared to a group of high IQ, less creative students, their standard achievement test scores were the same even though there was a 23 point difference in IQ between the two groups. Although both groups were very high in IQ (127 and 150 respectively), the study did demonstrate that even extremely large differences in IQ could be overcome by increased creative response. Torrance (1963), in an almost identical study, found the same results.

Another study (Taylor, 1963) demonstrated that undergraduate grades in college were inadequate predictors of success as a research scientist. In this study the undergraduate grade point averages of three groups of "journeyman" research scientists (a total of 239) were compared. The journeymen were then rated by their supervisors on a five-point scale for their efficiency as scientists. All were rated in the top three categories of the scale but differences in efficiency and competence were clear. Since among the three groups there was no significant difference in mean grade point average, grades could neither account for differences in performance nor be used to predict who would make a good, competent research scientist.

Creativity is, in some respects, a great equalizer--a particularly attractive quality in a democracy. Hammer (1964) showed that increased creativity helps to fuse what are traditionally considered feminine and masculine traits. He further pointed out that sensitivity, usually considered a feminine trait, and creativity go hand in hand. Lodico and Gaa (1978) found that less creative women are more submissive and hesitant while more creative women exhibit more initiative. In fact, in the same study, creative women were seen to demonstrate more than average aggression and dominance, traditional masculine traits. Creative women are also less passive, less restricted by society's expectations, and better able to explore a variety of alternative behaviors (Helsen, 1967).

Maw and Maw (1965) found that highly creative children, when compared to less creative children, had a greater level of self-sufficiency, felt more secure, were more flexible and dependable, and exhibited a healthier participation in group activities. Highly creative boys, specifically, were found to exhibit a higher level of maturity and social skill, and to feel that discipline was more fair. In addition, these more creative boys exercised better overall social judgement than their less creative peers.

Studies also have demonstrated that creative people are more observant, seeing and valuing things as others do not. Creative people are viewed as healthier and more energetic (Barron, 1963). And, as Getzels and Jackson have pointed out on several occasions (1958, 1962), creative thinking abilities contribute significantly to the acquisition of new information. Creative people have a well-developed ability to sense problems. They possess originality and flexibility which is spontaneous and adaptive. Their fluency of associations, expressions, and ideas allows them to relate and perceive ideas in unusual ways. This leads to a redefining and juggling of ideas, further visualizing, and still more elaborating. The tendency to think at right angles to the mainstream and to develop an ability to focus attention in many ways while working and thinking on problems is very common (Taylor, 1964). Creative people also show an ability to evaluate their own creativity, an ability perhaps related to their generally strong drive, inner-directedness, self-confidence, intellectual thoroughness, and aspiration to making theoretical and original contributions. A high degree of self-sufficiency, openness to the irrational, intuitiveness, awareness of their own impulses, and resourcefulness often lead to the creative acts, products, or ideas which characterize creative individuals. Being adventurous, personally complex, unconventionally employed, dedicated to and involved in their work, and liking to think and to toy with ideas may all promote the stamina and endurance which creative people are seen as having. A need for variety and autonomy, a preference for complexity and challenge, a striving for better and more comprehensive answers, a need to improve on currently accepted systems, a need to adjust the environment (rather than adjust to it), and a tolerance of ambiguity may all contribute to the creative individual's tendency to stand out from the usual, the accepted, and the conservative trends of peers (Taylor, 1964). Strong ego development (Barron, 1963) coupled with a tendency to be assertive about their ideas can often lead creative individuals into conflicts with teachers and peers.

THE CREATIVE PROCESS

The process of developing creative ideas, thoughts, or actions is usually considered to begin with a period of mental labor or preparation which involves sensing a deficiency or need, randomly exploring the problem area, and finally, clarifying the problem (Patrick, 1955; Taylor, 1963; Torrance, 1965; Wallas, 1926). A second stage in the creative process is that of incubation accompanied by discussing, exploring, and formulating possible solutions to the problem or looking for logical flaws. The well known act of illumination--a flash of insight, the birth of a new idea--characterizes the third stage. Finally, there is a deliberate effort and experimentation aimed at elaborating, revising, evaluating, possibly verifying and eventually perfecting the idea. This final culminating stage may involve the production of a work of art, an invention, a new theory, or some more new ideas. Creative individuals tend to resist premature closure but actively seek closure itself.

USING THE CLASSROOM TO PROMOTE CREATIVITY

Although creativity is sometimes thought to be an inborn trait, evidence suggests that creative development does not have to be left to chance (Torrance and Myers, 1970). In fact, the ability to do creative work and creative thinking has been shown to be largely dependent on a pupil's opportunities for creative work (Payne, 1958). Efforts to provide such opportunities should not meet with resistance since the weight of present evidence indicates that people fundamentally prefer to learn in creative ways by exploring, manipulating, questioning, experimenting, risking, testing and modifying ideas, and otherwise inquiring into their environment (Torrance, 1963).

If, in fact, students prefer learning in creative ways and if aspects of creativity can be taught, then all that remains for the teacher to do is to establish a classroom environment and a set of personal behaviors compatible with developing potential creativity. For people to take advantage of opportunities for creative endeavor, they must be free of crippling restraints and impoverishing inhibitions and thus able to assume the independence in thought and action that will enable them to strive for solutions to problems (Mackinnon, 1962). Students' preconscious mental processes have been shown to attain a higher degree of freedom in allegory and in figurative imagination than by any other psychological process (Getzels and Jackson, 1962), so giving them free reign in these arenas may greatly enhance creative potential.

Several educators have suggested ways in which we might help students develop creativity. Rubin (1963) suggests that if the curriculum were arranged to encourage students to engage in as many kinds of thinking as consistently as possible, we would in all probability: a) provide them with bases upon which to recognize opportunities to transfer learning; b) expand their capacities to respond in several ways to a single phenomenon; c) improve their abilities to select an effective way of thinking about a task; and d) provide them with cognitive alternatives they might otherwise have ignored.

Research has demonstrated that people tend to learn and develop along whatever lines they find rewarding (Torrance, 1965; 1970). To promote creativity, science educators might structure the curriculum so that creativity is valued and encouraged. With this in mind, Torrance speaks of rewarding creative behavior by treating unusual ideas and questions with respect while showing students that their ideas have value; providing opportunities and credit for self-initiated learning; and making evaluation contingent on causes and consequences. Rogers (1961) emphasizes the connection between evaluation and creativity in asserting that "The most fundamental condition of creativity is that the source or focus of evaluative judgement is internal." (page 354)

Many psychologists and businessmen have used Osborn's brainstorming techniques (1963) to develop a flow of ideas from individuals. Osborn's techniques include "deferring judgement and . . . making conscious efforts to adapt, magnify, minify, substitute, rearrange, or combine ideas" (Simonis, 1977). Other methods that have been successfully used to develop creative potential include sociodrama (Klein, 1956) and synectics. (Gordon, 1971)

Many ideas could be developed into specific creativity-stimulating classroom activities. For example, Knapp (1972) suggests using "pretending." In pretending, students examine their environment by role playing objects or people in their environment. In "body-twisting," students cast themselves into unusual physical positions in order to view the environment from different vantage points. In other activities students brainstorm to see how different characteristics of an object might be related to its function. Students may also try to change the object to better serve a given function and then compare the new object with other objects. Along with this, they may develop as many ways as possible to use the new object and then write a story using it.

An environment which enhances creativity will be promoted by teachers who exhibit creative behavior themselves and who eliminate as many cultural and emotional blocks as possible. Many of these blocks involve the effects of conformity, excessive faith in logic, fear of mistakes or failure, self-satisfaction, perfectionism, negativism, and a lack of independence combined with a reliance on authority. As in the brainstorming process, teachers can help students to defer evaluation and judgement and to concentrate on producing ideas before becoming critical. While this may be viewed as rather permissive, openness and self-directiveness have been shown to characterize environments which facilitate goals associated with creativity (Smith, 1959). Additionally, Treffinger (1978) has shown that evaluation inhibits curiosity, stifles inquiry, and encourages undue dependency. To encourage self-directed learning, he insists we must refrain from arbitrary evaluation and help children learn how to determine and apply specific criteria when evaluation is finally appropriate.

Much to the chagrin of many teachers, praise must be reconsidered and seen to be just one more form of arbitrary evaluation. Since praise emanates from the teacher, an authority figure, it is frequently received as evaluation. And, as Deci (1975) points out, praise reduces rather than increases motivation when a person receives it for a behavior previously performed for its intrinsic value. As Brophy (1979) is fond of saying, "Praise correlates sometimes positively, sometimes negatively, but usually not at all with learning . . . praise is generally overrated."

Dinkmeyer and Dreikurs (1963) suggest that we avoid the authoritarian by encouraging rather than praising. Encouragement is characterized by giving attention, watching, listening, questioning, and a whole array of nonverbal gestures.

Students are finely tuned to their environment and naturally respond to it. In a climate where freedom is lacking, where choice and decision are not allowed, students lose faith in themselves and come to reject their own senses--senses which allow them a freedom of imagination. In doing this, they no longer use the full power of their senses and have little inclination left to go beyond the reality of their lives. Without this desire and trust in self, students are not open to themselves and their experiences, prime components of the creative process. (Rogers, 1962)

The way that most curricula are now established, students soon learn that, to get along, they must do what teachers ask and expect. This conformity to existing norms inhibits most free and creative responses and is tantamount to a surrender of self. In the process, students become desensitized to the point that they may not recognize their own natural feelings, spontaneity, and experiences.

Creative learning will be promoted if the subject matter and instructional material are part of the student's natural environment. Many books, such as Creative Sciencing (DeVito and Krockover, 1976) and 100 Ways tc Enhance Self-Concept in the Classroom (Canfield and Wells, 1976), provide activities to stimulate creative thoughts and actions. If the student can relate to these materials, facts, and concepts, they are more likely to arouse and sustain interest. In creative learning, students are prompted to go considerably beyond memorizing and repeating course content to conceptualizing and rearranging it until it makes sense. Kagan (1971) feels that the child's "own need to know" is insatiable and forces the child to constantly rearrange ideas into patterns that make personal sense.

Just as adequate material and stimulation are necessary to the creative learning environment, so is a creatively inclined teacher. The effect of the teacher on students has been shown to be very great (Penick and Shymansky, in press). This study of fifth grade science students demonstrated that the teacher's use of directions, praise, rejection, and evaluation significantly reduced the students' ability to work with figural creativity, involving the development or completion of pictures. In a classroom where the teacher exhibited almost none of these behaviors, the students achieved significantly greater figural creativity with no loss of verbal creativity or achievement. In a related study (Penick, 1975), the figural creativity of high school students was found to be enhanced by a classroom setting low in direction-giving, stress, and evaluation, especially when compared to students in a classroom controlled by higher levels of directive behaviors. Again, no loss of verbal creativity was perceived. Ramey and Piper (1974) found that students in grades 1, 4, and 8 did better on figural creativity tests after experiencing a relatively open classroom while students in a more traditional classroom stressing competence, obedience, and hard work did better on tests of verbal creativity. In comparing classrooms of high and low structure, Klein (1975) found that third graders low in anxiety were more creative in the less structured classroom while children high in anxiety performed at the same level in either environment.

THE CREATIVE FUTURE

Although we have been riding the crest of an information explosion, we may not have been increasing our creative potential at the same rate. Increasing the number of creative citizen-workers can serve to enhance the future for all, and schools and influential teachers can play an important part in the process of developing creativity.

As Golovin (1963) points out,

> The largest number of creative workers in any field can be reliably obtained only by extending the opportunity for the necessary education and training to all those who demonstrate they have the capacity for acquiring the necessary volume and depth of structured, interrelated experience. (page 20)

Schools are likely places for these opportunities to unfold, but they won't unfold by themselves; an environment with the subject matter, material, and intellectual freedom shown to facilitate creative development is necessary and can be greatly promoted by teachers.

Creativity can be fostered in most children and many will experience significantly enhanced creativity as a result of teaching techniques emerging from research on the development of creative potential. The appended list might be thought of as a research-based prescription for a future in which education is a generative pleasure and continuing education, an ecstasy of creativity.

TEACHERS SHOULD ENCOURAGE CREATIVITY IN STUDENTS BY:

1. Accepting unusual ideas, questions, or products
2. Providing opportunities, including materials, for creative work
3. Showing students that we feel their ideas have value
4. Asking students to examine causes and consequences in order to make personal evaluations
5. Providing an environment in which it is safe for students to risk, question, experiment, and test
6. Allowing students to make decisions and choices
7. Reducing student anxiety
8. Allowing students to decide on closure of an idea, experiment, or train of thought
9. Allowing students opportunities to take leadership responsibility

TEACHERS SHOULD NOT:

1. Evaluate arbitrarily or prematurely the product or the process
2. Restrict access to ideas or materials
3. Emphasize norms or generalities
4. Constrain student freedom unduly through the use of directions or praise
5. Hasten or enforce closure

STUDENTS SHOULD BE ENCOURAGED TO:

1. Evaluate themselves
2. Interact with subjects, materials, and ideas in an atmosphere of intellectual freedom
3. Make decisions about their learning

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PIAGET'S MODEL OF INTELLECTUAL DEVELOPMENT: DERIVING CLASSROOM APPLICATIONS

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INTRODUCTION

Even though Piaget's research with children has generated much interest and spawned hundreds of additional studies, no concerted effort to apply his basic findings to actual classroom practice has yet been made. In this instance, the age-old dichotomy of "theory" on the one hand and "what to do in the classroom" on the other seems to persist, with only a rare meeting between the two. For example, teachers are often shown or taught some of the Piagetian interviews or tasks; some teachers have even administered these tasks to their students. Yet, what is the follow-up? How are the tasks related to actual classroom practice? More often than not the bridge between the tasks and educational practice is not completed, as evidenced by statements like, "This is all very interesting, but what does it have to do with teaching?"

The distance between theory and practice is perhaps most evident in certain textbooks or programs used in college-level courses for preservice and inservice teachers. These textbooks often contain an isolated chapter or section devoted to Piaget but unrelated to any other material throughout the remainder of the book. Statements like, "Children learn by acting on and manipulating objects" are often highlighted and underscored in these chapters, but then later in the same book, in the section devoted to how and what to teach, demonstrations and classroom discussions are emphasized over allowing students to explore and experiment. In addition, suggested content areas for elementary school children often include astronomy, weather, atomic structure, and other such topics. Procedures and topics like these certainly do not allow for hands-on manipulation and yet they are invested with a great deal of pedagogical authority, thus rendering the section on Piaget irrelevant.

Perceptive teachers sense that Piaget's work is important and that it should somehow be of value in the classroom. Because there is no bridge spanning Piaget's theory, related research, and classroom practice, applying the theory is difficult even for interested teachers. The Piagetian tasks and interviews, though enlightening and interesting, do not provide a basis for classroom practice; they are merely diagnostic instruments with which to assess and demonstrate children's developmental levels. A child's performance on a particular task provides information about the child's development at that time, but not about what the child should do next--that is, the topics or activities that would be appropriate to pursue in light of the child's level of intellectual development. Piagetian tasks, then, cannot be used to develop a curriculum, nor can they alone provide a bridge from theory to classroom practice; yet another step is required, the understanding of structures.

BACKGROUND ON PIAGET'S STRUCTURES AS INTELLIGENCE

Recurring themes of Piaget's work are that human intellectual development occurs in a systematic, ordered progression, and that the different components of an individual's cognitive make-up are interrelated. In effect, this means that intellectual development does not occur by chance or random association, but in a sequential and predictable manner in which each new level of development is attained only upon completing the prerequisites of the preceding level.

The formation and elaboration of these ideas spanned many years of research and the chronicle of their development is scattered across many articles and books. Only through a great deal of reading and synthesis can the entire picture of Piaget's model begin to emerge, especially the part of the model tracing the interrelatedness of intellectual development. An example of the evolutionary nature of Piaget's most powerful ideas may be found in precursors to Structuralism. Some of the early works contain references to "operations," a concept expanded in later works to "groupings"--meaning groups of operations--and then further expanded to apply the term "structures" to these groupings or sets of operations. Ultimately, Piaget authored the book Structuralism (Piaget, 1970) in which he pointed out the usefulness and importance of structures, not only in his own work, but in mathematics, logic, linguistics and social anthropology as well.

Focused through the idea of structures, Piaget's work begins to fit together; the various pieces and parts begin to mesh into a consistent, interrelated system of intellectual development. Even though this system is not yet complete--many aspects need further elaboration and definition--enough information is now available to identify many classroom applications. Through Piaget's structures a bridge can begin to be built between classroom theory and practice. The structures provide a framework within which a teacher can function at many levels, from determining an appropriate sequence of activities for a particular student, to evaluating the appropriateness of curricula. But before considering the specifics of these applications, a more detailed consideration of structures might be helpful.

A structure is defined as a system of transformations, a definition that requires some elaboration. First, the word "system" implies an interrelated and interdependent set of entities (i.e., operations) acting in concert to maintain the consistency and integrity of the structure. Second, the word "transformation" implies that structures are dynamic, not static, and that they are used to transform, move, or change something. This "something" we call content, or facts. Structures themselves are not facts; they are those mental mechanisms that act on, interrelate and make sense of facts. Structures can be thought of as acting the way that a computer program does; data (facts) may be entered into a computer, but without a program to tell the computer what to do, the facts are of little value. In effect, structures may be thought of as those things we think with.

Classifying, ordering, making correspondences, deriving relationships, solving spatial problems, and the like all require the use of structures. (Memorizing or recalling facts or words, on the other hand, does not involve using structures.) The act of, for instance, classifying a set of objects makes use of a structure, whereas naming the objects or memorizing a given classification system does not. Once fully formed, a structure can be used on any content; therefore, a particular classification structure can be used to classify anything, be it objects, people, events, etc. Furthermore, once formed, a structure can be utilized in thought without objects being present; only during the formation and construction of the structure are objects necessary.

Structures, then, provide a quite different view of intelligence, a view that transcends the "mind as memory bank" interpretation of intellectual development; a view that goes beyond skills, perception and memorization. The very things that educators in this country have emphasized and called "learning" for so many years have little to do with structures, so, not surprisingly, Piaget's definition of intelligence has often been misunderstood. Certainly skill development, perception and fact memorization are necessary, but they are only the starting points of human intellectual capability. Skills decay without practice, perception is plastic and inconsistent, and many facts are quickly forgotten. Structures, on the other hand, are self-maintaining, consistent and not forgotten.

From the structuralist viewpoint, intellectual development occurs by an individual's construction of structures. These structures develop in a sequential and interrelated fashion and are of different types, depending upon the developmental level of the individual. For example, the earliest structures, which are called schemes, begin to develop shortly after birth (sensory-motor thought) and are concerned with such feats as grasping, sucking, looking, coordinating eye-hand movements, and so on. These schemes are carried out in action and are not internalized in thought.

Around the age of eighteen months a more advanced set of structures begins to be formed. Thought becomes internalized through mental imagery and what is called the symbolic function emerges. The young child's use of delayed imitation, symbolic play, drawing, and language signals the inception of this higher level of development. Although representing very real intellectual gains, this level of intelligence (pre-operational thought) is still far short of an adequate means of interpreting the environment, for it allows only regulation of thought and no reversible operations.

Between the ages of five to eight years entirely new and more advanced structures begin to be constructed (i.e., concrete-operational thought begins). These and subsequent structures are called <u>operational</u> structures to indicate that they are composed of sets, or groupings, of operations. The structures formed at this level are the first logical structures that the child constructs. Finally, between the ages of eleven and thirteen, a still more advanced set of operational structures begins to be formed; these are the structures of adult thinking (i.e., formal-operational thought), and are applied not directly to objects but to other structures.

Again, structures are <u>not</u> content. A student memorizing the parts of an insect, the multiplication tables, the standard forms of integral calculus, or the kinetic theory of gases is <u>not</u> using structures, even though the content may sound very sophisticated. Labeling content either "concrete" or "formal" is, therefore, misleading since content can be memorized with absolutely no dependence upon structures. A Piagetian approach to teaching a subject involves examining a given content area to determine the structures necessary to comprehend that topic beyond rote memorization. More often than not a given piece of content requires using structures of several different levels. Adults utilize sensory-motor, pre-operational, concrete-operational and formal-operational structures depending upon the requirements of the problem at hand, for the earlier structures are not discarded as human beings ascend the developmental ladder. For example, most of the classifying, ordering and spatially relating involved in everyday living are more than adequately accomplished by using concrete-operational structures; formal-operational structures are not needed.

If structures were merely vague abstractions, educational applications would be impossible to derive--but quite the contrary is true. Certainly no one has ever "seen" a structure, yet many years of research with thousands of children provide a strong argument for the existence of these mental mechanisms. The similarity of responses to particular interviews or tasks cannot be lightly dismissed; certain common characteristics in the way the human mind develops apparently exist. Anyone who has thoughtfully prepared and administered Piagetian interviews cannot help but be struck by the consistency and similarity of the response types. Something, some mental process, must be acting to prompt these analogous responses, and one of the most complete and most widely researched explanations lies in the concept of structures.

If structures are accepted as important aspects of thinking, and if educators are concerned with the development of structures, then how can classroom applications be derived? Certain general characteristics of the structures provide avenues for constructing the bridge between theory and classroom application:

1. Individual structures are well defined and have a basic theme or idea;

2. Many structures occur in interrelated sets defined by their areas of application;

3. Certain subsets of structures are constructed in definite, ordered sequences;

4. Specific and recognizable interrelationships exist between the various sets of structures.

A complete discussion of all the various sets of structures is beyond the scope of this paper, but in order to demonstrate a few of the interrelationships, let us consider the concrete-operational structures listed in Table I. (See over.)

Of the two broad divisions in Table I, Logical Groupings deal with classes and relations, while the Infralogical Groupings deal with three types of space: topological, projective and Euclidean. Both "groupings" and "groups" appear on the table, the latter of which are concerned with number, measurement and quantitative time. Another division within Table I occurs at the horizontal, dashed line between all Groupings 4 and 5. In each set of structures, Groupings 1, 2, 3 and 4 deal with classes or elements, while Groupings 5, 6, 7 and 8 deal with relations.

The number system used in Table I has been employed to emphasize the interrelationships among the various sets of structures; homologous structures within different groupings bear the same number. For example, Logical Grouping 1 (LG_1) deals with class inclusion and part-whole relationships. Moving horizontally across the table we find TOP_1, PRO_1, and EU_1, each of which is concerned with part-whole relationships even though the specific area of application changes from one set to the next. The same holds true for all structures in Table I; those on the same horizontal line are related by certain common characteristics. Another example: Logical Grouping 5 (LG_5) deals with additive asymmetric relations (i.e., ordering); therefore <u>all</u> groupings bearing the number 5 deal with ordering in some sense.

Another aspect of the structures listed in Table I is the relationship between these structures and conservation, a term that, perhaps surprisingly, does not appear on the table. So much has been written about conservation of amount, number, length, etc., that the casual reader might well think that conservation was Piaget's only concern. Although conservation is fundamental to logical thinking, it is only one aspect of intellectual development. In the structures listed in Table I, conservation of certain aspects of the environment is required to various degrees depending on the type of structure, but direct tests of conservation are used to evaluate only five of the forty-six structures. A direct test of conservation involves a classic task in which the child must hold invariant some aspect of objects in spite of changes in other, irrelevant properties. Conservation tasks are used to evaluate the two number groups (N_1 and N_2) and three of the Euclidean Groupings (EU_1, EU_2 and EU_4), but no direct tests of conservation occur in the tasks used to test the other forty-one structures. Conservation is important, but it has a limited role and is not the pinnacle of Piaget's model of intellectual development.

TABLE I

OPERATIONAL STRUCTURES OF THE CONCRETE OPERATIONAL STAGE

LOGICAL GROUPINGS	INFRALOGICAL GROUPINGS		
STRUCTURES FOR CLASSES & RELATIONS	STRUCTURES FOR TOPOLOGICAL SPACE	STRUCTURES FOR PROJECTIVE SPACE	STRUCTURES FOR EUCLIDEAN SPACE
LG_1 PRIMARY ADDITION OF CLASSES	TOP_1 PARTITION OF SETS AND ADDITION OF SUB-SETS	PRO_1 ADDITION AND SUBTRACTION OF PROJECTIVE ELEMENTS	EU_1 ADDITION AND SUBTRACTION OF ELEMENTS
LG_2 SECONDARY ADDITION OF CLASSES	TOP_2 RECIPROCITY OF PROXIMITIES	PRO_2 COMPLEMENTARY PERSPECTIVE RELATIONS	EU_2 RECIPROCITY OF REFERENCES
LG_3 ONE-TO-MANY MULTIPLICATION OF CLASSES	TOP_3 ONE-TO-MANY MULTIPLICATION OF TOPOLOGICAL ELEMENTS	PRO_3 ONE-TO-MANY MULTIPLICATION OF PROJECTIVE ELEMENTS	EU_3 ONE-TO-MANY MULTIPLICATION OF EUCLIDEAN ELEMENTS
LG_4 ONE-TO-ONE MULTIPLICATION OF CLASSES	TOP_4 ONE-TO-ONE MULTIPLICATION OF TOPOLOGICAL ELEMENTS	PRO_4 ONE-TO-ONE MULTIPLICATION OF PROJECTIVE ELEMENTS	EU_4 ONE-TO-ONE MULTIPLICATION OF EUCLIDEAN ELEMENTS
LG_5 ADDITION OF ASYMETRICAL RELATIONS	TOP_5 ORDER OF PLACEMENT	PRO_5 RECTILINEAR ORDER	EU_5 PLACEMENT AND DISPLACEMENT OF OBJECTS
LG_6 ADDITION OF SYMETRICAL RELATIONS	TOP_6 SYMETRICAL INTERVAL RELATIONS	PRO_6 SYMETRICAL INTERVAL RELATIONS	EU_6 INCLUSION OF INTERVALS OR DISTANCES
LG_7 ONE-TO-MANY MULTIPLICATION OF RELATIONS	TOP_7 ONE-TO-MANY MULTIPLICATION OF TOPOLOGICAL RELATIONS	PRO_7 ONE-TO-MANY MULTIPLICATION OF PROJECTIVE RELATIONS	EU_7 ONE-TO-MANY MULTIPLICATION OF EUCLIDEAN RELATIONS
LG_8 ONE-TO-ONE MULTIPLICATION OF RELATIONS	TOP_8 ONE-TO-ONE MULTIPLICATION OF TOPOLOGICAL RELATIONS	PRO_8 ONE-TO-ONE MULTIPLICATION OF PROJECTIVE RELATIONS	EU_8 ONE-TO-ONE MULTIPLICATION OF PLACEMENT AND DISPLACEMENT RELATIONS

NUMBER GROUPS
N_1 ADDITIVE GROUP OF WHOLE NUMBERS
N_2 MULTIPLICATIVE GROUP OF WHOLE NUMBERS

MEASUREMENT GROUPS
M_1 ADDITIVE MEASUREMENT GROUP (One-Dimensional)
M_2 MULTIPLICATIVE MEASUREMENT GROUP (Two- and Three-Dimensional)

The purpose of giving a child a task--whether a direct test of conservation or some other kind of task--is to test for the existence of a particular structure. Each operational structure is composed of a set of operations: for example, each of the Logical Groupings entails the operations of closure, associativity, identity, reversibility and special identities. Establishing whether or not a child has constructed a particular structure, then, requires a knowledgeable interviewer to probe, question, pursue and evaluate various aspects of the structure in question by administering tasks appropriate to the operations involved. This type of evaluation cannot be carried out by means of a paper-and-pencil test, and Piaget spent many years of research using the individual interview to gather suitably sophisticated information about his subjects. The structures determine the form of the tasks, i.e., what objects to use and how to arrange them, what questions to ask, what areas to pursue and, most important, how to score and evaluate a child's responses. A task cannot be correctly given and evaluated unless the interviewer/researcher thoroughly understands the underlying structure the task is designed to test.

THE RESEARCH

If Table I were no more than a list of isolated entities they would be of little value in terms of educational applications, but because the structures are interrelated and develop in specific sequences, they suggest many pedagogical possibilities.

The numbering system used in Table I does not mean that all structures bearing the same number develop at the same time, and a great deal of overlap occurs among the various sets of structures as they develop. For example, the Topological Groupings provide the groundwork from which the Projective and Euclidean Groupings are built, but all of the Topological Groupings are not completed before construction is begun on the Projective and Euclidean sets. The first Topological Groupings (TOP_1 and TOP_5) occur in some children as young as four and one-half to five years of age, while the first Projective and Euclidean Groupings are typically not constructed until age six to eight years. Constructing these sets of spatial structures spans many years and involves varying degrees of developmental overlap. Data show that sizable proportions of high school and college students are not able to pass simple tasks that test for some of the final Projective and Euclidean structures.

The Logical Groupings begin to be constructed around six years of age, but completing all eight of these structures requires a number of years just as the spatial structures do. Data show that at least some high school and college students have not yet constructed LG_4 and LG_8, a discovery that is cause for concern since the Logical Groupings are the major components required for the construction of the basic structures of formal-operational thought.

Just as interrelationships exist among the various sets of structures, so specific patterns of development emerge within a given set. In the set of eight Logical Groupings, the subset dealing with classes (LG_1, LG_2, LG_3 and LG_4) develops sequentially; that is, LG_1 must precede LG_2; LG_2 must precede LG_3; etc. In like manner, the subset dealing with relations (LG_5, LG_6, LG_7 and LG_8) also develops in order, but the development of the two subsets of structures is interwoven. Data indicate that for many children (but not all) the order in which the Logical Groupings develop is LG_5, LG_1, LG_6, LG_2, LG_4 and then LG_8. (Groupings LG_3 and LG_7 are omitted due to insufficient data.)

A similar pattern of development is found within the other sets of structures; that is, each subset of 1, 2, 3 and 4 develops in sequence as does each subset of 5, 6, 7 and 8, but the two subsets are interwoven in slightly different sequences depending upon the particular set. For example, the Projective Groupings tend to develop in the order of 1, 5, 6, 2, 3, 4, 7 and 8. Again, we find order in the development of the two subsets (1, 2, 3, 4 and 5, 6, 7, 8), but they are interwoven in their own unique pattern.

Between the structures of groupings (logical and infralogical) and groups (number and measurement) shown in Table I, more sequences of development may be identified. For example, Logical Groupings 1 and 5 form the necessary basis for the development of the Additive Number Group (N_1), and Logical Groupings 4 and 8 serve the same function for the construction of the Multiplicative Number Group (N_2). Similar relationships exist between the Euclidean Groupings and the two Measurement Groups, illustrating that measurement is an activity dependent upon spatial structures and not merely an exercise in mimicry.

As mentioned earlier, Piaget's discussions of and research on the structures are scattered throughout many different publications, some of which have not been translated into English. The Logical Groupings are briefly discussed in Psychology of Intelligence (Piaget, 1963) while tasks and research results for some of these structures are reported in The Early Growth of Logic in the Child (Inhelder and Piaget, 1969). An excellent and detailed discussion of the Logical Groupings can be found in The Developmental Psychology of Jean Piaget (Flavell, 1963).

The complete set of spatial structures is presented in the final chapter of The Child's Conception of Space (Piaget and Inhelder, 1967). Tasks for some of these structures are given in this book as well as in The Child's Conception of Geometry (Piaget, Inhelder and Szeminska, 1960). This later work also contains tasks for the Measurement Groups while tasks pertaining to the Number Groups can be found in The Child's Conception of Number (Piaget, 1965). Data and protocols for various conservation tasks are found in numerous publications, but the most detailed treatment is in The Child's Construction of Quantities (Piaget and Inhelder, 1974).

In an attempt to elaborate these sets of structures and to define their interrelationships more clearly a number of studies have been originated and conducted over the past twelve years at the Science Education Center at the University of Iowa. The primary reason for citing these studies is their similar design and execution. Comparing Piagetian data among even highly similar studies is very difficult, but when the equipment, task protocols, methods of preparation, questioning techniques and scoring criteria are diverse, a meaningful comparison is impossible. Analyzing data from a series of overlapping studies in which similar tasks, scoring criteria, etc., are used allows a more precise examination of the various aspects of the system of structures.

Since one major area of interest has been the sequence of development within a given set of structures, several studies have investigated aspects of one specific set. One study examined the Logical Groupings (Camp, 1975); another the Topological Groupings (Cohen, 1978); two studies explored the Projective Groupings (Doyle, 1980; Kelsey, 1980); and two the Euclidean Groupings (Carlson, 1976; Morgan, 1979).

A second series of studies has focused on the sequence of development between sets of structures. Two investigations examined relationships between the Logical and Projective Groupings (Dettrick, 1977, 1978; Odegaard, 1975); and three other studies investigated relationships between the Projective and Euclidean Groupings (Reesink, 1976; Ott, 1978; Treagust, 1981).

A detailed analysis of all these studies and their results is beyond the scope of this paper, but a general conclusion would be that the sequences of development traced by the studies agree roughly with what Piaget found. Some points of disagreement, however, emerged; for example, Piaget states that the multiplicative structures develop along with the additive, whereas the Iowa data show a definite time lag in the development of the multiplicative structures. Piaget also maintains that the Projective and Euclidean Groupings develop in parallel fashion, but how closely parallel is not clear. The Iowa data show that the Euclidean Groupings develop after their Projective counterparts, not at the same time. Perhaps the most surprising and important discovery of the Iowa studies is that many high school and college students cannot pass tasks that test for some of the concrete-operational structures.

Research on the structures is far from complete and many questions remain unanswered: questions about unclear characteristics of certain structures, about which tasks best test for a particular structure, and about seeming ambiguities in some sub-sequences of development. In addition, subordinate sequences of development may be embedded within each major structure, an indication that will require researching before extended educational applications may be derived. Then, too, conditions of intellectual development exist for which structures have not been delineated. For example, Piaget only briefly alluded to investigative possibilities in areas such as chance, time, movement and speed. Might these areas also be formulated in terms of sets of structures?

TEACHER PREPARATION

The degree to which Piaget's structures are actually applied in the classroom is totally dependent upon the classroom teacher, the individual who serves as the all-important keystone in the bridge between theory and practice. Teachers cannot fulfill this vital role unless they have a knowledge and understanding of the structures, but just how extensive must this knowledge be? Fortunately, experience with many teachers indicates that a highly detailed knowledge of the structures' various components and complexities is not required. Teachers who know some of the basic structural characteristics, the sequences of development, and the interrelations within the system of structures can quite adequately begin to apply this knowledge in their classrooms. Obtaining this knowledge requires more time and effort than a brief workshop involves, but it does not entail years of study.

Three areas of understanding are essential to using structures in the classroom effectively: (1) characteristics of the structures; (2) tasks that test for the structures; and (3) exemplary activities for students pertaining to each structure. For example, in Logical Grouping 1 (Primary Addition of Classes), major points of understanding include: a) the basic idea of this structure concerns combining and subdividing simple classes of objects, ideas, etc., with particular emphasis upon the relative, qualitative sizes of the superordinate and subordinate classes; b) the prerequisites of this structure are the pre-classification "collections" (i.e., putting like things together) and several of the early Topological structures; and c) this structure forms the basis from which is constructed the next structure, Logical Grouping 2 (Secondary Addition of Classes), which is concerned with complementary classes and their many characteristics.

Understanding Logical Grouping 1 and where it fits in the overall scheme of things also involves a familiarity with one or more tasks that test for this structure. Learning and giving a task that tests for a particular Grouping not only helps clarify the structure itself, but also helps to identify appropriate questions and interactions with which to explore a student's grasp of the structure. Many of the techniques and questions used in Piagetian tasks can be employed directly with individual students in the classroom.

For example, suppose a young student is arranging a set of toy animals into groups. A knowledgeable teacher can interact with that student by asking, "Can you make more (or fewer) groups from each of these groups? If we took all the animals away, would there be any cows left? If we took all the cows away, would there be any animals left? Are there more cows, or more animals?" These questions are similar to those used in tasks to test the child's grasp of pre-classification collections and class inclusion (Logical Grouping 1).

By interacting individually with students engaged in activities directly and clearly related to a particular structure, a sensitive teacher can observe the wide range of developmental levels among students. The diversity of interpretations, strategies and patterns of thinking found within a single classroom provides a strong argument for teaching different students different things at different times.

The path to constructing a particular structure may well be unique for each individual; therein lies the importance of using different activities pertaining to the same structure. For example, activities related to Logical Grouping 1 would be composed of many different sets of objects for the students to sort, arrange and group in various ways. In addition, the students should be encouraged to make up their own criteria for arranging the objects since teacher-dictated criteria permit little more than following directions. Through determining various criteria in an assortment of activities, the classification structures are applied to a wide range of objects and therefore become generalized.

All three areas of teacher preparation are integral to one another, for a knowledge of the structures and tasks illuminates the variety and range of application. Interrelating activities, extending activities, and developing new activities cannot be effectively achieved without understanding the structures. Using activities without a basis guarantees a superficial application and ultimately, an unjustified foreclosure on applying structures to the classroom.

IN THE CLASSROOM

Once the classroom teacher is properly prepared, all kinds of applications are possible. Applications within a single structure (as described above with Logical Grouping 1) are elaborated by applications within sets of structures. A teacher aware of the sequentially developed subset of Logical Groupings 5, 6, 7 and 8 can select appropriate activities for a student based upon the student's level within the sequence.

For instance, Logical Grouping 5 deals with additive, asymmetric (ordered) relationships. Appropriate activities would involve many different sets of objects with each set capable of being ordered by means of one characteristic such as length, thickness, texture, weight, volume, color, and so on. A student who can order many different sets and insert additional objects correctly into an existing ordered array has likely developed Logical Grouping 5. Following this, the student should have access to activities related to Logical Grouping 6 which concerns additive symmetric relations. Activities for this structure include balancing, making mobiles, and other procedures that deal with symmetries. When a student completes various activities pertaining to Logical Groupings 5 and 6, then activities for Logical Grouping 7 should be made available. This structure requires multiplicative combinations of relations (i.e., considering two or more relationships at once) and is actually a combination of Logical Groupings 5 and 6. Making up classification hierarchies is an activity that requires the use of Logical Grouping 7, so many different sets of objects (from simple to complex) could be made available for the student to use in constructing such hierarchies. Finally, Logical Grouping 8 deals with multiplicative asymmetric relations. These relations are not triangular arrays like the hierarchies above, but are ordered relationships along two or more dimensions. An example requiring the use of this structure is a matrix constructed of a set of sticks whose length decreases (or increases) along one axis and whose diameter decreases (or increases) along the other.

Knowing the order in which the structures develop allows a teacher to prepare and present appropriate activities based upon a developmental sequence, a method of application that can be used to achieve long-range objectives rather than on a day-by-day basis. The construction of structures takes time and no two individuals are likely to proceed at the same rate, so the idea of lesson plans (e.g., Monday, LG_5; Tuesday, LG_6; Wednesday . . .) cannot be appropriately applied to instruction based on Piaget's theories.

Another important way a knowledge of structures may be applied is in evaluating curricula, programs and textbooks. Each content area presented in a particular textbook or on a course syllabus could be examined in terms of what structures are needed to comprehend the topic. Of course, if the primary goals of teaching a particular topic are no more than to invite mimicry and enforce memorization, then the question of structures need not be raised. But if a teacher wants students to deal with a topic at a deeper level, a consideration of the structures required is warranted.

A knowledge of just the structures listed in Table I leads to a host of questions concerning the appropriateness of certain content at particular grade levels. For example, topics such as the solar system or the phases of the moon are commonly found in elementary school science textbooks, yet a grasp of why the moon has phases or how the solar system works requires the use of some of the more advanced Projective Groupings not often found in many elementary school children. Map reading is another topic commonly encountered in elementary school; this requires structures from the Projective and Euclidean Groupings and may also require the formal-operational structure of proportionality if scaling is included.

Structures can be related to a wide range of activities. The act of constructing a data table, for example, requires the use of Logical Grouping 4, while Euclidean and Logical Groupings 8 are brought into play when constructing a graph. Even young children's difficulty in learning to tie their shoes is not primarily due to a lack of dexterity, but rather to a lack of structures from certain Topological Groupings.

If structures are valuable and applicable in classrooms, how can a teacher provide opportunities for students to construct these structures? Here, too, much more research remains to be done, but at least some classroom procedures appear to be consistent with what is known about the structures and their development. A classroom geared to structure building might be characterized by the following: 1) students would be allowed to select from and engage in a wide assortment of activities with objects; 2) students would be allowed to begin these activities at their own levels, move through them at their own paces, and pursue the activities to the extent of their individual capabilities; and 3) the activities would primarily encourage the derivation and exploration of relationships rather than eliciting mere memorization and mimicry.

The teacher's role in such a classroom becomes far more important and at the same time much different from other classroom arrangements; gone are the demonstrations, class discussions, lectures, and teacher as "source of all knowledge." The teacher instead interacts with individuals through encouraging, questioning, suggesting, offering alternatives, challenging conclusions and assessing progress. This shift in role may at times seem impossible to effect, but the hard work it requires has been found to pay off in rewards for teachers and students alike.

The use of structures as a basis for classroom practice removes much of the guesswork from decisions about what to teach, to whom and when. Viewing intelligence as a system of interrelated structures instead of the capacity to acquire skills or memorize pieces of information permits a unique and powerful approach to the teaching/learning process.

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THE DEVELOPMENT OF AN ATTENTIVE PUBLIC FOR SCIENCE: IMPLICATIONS FOR SCIENCE TEACHING

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Science education literature indicates that the main reasons for school science are (1) to provide background for citizenship, (2) to provide background for those entering occupations or careers oriented toward science and technology, and (3) to contribute to the preparation of scholars. Science teaching in elementary and secondary schools should emphasize citizenship education. Schools, the province of all citizens, can best serve future scholars and science-related career aspirants in an educational atmosphere where scientific literacy for all citizens is given top priority.

In a society increasingly oriented toward science and technology, scientific literacy and citizenship should include awareness and understanding of public policy issues surrounding science, technology and society. Such understanding is necessary to enhance the general societal welfare and to meet the daily personal needs of citizens. One desirable outcome of education for scientific literacy is a citizen favorably disposed toward science and technology with the attitudes, knowledge, and skills to influence public policy directly or indirectly. The K-12 curriculum should reflect this view of citizenship and instruction should contribute to that goal.

Within this frame of reference a science educator, a political scientist, and a sociologist initiated a national study entitled the Scientific Literacy of the Attentive Public for Organized Science (Miller, et al., 1980).* This team desired to determine whether students are developing attitudes leading to reasoned public policy decisions. They wanted to know whether science education was promoting a public with the interest, knowledge, and information acquisition skills required to participate in societal problem-solving and decision-making.

CONCEPTUAL BASE OF THE STUDY

Writings in science education are replete with statements about interests, attitudes, knowledge, and skills. Materials have been developed and research conducted to facilitate each objective. But research on the simultaneous attainment of several objectives has been limited, as has research dealing with public policy decisions. In this study some major steps were taken in examining the attainment of these science education goals.

School science programs often attempt to provide students with the tools to function in their immediate environment. Equally important is an attempt to provide the tools for students to function ultimately as adult citizens. For these reasons science education should be conducted to develop in students a progression of successive approximations to adulthood. Science educators should identify components necessary for persons to function as productive citizens and study the progress toward that end made by students of various characteristics.

A model was sought that would merge the goals of school science with the concern for citizen participation in public policy making. Such a model was found in Almond's

*Miller, J.D.; Suchner, R.W.; and Voelker, A.M. Citizenship in an Age of Science Changing Attitudes Among Young Adults. New York: Pergamon Press, 1980.

conceptualization of four publics for a given policy or issue area (Almond, 1980).* The "mass public" is composed of those persons not able or willing to devote the time or resources to become and remain informed in the respective issue area. Those persons willing and able to inform themselves in an issue area comprise an "attentive public" for that area. There can be attentive publics for many specialized interests such as science and technology or foreign policy. From the attentive publics come the "elites," those with higher levels of knowledge and substantive outlook; and the "decision-makers," the leaders of the executive and legislative branches of the federal government, and perhaps the leaders of selected multinational corporations. This study was concerned with the development and characteristics of an attentive public for science and technology in high school and college students.

To be attentive to science and technology requires that a person express interest in the area, possess knowledge about the area, and regularly pursue information sources to maintain both interest and knowledge in the area.

Several major implications for science education evolve from this discussion. First, citizenship education has to be a planned and priority dimension of the science program. Science related elements of citizenship education must be initiated early in the elementary school and continued throughout the K-12 program. Science-related concerns such as environment, health, and energy are logical points of entry and provide an appropriate fusion with the social studies curriculum. Second, program content must be derived from a curriculum model that has as a focal point an awareness and understanding of real problems and issues of citizens. Students must be engaged in dealing with public policy issues. And third, a responsible curriculum must simultaneously promote interest in issues, awareness and knowledge of issues, and the desire and skill to pursue information about issues.

STUDENTS INVOLVED IN THE STUDY

The students involved in this 1978 study were approximately 3000 high school students in grades 10-12 and 1000 college students in four-year colleges and universities. High school students came from urban, suburban, and rural communities in 16 different states from all regions of the country. Seventeen school districts and 34 high schools participated. College students came from 38 four-year colleges/universities, about equally divided between those that did and those that did not offer graduate degrees.

IMPLICATIONS ABOUT INTEREST IN SCIENCE AND TECHNOLOGY ISSUES

The way interest was measured in this study carries another implication for science education. Historically, interest has been measured by asking students whether they are interested in astronomy, plants, or laboratory work, assuming that such interests transfer to interest in applications of science in society. Further, students' interests are usually inferred from responses to single topics. This study measured interest in terms of the kinds of science and technology issues confronting a citizen.

Students were asked directly whether they were interested in science and technology issues. However, some students' interests are so specific that they may not associate specialized interests with the broader area. Therefore, students were also asked about their interest in specific public policy issues in science and technology.

*Almond, G.A. The American People and Foreign Policy. New York: Harcourt, Brace, and Company, 1980.

Logically, interest in public policy issues should be measured in terms of citizen behavior. Citizens can pursue their interests by consulting public media, so students were asked about their likelihood of reading newspaper articles with headlines associated with energy, ecology, basic scientific research, space exploration, weapons development, and biomedical research issues. Since there are so many specialized areas that it is impossible to follow them all, and since a student concerned about weapons development, for instance, may feel only modest interest in broader issues, it is critical to use multiple measures of interest and it is equally important to broaden the conceptualization of interest in science to include public policy issues.

About 70 percent of the non-college-bound and 80 percent of the college-bound high school students were somewhat interested or very interested in science and technology issues. And twice as many college-bound as non-college-bound students indicated that they were very interested. But there was no growth in interest across the high school or the college years.

These results suggest several things for the K-12 curriculum. Apparently the K-9 program is having some impact on interest development. Since a majority of prominent societal issues are somehow associated with science and technology, however, it would be desirable to produce a greater percentage of high school students who are very interested in science and technology issues. A broader implication is that the total school program does not sufficiently consider public policy issues in the context of citizenship education.

If, however, the percentage of interested high school sophomores is considered adequate given their limited opportunities for real citizen participation to date, the indictment is on the high school. After entering high school, non-college-bound students usually do not take more science courses, but the college-bound students do. Yet students in the upper grades do not exhibit any more interest than they did when they entered high school. Science and the total school program are still inadequately promoting interest in science-related citizenship issues. Interests appear to develop because of general educational and career aspirations, not because of what is happening in school generally or in school science in particular.

Especially disturbing is the much lower percentage of interested students among the non-college-bound students, half our future citizens. They are getting less from both the elementary and secondary science programs than the other students.

For this study, students' general expression of interest was combined with their interest in special issues such as energy. Thus both those who are somewhat interested in general issues but who would probably or definitely read articles dealing with several specific topics and those who are very interested but who follow a narrow line of specific topics are able to be considered highly interested in science and technology issues.

Using the above criteria, more college students qualify as interested in science issues (60 percent) than college-bound high school students (47 percent) or non-college-bound high school students (30 percent). A similar pattern was observed for interest in technology issues but in greater proportions. Slightly more than 40 percent of the non-college-bound and over 60 percent of the college-bound students were interested in technology issues. Interest in science issues and interest in technology issues are strongly related, but a higher percentage (80 percent) of those interested in science were interested in technology than the reverse. About two-thirds of those interested in technology were also interested in science.

What, then, might be done to promote interest in science and technology issues in the K-12 science curriculum? First, citizenship education must be made a top priority and teachers should view themselves as both science educators and social science educators. Second, real societal issues--those that all segments of society face--must be brought into the curriculum. Third, much of the archaic "academic preparation" must give way to issue awareness and issue knowledge for all students. And fourth, a program that develops interest in science issues appears to promote interest in technology issues better than the reverse.

IMPLICATIONS ABOUT KNOWLEDGE OF SCIENCE CONCEPTS AND SCIENCE/TECHNOLOGY ISSUES

An important outgrowth of the development of interest in issues is that it should lead to knowledge of science concepts at the base of public policy issues facing society. Even more important, interest should lead to awareness and knowledge of the variety of arguments surrounding an issue. Schools should be developing both kinds of knowledge. The study measured students' acquisition of both types of knowledge because the typical knowledge measurement gives insufficient consideration to knowledge associated with personal and societal problems.

The science concepts measured were: molecule, organic chemical, amoeba, and DNA--concepts at the core of the physical and biological sciences and a multitude of science-related public policy issues. Development of these concepts also parallels knowledge growth associated with enrollment in advanced and diversified science courses and with a growing interest in citizenship responsibility. As an indicator of knowledge of public policy issues, students were asked to identify arguments for and against building additional nuclear power plants. Such issues are consistently in the public arena.

About 40 percent of the students knew what an amoeba and DNA were but only one-fourth of the students knew what a molecule was. Slightly less than 20 percent knew what an organic chemical was. It is not surprising that an organic chemical would be less well known than the other concepts, but given the degree of emphasis on molecules at all curricular levels, it is disturbing that so few students knew what a molecule was. Even allowing for loss in retained knowledge, the percentage of students who correctly answered questions about molecules is low. The suggestion is that these concepts are inadequately developed or that they are not developed in a context that encourages students to remember them--e.g., a context connecting science and society.

Students' knowledge of controversies about nuclear power plants exhibited a similar pattern. About half of the students could give one argument for building additional nuclear power plants and nearly 60 percent could give one argument against building more plants. Only one-fourth of the students could give a second argument of either view.

Further, only 26 to 32 percent of the non-college-bound high school students knew one or more of the science concepts and no one in this group knew all four concepts. Most of the non-college-bound could identify correctly only one concept. The situation for college-bound students was somewhat better. Only 40 percent of these students were unable to identify correctly a single science concept. Particularly alarming, however, is the negligible impact of interest in science upon knowledge of science concepts. Neither science courses, issues courses, or non-school experiences appears to improve this cognitive knowledge. What has happened seems to have occurred before senior high school and students in higher grades do not exhibit additional knowledge.

The situation is better for public policy issues. All groups surveyed had a higher proportion of students aware of nuclear power issues than knowledgeable about basic science concepts. A major disappointment is that a third of the college-bound and almost 60 percent of the non-college-bound students could not list one argument for or against the construction of nuclear power plants. Again, there was no additional knowledge among the students in the higher grades.

Approximately one-fourth of the non-college-bound and three-fourths of the college-bound students could cite two or more arguments about the public policy issues surrounding nuclear power. These students were considered to have a high degree of knowledge about technology issues. About 70 percent of the non-college-bound and 40 percent of the college-bound students were low on both cognitive knowledge and issue knowledge. Just over 20 percent of the non-college-bound students were knowledgeable about technology but less than five percent of this group was knowledgeable about science concepts or science and technology simultaneously. For college-bound students the situation was improved. Increases occurred in all categories but especially in knowledge of both science and technology, an increase from less than five percent for the non-college-bound to about 25 percent for the college-bound. Unfortunately, the no-growth-across-years phenomenon continued to persist. In fact, it appears that the level of information about science and technology issues actually declines with additional exposure to the high school curriculum.

Results of this part of the analysis suggest that the high school curriculum--science and/or other areas--is not contributing to the acquisition or the retention of cognitive knowledge or issue knowledge associated with the interrelationships between science and society. The situation is especially bad in the courses and curricula being pursued by the non-college-bound students.

IMPLICATIONS ABOUT INFORMATION ACQUISITION

To be an effective citizen an individual must pursue information to aid retention of existing knowledge and to acquire new knowledge. One way to pursue information is to enroll in pertinent courses. Other excellent sources of information are the various forms of public media. Students were asked what media--newspapers, magazines, TV, etc.--they consulted regularly and what they followed when using the various sources. Students also indicated which medium was their most important source of information. Taking time and resources to follow an area of interest is necessary to sustaining and developing both interest and knowledge.

Only five percent of the students indicated that they did not read a newspaper at all while slightly over 40 percent of the students indicated that they read a newspaper at least five times per week. As with interest and knowledge, the percentage of high school students reading newspapers was greater among the college-bound students than among the non-college-bound. But there was modest, steady growth in newspaper readership across the years.

Another positive result was that students who read newspapers five or more times per week tended to read the local, state, and national news. But as reading frequency decreased so did the emphasis on national news. College students were more likely to read the editorial section. Students reading a newspaper five to six times a week and who read the national news section were considered to be high-level newspaper readers. This measure of newspaper readership shows a gradual growth pattern across the years for all groups but readership among the non-college-bound is much less than among the college-bound.

A second major source of public affairs information is a magazine that includes information about science issues. Students were asked to list six magazines that they read regularly and three magazines that they read occasionally.

The non-college-bound students reported the lowest readership of news magazines. However, the overall readership of news magazines was not as broad as for newspapers. About 70 percent of the non-college-bound and 60 percent of the college-bound high school students reported no reading of news magazines. The situation is even worse for magazines oriented toward science and technology. Nearly 90 percent of the non-college-bound students and 70-80 percent of the college-bound high school students do not read regularly or even occasionally one science or technology magazine. College-bound high school students are similar to college students in what they read and how frequently they read news and science magazines.

High school students are more regular viewers of TV news than college students. Slightly more than half the non-college-bound and the college-bound students indicate that television is their most important news source. One inference from these findings is that the school and school science programs are not encouraging students to develop habits of using science information sources other than textbooks. Nor are they coordinating non-school science education opportunities with the formal school program.

INFORMATION SOURCES THE STUDENTS TRUST

When considering students' outlooks on public policy issues it is important to take into account the degree of credibility given to various media and people information sources. Students were asked how much they would "trust" each of 13 people or media sources to give accurate and truthful information about science policy issues. Students were very selective in whom they would trust.

Both high school groups gave the highest credibility rating to "A Congressional Committee on Science and Technology." But only 15 percent of all the students reported high trust in the President. The second highest level of confidence was assigned to a university professor, the reponse for 36 percent of the non-college-bound students compared to a majority of the college-bound and college students. And the third most trusted source was the Environmental Protection Agency which was trusted by a majority of the college-bound students.

About a third of the students placed a high level of confidence in news magazines and television news as information sources. These results suggest that trust is placed in the statements or actions of the persons and organizations reported by the media rather than in the media reporting on them.

Few students assigned a high level of trust to parents, other students, or the United Nations. And few high school students place a high level of trust in their teachers for information about science policy issues. This goes along with a general lack of confidence in experts or opinion leaders; e.g., even the most trusted source, the Congressional Committee, was trusted by only half of the respondents. The results of the study also show that students do not necessarily depend on the information sources they trust the most.

These results were used to identify "information acquirers," students who are regular readers and who pay attention to national news, those who read one or more news magazines, and those who read one or more science news magazines. Students were considered highly acquisitive of information if they met at least two of these criteria.

Only 26 percent of the students met the criteria. But unlike the "no-growth" results displayed in the earlier discussions, the percentage of students meeting the criteria increased with the year in school. As before, however, college-bound high school students in all grades are more likely to meet the criteria than their non-college-bound peers.

HOW MANY ATTENTIVES EXIST?

Previously described were students' interests, knowledge, and information acquisition patterns. Each is an attribute of a member of the attentive public for science and technology issues. But how many students possess all three of these characteristics; i.e., how many are attentive to science?

Only 11 percent of the students surveyed may be considered attentive to science issues. Another 14 percent of the students scored high on interest and information but did not meet the criterion for information acquisition, and 16 percent met the interest criterion but neither of the other two criteria. It is possible that such students might become attentive. A small percentage of students possessed knowledge and pursued information but lacked interest in science, and 10 percent scored high on information but did not meet either the interest or the acquisition criteria.

The situation was slightly better for attentiveness to technology issues: 15 percent of the students met the three criteria in this area. The percentages of students meeting some of the criteria were similar to the percentages for science issues but were somewhat higher. Slightly more than 20 percent of the students scored high on technology interest and knowledge but were low on information acquisition. And another 16 percent scored high on technology interest but were low on knowledge and information acquisition.

In the areas of both science and technology issues, there are many students who might become attentive, particularly if they were encouraged to seek out information on these subjects regularly. Less than 10 percent of the students were attentive to both science issues and technology issues. And of those who were attentive to one area, more students (6 percent) were attentive to technology than were attentive to science (2 percent). Thus, most of those attentive to science issues are also attentive to technology issues but the reverse relationship is not as strong.

Because the differences between science and technology are not clearly delineated to most students, these two measures were combined to form a group known as those "attentive to organized science." This combined group is the focus of the remaining discussion.

WHO IS ATTENTIVE TO ORGANIZED SCIENCE?

When the interest, knowledge, and acquisition criteria were combined, 17 percent of all students were considered to be attentive to organized science. This demonstrates that science and technology issues have low priority for most high school and college students. Who, then, are the students who are becoming attentive?

Hardly any of the non-college-bound students were attentive to science issues. But about nine percent of the college-bound students were attentive to science issues. Unfortunately, no growth occurred in the percentage of those attentive to science in either high school group from the sophomore to the senior year. But there was a weak development of attentiveness to technology issues. In the non-college-bound group, this attentiveness increased from three percent of the sophomores to seven percent of the seniors. Sixteen percent of the college-bound students were attentive to technology--about double the proportion of attentive non-college-bound students--but there was no increase across the high school years.

When the two issues were combined the percent attentive to organized science among college-bound students decreased from the sophomore to the senior year while it increased across years for the non-college-bound students. Presence in school and participation in additional science courses seems not to promote attentiveness of any type among the college-bound students. However, continuing and increasing exposure to high school science courses may have the effect of stimulating an interest in science issues among those already interested in technology issues.

Clearly there are notable differences between the non-college-bound and the college-bound high school students in terms of their attentiveness to science issues, technology issues, or both.

DIFFERING VIEWS OF ATTENTIVES AND NON-ATTENTIVES

A major concern of K-12 science programs is student participation in science/society interactions. In this section an examination is made of differences between those who are attentive ("attentives") and those who are not ("non-attentives") in relation to general orientations to science and technology issues, specific policy questions, and federal spending priorities.

The study included eight attitude items about science and technology, four dealing with potential benefits and four dealing with potential risks. Approximately 75 percent of the students agreed that science is making our lives healthier, easier, and more comfortable. Attentives were more likely to agree than non-attentives. Students also strongly agreed that scientific invention is largely responsible for our standard of living. In both high school groups attentives were more likely to agree than non-attentives. Most of the disagreement about the impact of invention on the standard of living was voiced by the non-college-bound high school students. "Spending federal funds on science research" received less support than the other three items concerning science benefits. But again, more attentives than non-attentives felt that spending money on science research was a good investment. Attentives were also more likely to agree that the benefits of science have outweighed the risks. Nearly all the respondents held a generally positive and expectant view of science and technology. Attentives were more positive than non-attentives but there did not appear to be any developmental pattern across years.

The first item dealing with the risks of science and technology asked whether "science" makes our lives change too fast. Over 60 percent of the attentives but less than half of the non-attentives disagreed with this statement. In the case of whether the growth of science "means that a few people could control our lives" there was no clear difference between attentives and non-attentives in their agreement or disagreement. However, fewer uncertain responses occurred among the non-attentives.

Students were also asked about the impact of science on breaking down "people's ideas of right or wrong." In the non-college-bound high school group, attentives and non-attentives were very similar in their responses. Both groups were slightly more likely to agree than disagree. However, a clear majority of college-bound students disagreed with the statement and a plurality of the non-attentives disagreed with it. Concern about science as a source of moral erosion was strongest among the non-college-bound who have had the least exposure to science instruction and whose exposure to science will be much less than their exposure to technology during their lifetimes. The fourth item concerning science risks stated that "we depend too much on science and not enough on faith." The non-college-bound attentives were slightly more likely to disagree with the statement and the non-attentives were slightly more likely to agree. In the college-bound group, a majority of both attentives and non-attentives rejected the statement but significantly more attentives were opposed to the statement than were non-attentives.

When the responses to the four items concerning science risks were considered together there were no significant differences between the attentives and non-attentives in either high school group. And the highest level of concern about risk was expressed by the non-college-bound high school students.

How, then, did the students balance benefit and risk as they would need to do in making public policy decisions? Students who consider benefits to outweigh risks can be called "advocates" and those who feel the opposite way can be called "doubters." "Balancers" are those who express concern about risk while granting the benefits derived, and "neutrals" consider science and technology neither beneficial nor risky. Attentives are most likely to be advocates and the tendency to advocate science and technology is strongest among college students. The non-attentive non-college-bound high school students are about equally split among the four types.

Generally speaking, then, students were positive toward science and technology. Yet a significant portion of them expressed moderate to high concern about the potential risks. In almost every student group the attentives were more positive toward science and technology and more willing to take risks in pursuit of potential benefits.

In addition to asking the students about their general views regarding science and technology, they were asked about their viewpoints on some specific policy issues related to science and technology. These areas dealt with energy, international competition, regulatory issues, and outer space.

Approximately 80 percent of the students had some reservation about the safety of nuclear power and there were no significant differences between attentives and non-attentives. Overall, about 30 percent of the students agreed that "the risk involved in generating nuclear power is relatively minor and should not block the construction of new nuclear power plants." Of the three student groups, the non-college-bound students were most likely to agree with the statement, and within each group, attentives were significantly more likely to agree with the statement than non-attentives.

A majority of the students agreed that "solar energy is the best single long-term solution to our energy problem." But the attentives were no more likely to support the idea than the non-attentives. High school students were more likely to agree with the statement than college students. Even though there were some doubts about nuclear <u>and</u> solar energy sources, there was a high level of agreement with the contention that science and technology can be depended upon to find a long-term solution to the current energy difficulties. The non-attentives in the non-college-bound group were, however, the least likely to agree with this proposition.

The relative willingness of the attentive groups to support more nuclear power facilities illustrates their greater willingness to take a calculated risk, and their higher level of expectation for a long-term solution from science and technology reflects the more general expectation of benefits discussed earlier. An item concerning international competition dealt with "developing weapons at least as fast as the Russians." Attentives were more likely to agree with this statement than non-attentives in all groups, but the students were more conservative in this regard than they had been in regard to the nuclear power situation. A second item was concerned with whether the United States "has lost its lead in science research to the Soviet Union and other nations." Response to the item indicates that this trend is not perceived to be as threatening as it was in the post-Sputnik era, and that a sense of inferiority is not the motivation for whatever competitive spirit the students exhibit. There was no significant difference between attentives and non-attentives in their agreement with the statement but college students were less likely to agree than either of the high school groups.

Another item concerned the value of the space program to the country. College students were less likely to be critical of the space program than high school students. All groups indicated strong support for the regulation of chemical companies, an endorsement of the rights of the public, but there were no patterns distinguishing attentives from non-attentives. However, there were differences between attentives and non-attentives on their assessment of spending priorities for various scientific and technological research efforts. Attentives were significantly more likely to support energy research, weapons development, and space exploration and they were significantly less likely to support research to reduce crime, improve automotive safety, or cure drug addiction.

Thus, being a member of the attentive public does make a difference in both general and specific policy perspectives. And because the views of the attentives are more likely to become part of the policy formation process, it is important to know who becomes a member of the attentive public for organized science.

WHO BECOMES ATTENTIVE?

The students in this study were high school and college students. Thus, they were likely to be influenced by their families, their schools, and their peers. Student personalities could also be major factors in determining whether they become members of the public attentive to science and technology issues.

Family-Related Influences

The family variables considered were socioeconomic status, educational aspirations, occupational aspirations, sex-role socialization, religious belief and participation, and family politicization. Families provide a social status; they can lead by example, by subscribing to media and by monitoring television viewing; and they can directly impart interests and skills.

A social status variable was created by combining measures of both parental education and parental occupation. Parental education as a measure of social status was found to be more strongly related to attentiveness than parental occupation. The family can also influence the level of a student's educational aspirations by providing educational opportunities and encouragement. When students' educational aspirations were considered along with current position in school and family social status, 39 percent of the college students from higher status families who aspire to graduate or professional school were attentive to science compared to four percent attentive among high school students from lower status families who do not expect to complete a bachelor's degree.

Families also tend to transmit values about various occupational aspirations. High school students who have decided on an occupation are about five percent more likely to be attentive than those who are "undecided" about an occupational choice. The prestige of the occupation chosen by high school students does not seem to relate to their attentiveness.

Young women were less likely to be attentive to organized science than young men of comparable background, regardless of their family social class, the education they have or aspire to, or their occupational aspirations. Even though their effects are differential, these factors do aid the development of attentiveness in young women. And gender is second only to educational status and plans as a factor influencing the development of attentiveness.

Religious beliefs and practices are also influenced by the family. Different aspects of religious belief were incompatible with attentiveness to science for different people, but no single belief necessarily reduced the likelihood that one would become attentive. Responses to several items concerning religion were combined to form a measure of General Religious Belief. Fourteen percent of those considered relatively religious were attentive to science compared to 23 percent attentive among those considered less religious. But there is no evidence to support the idea that the association between religious belief and attentiveness to science depends on the kind of religious services one is exposed to or the frequency of one's attendance. And a student's religious beliefs have little to do with attentiveness to science once social status, educational status, and educational and occupational aspirations are considered.

Discussions among family members can do a great deal to influence attentiveness especially in terms of direct transmission of interest and information. Students were asked how frequently public issues associated with science and technology, foreign policy, economic policy, and civil rights were discussed within the family in the past year. Slightly more than 40 percent of the students were considered to have highly politicized families, meaning that two or more of the above issues had been discussed three or more times. Comparing students with high and low levels of family politicization showed an average 16 percent difference in the proportion attentive, a difference which did not vary significantly among students from different family backgrounds or with different educational or occupational aspirations. Family politicization has a large direct effect on the likelihood a student will become attentive to science during high school or college.

The "family variables" that had the major influence on the development of attentiveness were educational aspirations, gender, and discussions of public issues in the home. Thus, to summarize the conclusions from the family-related data base, college-bound males with high educational aspirations and who are exposed to high levels of family politicization are more likely to be attentive to organized science than any other group.

School-Related Influences

Students are exposed to many formal and informal school experiences that could aid the development of attentiveness to organized science. Such exposures include the formal science curriculum and other school activities associated with technological development and public policy issues. School-related variables considered in this study dealt with academic achievement, amount of exposure to science instruction including the number of courses and the breadth of areas studied, discussion of social issues in classes, out-of-class discussions with peers, and decisions about life goals and future plans. One notable finding was that the brightest students are not the only ones taking science courses. Apparently students are taking more science because of college or career plans or because more attractive course offerings are now available.

Academic achievement was not a good predictor of attentiveness. It was strongly associated with the knowledge component but not with interest. Thus, how well students are doing in school does not add much to attentiveness beyond the earlier discussed family effects. This result is not wholly unexpected but it is of some concern that academics are not more connected with the development of interest and pursuit of information from various sources.

Those students having had some study in either biology, chemistry, or physics were no more likely to be attentive than those students with no study in any of these separate areas. However, the number of these disciplines studied did make a difference in the percent attentive. And several noteworthy relationships to educational plans and educational status emerged. For non-college-bound students, diversity of science study contributes to a higher level of science knowledge but does not aid in the development of interest or information acquisition. For college-bound students, the broad exposure to science courses is associated with higher interest, knowledge, information and attentiveness. Unfortunately, however, exposure to courses adds little to the development of attentiveness beyond the level associated with the family base. The traditional school role of transmitting knowledge is reaffirmed by these results regardless whether the target of inquiry is the college-bound or non-college-bound student.

Even so, the brighter students are not automatically interested in or curious about science and technology issues. And neither academic achievement nor breadth of science studies is associated with a high level of information acquisition. The school science program does not appear to promote much other than cognitive knowledge.

Much science course content is devoted to process skills and cognitive knowledge. But there are some opportunities for students to apply knowledge both in and out of classes. Such opportunities include becoming politicized, discussing science-related issues in classes, and engaging in out-of-class discussions with peers.

Students were grouped as to whether they were high or low in their involvement in classroom discussions of science and technology issues. Unfortunately, classroom discussions added very little to the development of attentiveness beyond that attributable to family influences. But peer discussions outside the classroom had a significant impact on attentiveness, above and beyond the effects of the family. There was also a significant relationship between peer discussion and family discussion. When family discussion was high the level of peer discussion made little difference in the level of attentiveness. But when there was no family discussion, peer discussion became very influential.

Young adult life goals and occupational preferences evolve during the school years and might be expected to have some influence on the development of attentiveness or its components. The highest percentages of those considered attentive were found among those aspiring to be scientific researchers (44 percent), physicians (35 percent), and engineers (30 percent). And students intending to pursue public service careers were more likely to be attentive than students seeking other occupations.

Career interest was measured by expressed concerns for becoming accomplished in the career or becoming an authority in the career field. A high career interest makes only a minimal contribution to the development of attentiveness. But the student's occupational preference does make a sizeable contribution to the development of attentiveness. Students who aspire to scientific and public service occupations are more likely to be attentive than students pursuing other occupations. Personal and professional interests are highly influential in developing attentiveness.

Class and peer interactions that occur in school seem to have little effect on patterns already established when the student enters high school. And the school does not moderate the strong gender differences established before high school. School is third in relation to family and peers as a source of influence in promoting attentiveness to science and technology issues.

Personality Influences

In addition to family and school influences, the type of person one is, or is becoming, can influence the development of attentiveness. Those students who are more self-confident--e.g., those who find it easy to speak in front of a group--are more apt to be attentive as are those who perceive themselves to be popular and consider themselves opinion leaders. Attentiveness does not appear to be connected with the unpopular, "egghead" syndrome.

Although it might be reasonable to infer greater attentiveness among students who feel their efforts can influence policy decisions, this was not the case.

Factors associated with open- and closed-mindedness might influence attentiveness. To deal with public issues one must be open-minded. Open-mindedness requires a willingness to listen to and to consider other people's ideas and the capacity to entertain a variety of approaches to problems without settling on a single solution prematurely. It also necessitates the use of objective criteria to judge the value and validity of new ideas. These three conditions correspond to the concepts of estrangement, ethnocentrism, and single-mindedness, which are not separate and distinct categories.

Because the knowledge and information components of attentiveness depend so much on people, trust and faith in people and in what they say and write could have a major influence on the development of attentiveness. Students who do not have faith in others or who have not made up their minds about trusting others are less likely to be attentive than those who do trust others. Attentiveness apparently involves making a commitment to listen to others and then to make up one's own mind. It does not involve trusting everything one hears or reads.

Four personality factors--estrangement, trust, efficacy (the ability to influence decisions), and self-esteem--are associated with attentiveness. Only 11 percent of the students devoid of all these characteristics are attentive to science compared to 26 percent attentive among those who possess all four of the traits.

General Political Interest

Since the issues of organized science in a society oriented toward science and technology are tied closely to many other prevalent public issues, it is possible that a perceived attentiveness to organized science is merely a measure of general political interest. Therefore, general political interest was analyzed in relation to the general family, school, and personality models (variables) that had been found to predict attentiveness. But these models were not good predictors of general political interest.

Certainly general political interest and attentiveness to organized science are related. Conceptual differences between the two, however, suggest that they be treated separately, and analysis of results from the political interest survey supports its separate consideration.

THE BEST PREDICTORS OF ATTENTIVENESS

From the many family, school, and personality variables considered, five are strongly associated with attentiveness to organized science. These are the student's occupational preference, educational plans, politicization, gender, and self-esteem. The many other variables were left out of the final predictive model because their influence either was weak by comparison, had its effect primarily through other variables, or faded away when the effects of occupational and educational plans were held constant. These variables in order of their relative strength in predicting attentiveness were: planning to go to college (or being in college), politicization, gender, occupational preference, and self-esteem. Unfortunately, the school plays a part in the picture only through the "extra curriculum"--i.e., what goes on out-of-class.

Additional points of interest are these. Young women are less likely to discuss political topics with peers than are young men. And young women are significantly more likely to discuss political subjects with neither family nor peers than are young men. Young men and young women do not differ in self-esteem and young men and young women are equally as likely to aspire to science or public service careers. Apparently young women do not view politics as either an appropriate or an interesting subject for discussion, especially among their peers.

BROAD IMPLICATIONS

Many implications about attentives have been articulated throughout the discussion of the study's findings. There are, however, some other points to be made.

The percentage of high school students who are becoming attentive to organized science is low, especially among the non-college-bound. What might be done to remedy this situation? One implication is the need for a change in our thinking about the thrust of the school science program. Existing curricula are still based on a model that emphasizes science for elites and conceives that the way to improve science education involves devising ways to impart cognitive knowledge better. Even recently developed curricula such as in the area of energy education are heavily oriented toward cognitive knowledge. What is needed is a recognition that most knowledge has meaning for citizens only in the context of personal living. Concern for public policy issues is not likely to evolve from a science curriculum that treats societal concerns as problems to be solved by someone else. Nor is concern likely to evolve when issues are not regularly included in programs or when they are treated as something to hear about rather than participate in. The solution is in rethinking what is important for the citizen. Knowledge is important, but knowledge of issues is probably more important than cognitive knowledge. We do not need new courses and new materials to address this need. Rather, we need a commitment to the needs of all students as future citizens.

Another major implication for science education is associated with the minimal contribution to attentiveness that school makes compared to the effects of the family. For most students inattentiveness to science seems to be established before high school, primarily because of the development of other interests and poor information acquisition habits. Thus, to reverse this trend, a major burden falls upon the elementary and middle/junior high schools. Attentiveness may be encouraged by devoting a greater proportion of class time to science, but just as important is giving top priority to the involvement of students, individually and collectively, in public policy issues. Some prescriptions toward this end include: create more interaction between the school and the family. Get students to discuss controversial issues. And above all require students to provide an information base for their opinions that comes from many and varied sources. Change the pattern of assignments. The high school can reinforce these efforts by continuing the pattern and involving the students with more issues and in more depth.

A third implication for science education is the need to redefine what constitutes the knowledge component of all school science programs so that it is in keeping with citizen/societal needs. Knowledge of issues is as important to the citizen as cognitive knowledge. Because an awareness of issues thrives on discussion, and because discussion can be most effectively cultivated or quashed by the power of the peer group, the middle school might serve as a strategic ground on which to engender this knowledge. More and better acquisition of the knowledge of science products and processes helps people only when they understand and reach the point of using it. Knowledge of issues creates the need for the other kinds of knowledge.

A fourth implication is for the school as an institution. The school does not seem to be a potent force in promoting attentiveness to organized science. This is in part due to lack of curricular emphasis on the interest and information acquisition components of knowledge. Another reason for this impotence is the lack of early school emphasis on a science program for citizens. An additional reason, however, may be a lack of recognition that certain subtle interactions of the school with the family, peer group, and the individual student can be as powerful in developing attentiveness as the content of the K-12 science program. Thus we should be designing programs and making assignments that promote these interactions instead of keeping the science program confined to disciplinary boundaries. For example, class discussions of issues aid attentiveness more through what they engender outside the classroom than through what emerges during class, so the focal point of in-class discussions should expand to encourage and include their outside component.

Last, if we want a science program that is truly responsive and responsible to the citizen in a scientifically and technologically oriented society, we must elevate current and future citizen concerns. We cannot assume that curricula which emphasize traditional cognitive knowledge and an understanding of the scientific process will lead to an understanding of the science-related issues confronting society. Neither can we assume that such traditional curricula will assist our student-citizens in applying their scientific knowledge and processes to these issues. Some sacred cows of the science curriculum must be eliminated. But the short-term trauma this sacrifice may elicit will be replaced by a long-term gain for all citizens.

FACTORS AFFECTING MINORITY PARTICIPATION AND SUCCESS IN SCIENCE

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Teachers often ask what is different about their students. For example, do they have special needs; are they described by certain personal or academic characteristics? If the answer to questions such as these is "yes," then teachers may turn to their colleagues, supervisors, or educational researchers for more answers, for all teachers hope to match their teaching strategies to the identified needs of their students.

Recently a group of teachers at Southern colleges and universities primarily for black students asked these questions. In order to find answers, they decided to survey their student populations and to develop a profile of black students. This profile, or characterization, of the largest minority in the country would help to predict successful science teaching practices for black students. What did they learn? What suggestions for teaching did they make? This paper describes their work.

PROCEDURES FOR PROFILING

First, the teachers developed a survey to collect demographic data concerning undergraduates at Southern minority institutions. The majority of the students were enrolled in introductory biology courses, while a smaller number were enrolled in mathematics and social science courses. Then, a battery of standardized measures was selected to assess a wide variety of personal and academic characteristics. Last, the teachers used the survey and standardized measures selectively on five different campuses whose student populations represented a range of geographic, socio-economic, and religious backgrounds.

The demographic survey probed deeply into societal, familial, and personal characteristics of the students. Efforts were made to create a simple, yet reliable and valid survey instrument. Sensitivities of students, cooperating faculty, and institutional administrations were considered in the survey design. Standard descriptions of community type and size, developed by the Education Commission of the States for their National Assessments of Educational Progress (NAEP, 1979), were used. Items ranged from standard ones concerning age, gender, major, and class of the student to less conventional ones concerning number of reading materials in the home, number of siblings, and composition of family (e.g., one working adult, two or more working adults, no working adults, etc.).

Both the implementation of the survey and the use of standardized measures were subject to school or personal discretion. For example, several schools deleted the items related to religious preference and personal finance, and all students were instructed to delete any item which they felt invaded their privacy. This standard, yet flexible, format enabled teachers to obtain a wide range of information concerning a substantial number of minority students.

Although the results must be considered tentative and subject to error, they provide a general description of Southern black students. The sample consisted of students enrolled in introductory biology, mathematics, and social science classes. Of the total sample, 55 percent were female and 45 percent male; 82 percent of the students were in the 16-21 age group; and 76 percent of them were freshmen or sophomores.

Although 94 percent of these students worked at paid jobs while in college, 39 percent of them worked less than 5 hours per week. Data gathered on their family backgrounds indicated that 38 percent came from families with 5 or more siblings, that the majority of their parents (55 percent) had completed high school, and that 26 percent of their parents had completed college. In 36 percent of their families, both parents lived at home and both worked. One-third of the students came from communities under 25,000 and one-third from cities over 200,000. Students selected descriptors (rural, disadvantaged-urban, and advantaged-urban) about equally in characterizing their home communities.

Additional data were collected by using standardized measures. Aptitudes, abilities, attitudes, cognitive learning styles, number and enjoyment of spatial experiences, levels of mathematical anxiety, and locus of control orientations were all assessed in the attempt to develop as complete a profile as possible. These results are interesting and have much to say about science education for minority children.

Two measures of personality were studied, cognitive style and locus of control. Cognitive style was assessed by the Group Embedded Figures Test (GEFT), which requires the student to identify and trace simple figures embedded within complex ones (Oltman, Raskin, & Witkin, 1971). Individuals who successfully identify the simple figures score high on the test and are said to be field-independent (FI); those scoring low cannot locate the simple figures and are classified as field-dependent (FD).

A second personality dimension, called locus of control, was assessed by Rotter's internal-external (IE) scale which determines the degree to which luck or fate is believed to control a person's life (Rotter, 1966). Each item is composed of two statements; for example, a) "What happens to me is my own doing." and b) "Sometimes I feel that I don't have enough control over the direction my life is taking." Students respond by selecting the alternative they believe to be more true. There are no right or wrong answers, and numerical values are assigned so that aggregate high scores imply an external locus of control orientation, while low scores reflect an internal orientation. An external orientation indicates that a student believes that luck or fate controls his or her actions. An internal orientation suggests that the individual believes that he/she is in control of his/her own behavior.

Other measures were used to estimate abilities, aptitudes, and attitudes toward science in these minority students. For example, the Cooperative School and College Ability Test (SCAT) (ETS, 1966) was used to assess scholastic aptitudes. This standardized test, which can be given at the pre-college or college level, consists of verbal and quantitative subsections. The verbal section (SCATV) uses verbal analogy items to assess language understanding. The quantitative section (SCATQ) uses comparison items to measure how well a student understands basic numerical operations. For example, some items involve a comparison of the magnitude of two mathematical quantities. According to the test manual, the quantitative items have been designed to place minimum emphasis on reading and to require quantitative understanding and insight rather than to measure traditional computational skills. The test yields a verbal, quantitative, and total score.

Another instrument used was the Spatial Experience Questionnaire (SEQ) (McDaniels, 1979). It was developed as a screening tool to discern the number of spatial experiences encountered and the extent to which they were enjoyed as well as to estimate a student's spatial ability. For example, to determine the extent of their spatial experiences, students are asked to rate on a scale of "never" to "very often" the extent of their participation in 25 activities such as sketching house plans, solving mathematical riddles, drawing/painting, and sewing/embroidery. Similarly, students rate on a scale from "very much" to "none" the amount of enjoyment they receive from each experience. Another section provides an estimate of the ease with which students perform certain spatial tasks by analyzing their competencies in constructing a mental map of a city, mentally manipulating a mathematical equation, and visualizing the rotation of a cube. Two scores are obtained, one for number and enjoyment of spatial experiences and one for spatial ability. In both cases, high scores indicate spatial accomplishment.

Another instrument used was the Biology Attitude Test (ATT) (Russell & Hollander, 1975). This test uses two scales to gather information on students' attitudes toward biology. The first part consists of 14 statements expressing attitudes about biology; for example, "It makes me nervous to even think about doing a biology experiment," or "I feel at ease in biology and like it very much." Students indicate on a numerical scale the extent of their agreement or disagreement with the statements. The second part consists of an eight-item differential scale that allows respondents to choose descriptive terms that express their feelings toward biology. The scoring procedure registers the degree of positive or negative attitudes a student has toward biology, and although there are no correct answers, high scores indicate positive attitudes.

The data collected from both the demographic survey and the various standardized instruments provide a composite profile of the personal, social, and academic characteristics of Southern minority college students. Elementary, secondary, and college teachers can use this profile to better address the special learning needs of their black students.

A PROFILE OF BLACK STUDENTS

A variety of community, academic, and personal factors were individually assessed. The responses were then analyzed to determine relationships among the various factors. The individual factors and their interrelationships were used to develop a profile which describes the characteristics of black students by four different dimensions.

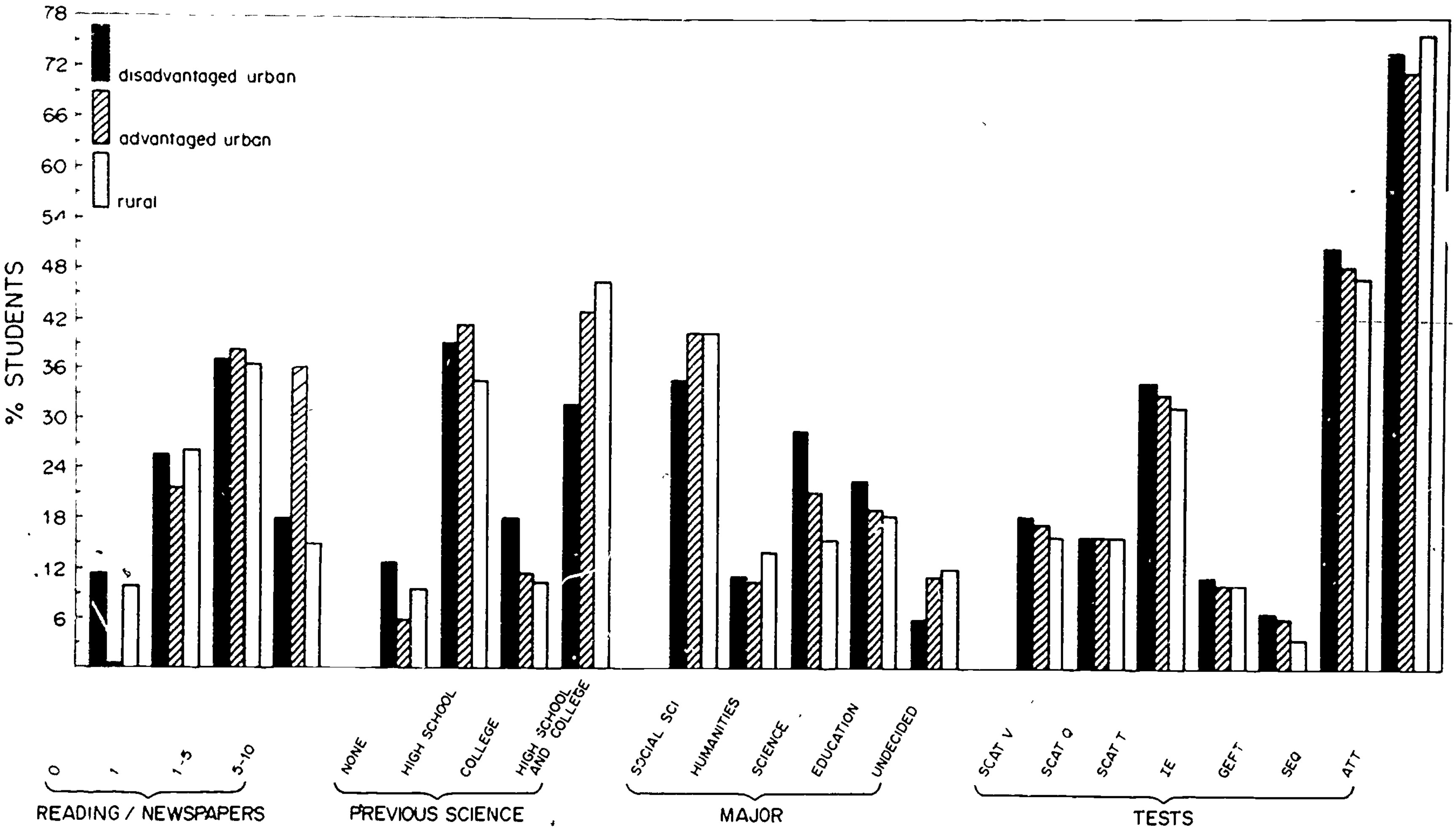
By Community Type

As one part of the survey, students selected the type of community which best described the one in which they had attended high school. They selected from the following descriptions: "disadvantaged-urban" (communities in or around cities with a population greater than 200,000 in which a high proportion of residents are on welfare or not regularly employed); "advantaged-urban" (communities in or around cities with a population greater than 200,000 in which a high proportion of the residents are in professional or managerial positions); or "rural" (communities in areas where the population is less than 25,000 and where most of the residents are farmers or farm workers).

Figure 1 graphically compares student responses grouped according to types of home communities. As expected, the data indicated that advantaged-urban youngsters have more magazines and newspapers available. On the other hand, Figure 1 shows that more Southern minority students from rural schools than from either advantaged or disadvantaged-urban areas take science in both high school and college. Although 41 percent of the students who describe their home communities as disadvan-

FIGURE 1

Percentages of Students from Three Community Types Compared in Four Categories



taged-urban take science in high school, only 20 percent of them enroll in science courses in college. Other data indicate that disadvantaged-urban black students enroll in science in high school, but few continue in college. Two factors contribute to this trend: first, only one science or mathematics course is required for high school graduation in one-sixth of our schools (NSF, 1980); and second, minority students avoid advanced courses in mathematics (NSF, 1980). The lack of mathematics courses effectively eliminates students from advanced science courses. Stake & Easley (1978), Ignatz (1975), and Kahle (1979) also attribute low science enrollments among minorities to academic tracks which allow for little flexibility in high school programs and to inadequate counseling of minority students. Perhaps the more personal counseling approach possible in rural schools results in more science opportunities for black students.

Students describing themselves as being from disadvantaged-urban communities, however, comprise the highest percentage selecting science as a college major. This is in keeping with National Assessment results which showed that black 13- and 17-year-olds valued scientific studies and thought that careers in science were worth both the expense and the time involved (Kahle, 1979).

Other data in Figure 1 illustrate mean scores on various standardized measures by community type. In the case of some measures, such as Rotter's Internal/External scale (I/E), the Group Embedded Figures Test (GEFT), and the Biology Attitude Test (ATT), high mean scores do not reflect higher abilities or aptitudes. They simply indicate a more external locus of control, a more field-independent mode of cognitive style, and more positive attitudes toward biology. In other cases, such as the verbal, quantitative, and total mean scores of the Cooperative School and College Aptitude Test (SCATV, SCATQ, and SCATTOT), higher mean scores indicate higher predicted levels of school achievement.

Although mean scores on selected tests do not differ significantly by community type, one pattern emerges. Among this sample of Southern minority college students, subjects from disadvantaged-urban areas have slightly higher mean scores on most of these measures than students from advantaged-urban or rural communities. Although it could be argued that only the most able students from disadvantaged-urban areas continue to college, two of the participating colleges have open admission policies and attract students mainly from urban areas. Urban area compensatory educational programs for the disadvantaged may account for these slightly higher achievement levels, as suggested by Kahle (1979) and Douglass (1976).

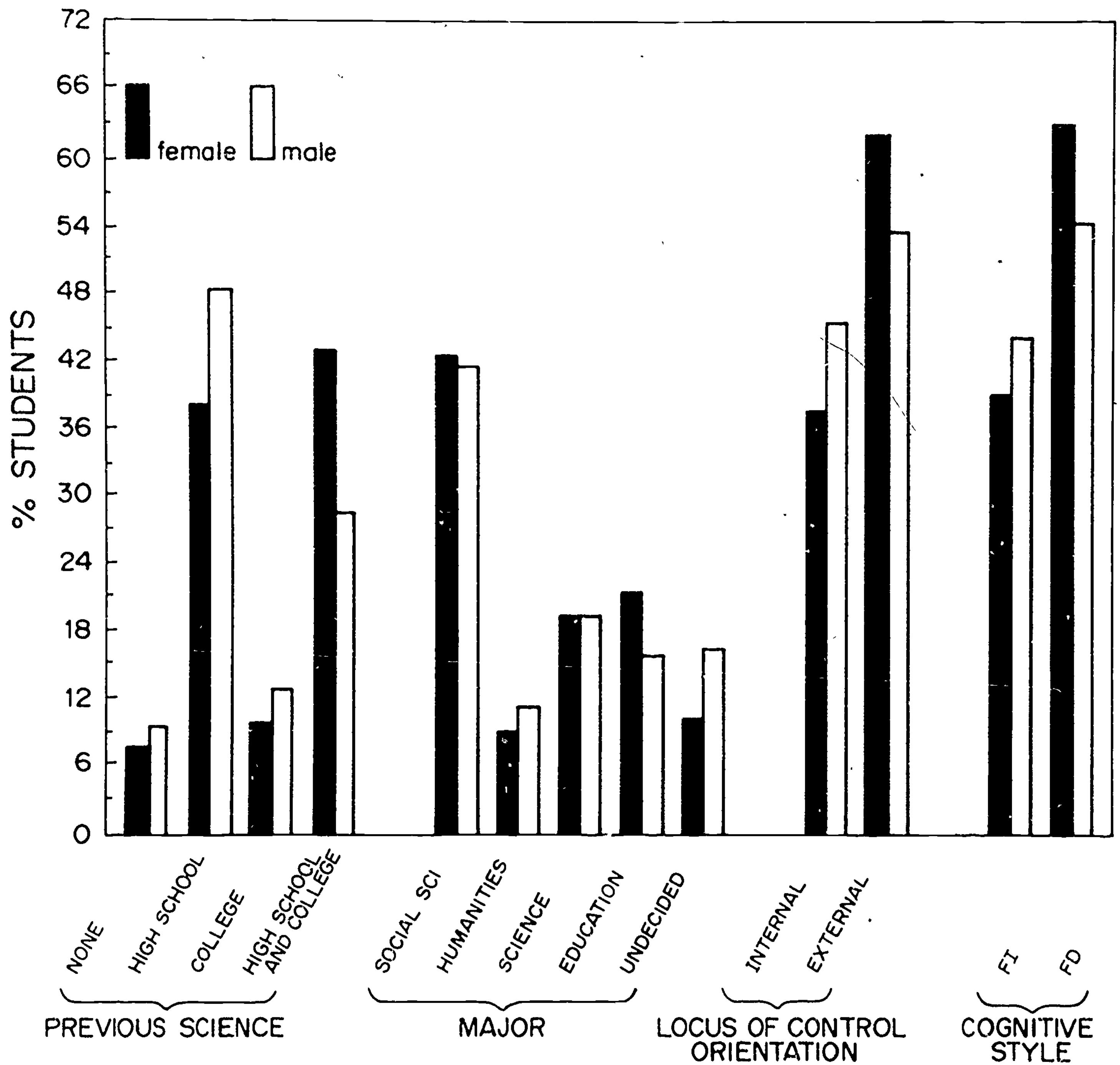
By Gender

Figure 2 compares percentages of females and males in terms of previous science enrollments, selected college major, locus of control orientation, and type of cognitive style. Although the results indicate that males take more high school science courses than females, equal percentages of minority men and women select science as a major in college. Perhaps women in college are freer of the social and peer pressures which restrict their enrollment and performance in high school science courses (Vockell & Lobonc, 1981).

Differences between the sexes are found in locus of control orientation. The mean score (10) of the total sample on Rotter's IE scale was used to divide the subjects into two categories, internal (less than 9) or external (greater than 10). According to this delineation, 63 percent of the females have an external orientation while 37 percent are internally-oriented. On the other hand, 55 percent of the males are exter-

FIGURE 2

Percentages of Male and Female Minority Students in Several Categories



nally-oriented while 45 percent view themselves as internally-controlled. These differences in percentages of males and females follow a general pattern; that is, regardless of race, females tend to be more externally-oriented than males (Phares, 1976; Feather, 1968).

Students were also divided into groups according to whether they were considered field-independent or field-dependent based upon the mean scores of the GEFT test of cognitive style. In this sample, subjects scoring at 5 or above were grouped as field-independent, while those scoring at 4 or below were categorized as field-dependent. Divided in this way, 59 percent of the total sample was grouped as having a field-dependent cognitive style. When males and females were divided separately, a higher percentage of females (62 percent) than males (54 percent) was characterized as field-dependent. According to Maccoby and Jacklin (1974), "It is well known that males tend to score higher than females on tests of 'field-independence.' " (p. 104) These findings with a large sample of Southern minority students support the hypothesis that there is a difference in type of cognitive style related to the sex of the student.

Mean scores were calculated by gender for each standardized measure used. Generally, the data do not reveal any differences between the sexes. The mean score of males on the spatial experience questionnaire was slightly higher than that of females taking the same test. Thus, in this sample of minority students, males have had more spatial experiences and have enjoyed such activities more than females. This finding parallels research concerning majority students (Bouchard & McGee, 1977; Petrusic, Varro, & Jamieson, 1978).

By Cognitive Style

Cognitive style is one of the attributes which makes a difference in science achievement levels. Cognitive style refers to the way in which individuals perceive their environment. Recently Cross (1976) and Douglass (1979) have suggested that type of cognitive style also affects how efficiently people learn in a particular learning environment and how effectively they solve problems. Generally, field-independent students are more successful with inductive learning materials and open-ended problem solving activities. Field-dependent students, on the other hand, are said to have a global approach to learning. They often experience more success with deductive learning materials.

Generally, the highest percentage of field-dependent students come from the small, rural communities or from disadvantaged-urban centers. Douglass has identified several reasons for this finding:

> We would expect inner city students to be relatively field-dependent because, due to their social status, they are forced to juggle more things at one time. . . . This is required of people who have school, job, survival, and child care responsibilities. They do not have the luxury of concentrating on a discrete task independent of the embedding context; that is, of their environment and social circumstances. (Douglass, 1981)

She continues her explanation with the observation that a rural student's circumstances are similar to those of the inner city student in several ways. Often rural students have responsibilities at home (chores) as well as at school. In contrast, many suburban/college-bound students (fringes around cities above 200,000) work only in the summer, have no child care responsibilities, and often do not have home responsibilities. Students for whom these conditions exist are more free to use a field-independent mode in their approach to their environment than are students who are more tied by their circumstances (Douglass, 1981).

GEFT scores for all participating minority schools were combined and the mean score (5.23) was calculated. The distribution of scores indicated a relatively field-dependent cognitive style among these students (range 0-18, total 18). Furthermore, the mean score of this sample registered greater field-dependency than mean scores of other college samples (10.8 to 12.3) (Kahle, in press). To compare the minority students' responses with one another, those scoring at or above 12 (N=44) were placed in a field-independent group, while those scoring at or below 3 (N=175) were categorized as a field-dependent group.

Percentages of students grouped as relatively field-dependent or field-independent were compared considering college major and mean scores on standardized instruments. When student responses were graphed, as in Figure 3, a higher percentage of field-independent students selected science as a major. (See over.)

The remaining data, presented in Figure 3, show percentages of relatively field-independent and field-dependent students scoring above the mean on each of the standardized tests used. In all sections of the Cooperative School and College Ability Test, more field-independent students scored above the mean. This finding is consistent with others which show a relationship between a field-independent cognitive style and other measures of school ability and aptitude (Douglas, 1976; Lehman, 1979; Sherris, 1980). However, nearly equal percentages of field-independent and field-dependent students were characterized as internal or external, and equal percentages had positive attitudes toward biology. More field-independent students scored above the mean on the Spatial Experience Questionnaire, indicating that these students had and enjoyed more spatial experiences.

To summarize the results of categorizing this sample of Southern minority students according to field-independence and field-dependency, the following observations are offered:

1. The sample did not form a normal distribution according to scores on the GEFT test of cognitive style.

2. Generally, percentages of field-dependent students decreased with increased size of home community.

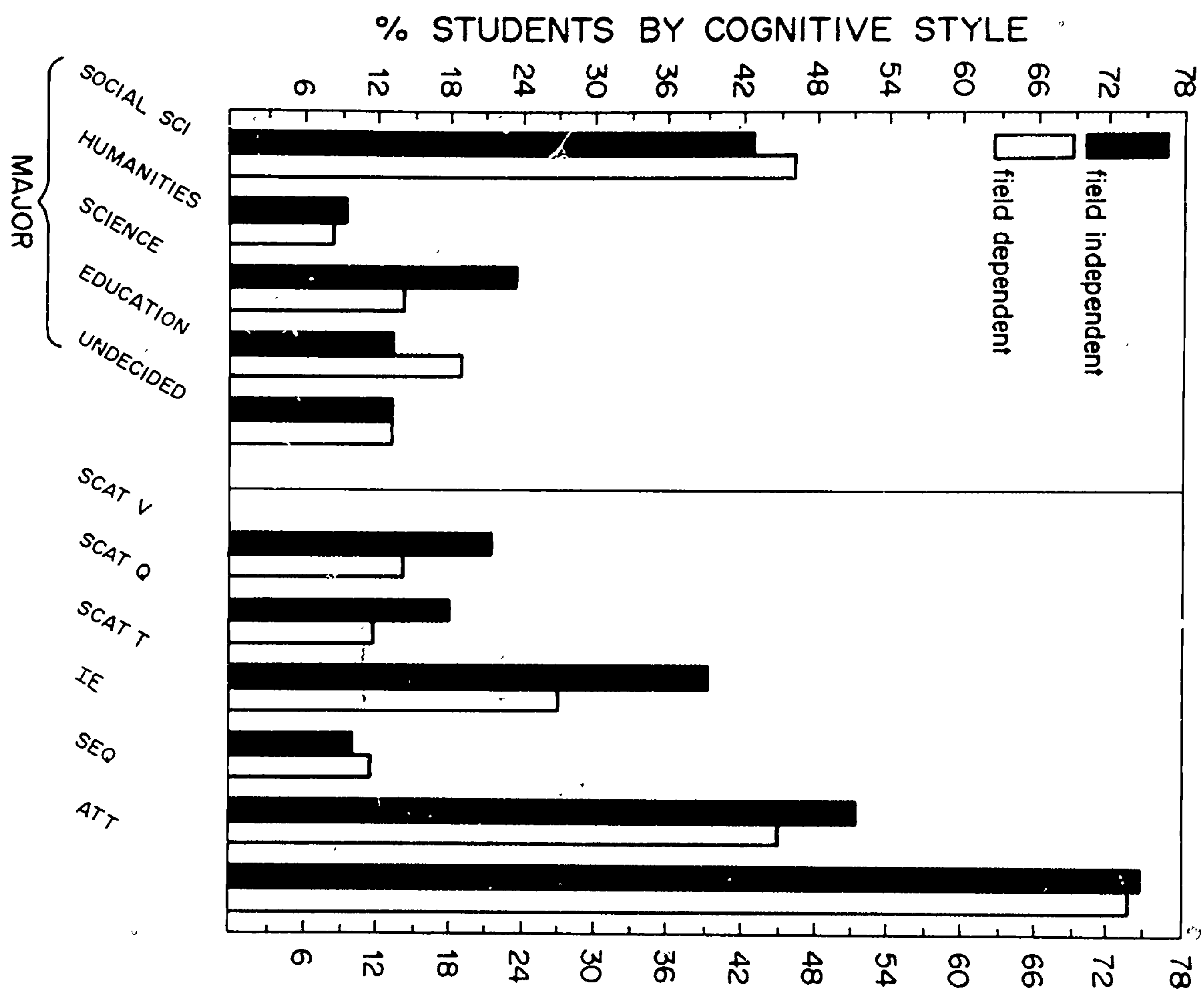
3. Twenty-three percent of the students selecting science as a college major had a field-independent cognitive style, whereas only 14 percent of those characterized as field-dependent indicated science as their major.

4. More field-independent students scored above the group mean on measures of verbal, quantitative, and spatial abilities than did field-dependent students.

5. Approximately equal percentages of field-independent and field-dependent students had positive attitudes toward biology and were identified as internally- or externally-oriented on a locus of control scale.

FIGURE 3

Percentages of Students Grouped as Relatively Field-Independent or Field-Dependent Selecting Certain College Majors and Scoring Above the Mean on Standardized Tests



Key:

Field-Independent = Scores ≥ 12 (N = 44)

Field-Dependent = Scores ≤ 3 (N = 175)

By Locus of Control Orientation

Studies have found that blacks and people from disadvantaged socioeconomic stituations view themselves as more externally-oriented than majority individuals and those from higher socioeconomic levels (Battle & Rotter, 1963; Lefcourt & Ladwig, 1966). Joe (1971) suggests that these

> . . . data are consistent with the theoretical expectation that individuals who are restricted by environmental barriers and feel subjected to limited material opportunities would develop an externally-oriented outlook on life. Also, social class interacts with race so that individuals from the lower classes and minority groups tend to have high expectancies of external control. (p. 624)

When scores from the internal/external measure of locus of control were graphed, they approximated a normal distribution. The sample mean (9.97) was similar to that of other comparable samples, which ranged from 7.12 to 12.07. Scores more than one standard deviation (3.8) above and below the mean were used to separate subjects into two groups. Those scoring at or above 14 were considered externally-oriented, while those scoring at or below 6 were considered internally-oriented.

Percentages of students grouped as internal and external are shown in Figures 4 and 5. Figure 4 presents percentages of students identified as internally- or externally-oriented according to size of home community and level of parental education. A higher percentage of the internally-oriented students come from small communities (less than 25,000) and from families in which the parents had at least a high school education. In addition, as shown in Figure 5, more internally-oriented students select science as a major. Since the scientific process, by definition, excludes a belief in fate, chance, or luck, externally-oriented students tend not to select science as a field of study.

Higher percentages of internally-oriented students score above the mean on both the verbal and quantitative portions of the SCAT test (Figure 5). However, the difference is not as great as that found when students are divided by type of cognitive style. Only slight differences are noted in percentages of externally- or internally-oriented students scoring above the mean on other measures (cognitive style, spatial experiences, attitudes toward biology).

Again, certain observations may be made on the basis of these results:

1. The sample was nearly normally distributed according to locus of control orientation.

2. More internally-oriented than externally-oriented students came from rural home communities and had parents with at least a high school education.

3. Science was selected as a college major by a higher proportion of internally-oriented students than externally-oriented ones.

4. Approximately equal percentages of both internally-oriented and externally-oriented students score above the mean on selected standardized measures of aptitude.

FIGURE 4

Percentages of Relatively Internal and External Students by Size ome Community and Level of Parental Education

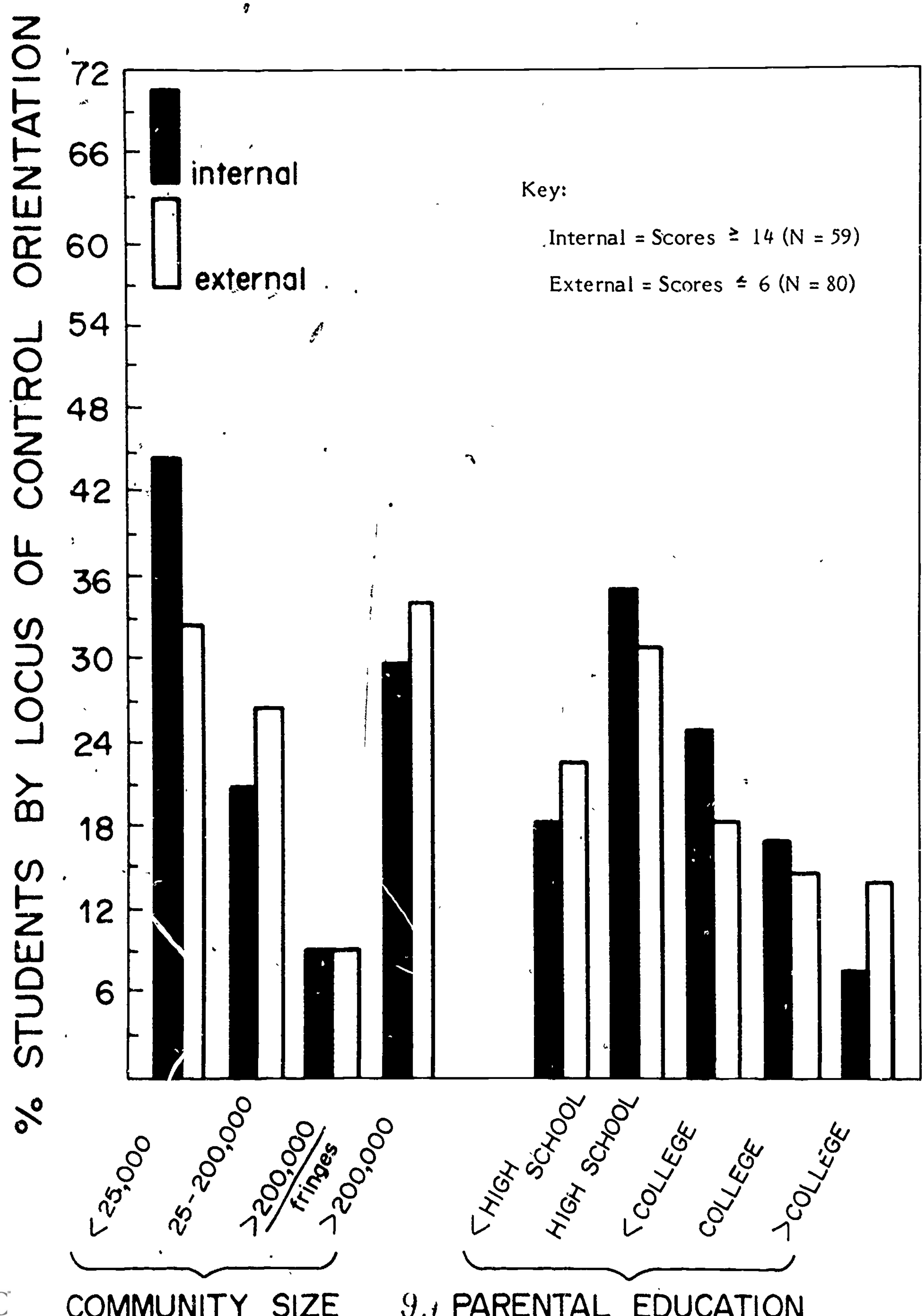
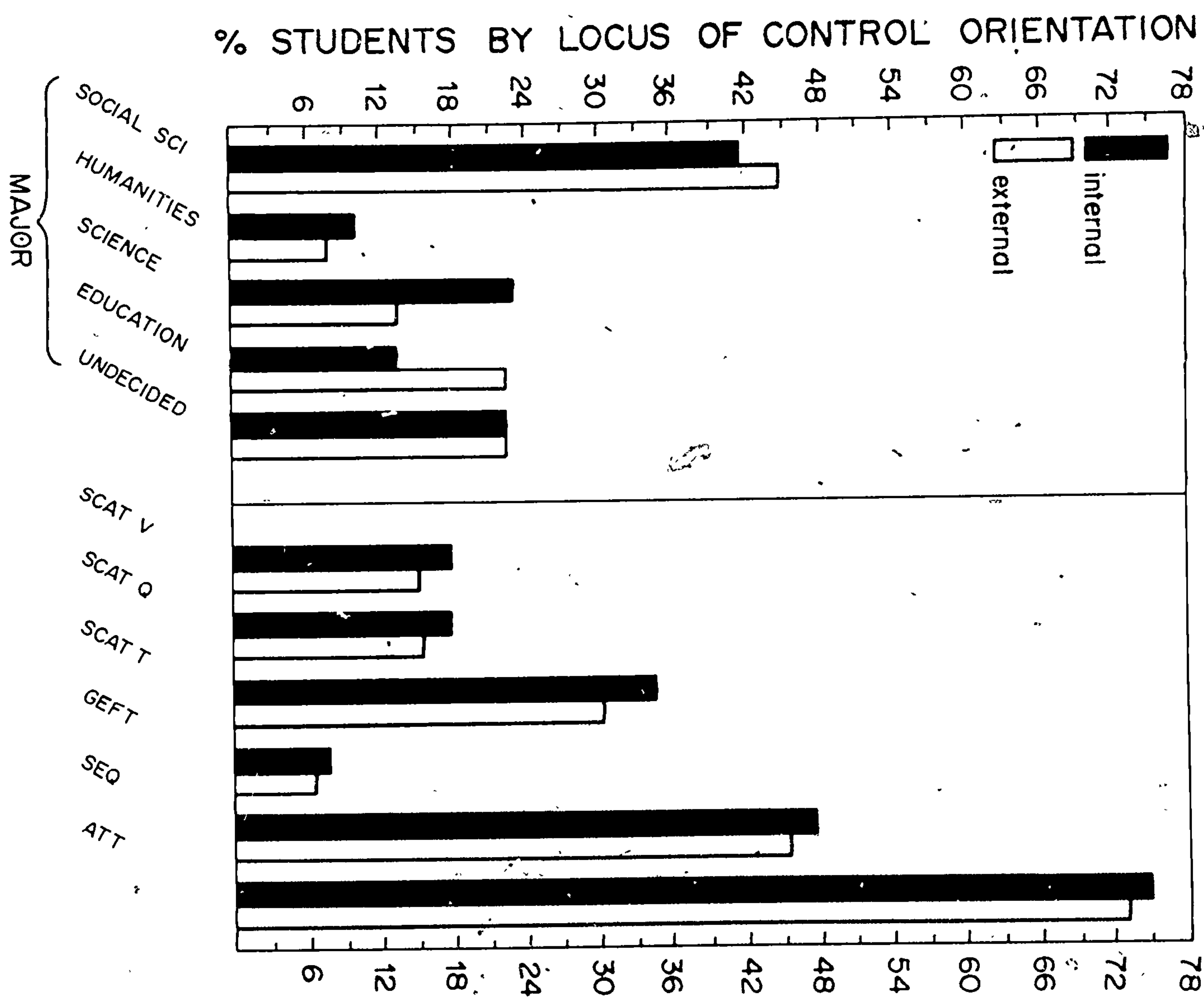


FIGURE 5

Percentages of Students Grouped as Relatively Internally or Externally-Oriented Selecting Certain College Majors and Scoring Above the Mean on Standardized Tests



Key:

Internal = Scores ≥ 14 (N = 59)

External = Scores ≤ 6 (N = 80)

PREDICTIONS FOR TEACHING

The teachers involved in this study wanted to use their results to tailor instructional methods specifically for black science students. The profile emerging from the study suggests several modifications appropriate for high school and college science courses. For example, the findings concerning the locus of control orientation of black students are important in two ways. First, since science precludes a belief in luck, fate, or "powerful others," potential minority scientists ought to be internally-oriented in terms of their locus of control. Second, correlations between internal control and standard measures of academic aptitude suggest that generally improved achievement as well as improved science achievement may be promoted by helping students become more internally-oriented.

Research concerning locus of control orientation has focused on understanding and interpreting this personality dimension, not on changing or redirecting individual orientation. However, Rowe's (1978) pioneering work indicates teaching strategies which may be successful in fostering a more internal locus of control. For example, science instruction must provide sufficient time to work with experimental materials and for events to be repeated. Such experiences should introduce the notion that events are replicable and, therefore, under one's own control. Rowe suggests that the opportunity to work directly with science materials is especially important for externally-oriented individuals. She states that, "This may be the most specific kind of intervention available to help them develop a sense that the world can to some extent be managed by them. . . . There may be a connection between developed ability to understand and manage science phenomena and problem solving in social, economic, and political contexts." (p. 393) It is important for externally-oriented black students to have laboratory experiences in science courses from elementary school through college.

In addition, the relatively field-dependent orientation of the black students tested is important in formulating more appropriate teaching strategies. It indicates the need for both curricular and instructional changes. In teaching science to primarily field-dependent students, teachers should use deductively-sequenced curricular materials (Douglass, 1979) and teach in a manner which maximizes learning for these students. For example, discussion sessions, directed problem-solving experiences, and controlled experiments in structured laboratories may be more pertinent activities than discovery or open-ended laboratories.

Because of the sensitivity surrounding the use of standardized measures of ability and aptitude with black students, the usefulness of the Group Embedded Figures Test in assessing probable success in science classes is an important finding for teachers. The research reported here suggests that the short, non-verbal, easy-to-grade Group Embedded Figures Test may be used as a preliminary screening tool for black students. Its results could be used with other information about the students to place them in special laboratory sections, to suggest appropriate teaching strategies, and to counsel students to enroll in appropriate science and mathematics courses.

SUMMARY

In summary, teachers can no longer allow the pattern identified by Nordland, et al. to describe minority education (Nordland, Lawson, & Kahle, 1974). He and his colleagues used eight Piagetian-styled conservation tasks to test two comparable samples of black students, one in the seventh grade and one in senior high school. They found no differences between the two samples in the ability to conserve quantities. Essentially little, if any, cognitive development had occurred in the two to three years of schooling which separated the samples.

Regardless of dedication and determination to provide the best possible education for all students, teachers have often felt frustrated by the lack of information available to help them achieve this goal. It is difficult to keep abreast of curricular developments and frustrating to try them unsuccessfully. It is impossible for individual teachers to review the mass of educational literature or to survey a large number of similar students. The profile of black college students, developed by teachers concerned about using the most appropriate instructional strategies possible, provides specific indications to all teachers of minorities. Using the instructional strategies and materials suggested by the results of the study will encourage black students to take more science courses and to achieve better in them.

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STATUS OF GRADUATE SCIENCE EDUCATION: IMPLICATIONS FOR SCIENCE TEACHERS

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At the 1979 meeting of the National Science Teachers Association in Atlanta, Georgia, science educators from more than thirty institutions participated in a symposium at which an array of science education issues were aired. The data provided at that meeting indicated that science education was plagued with several serious problems (Yager, 1979). Among the key problems discussed was the evident and continuing decline in graduate science education enrollments and budgets. A second problem concerned the lack of a sound, coherent conceptual base to guide research and practice in science education.

To provide more systematic data on the former problem, a small grant was provided by the National Science Foundation for a status study of graduate science education in the U.S. This new study was designed to complement the three status studies of precollege science education which were completed in 1978 (Helgeson, Blosser, and Howe; Stake and Easeley; and Weiss). The purpose of this study was to assemble accurate data on the nature of and trends in graduate science education at American tertiary institutions.

The study consisted of two phases. First, a survey was conducted of all graduate institutions in the United States to determine the number of graduate programs in science education and the number of persons enrolled at Baccalaureate, Master's, and Doctoral levels at these institutions. Table 1 shows these data. Of 365 graduate institutions listed in the 1979 Directory of the Council of Graduate Schools, 328 (90 percent) responded to the survey. Of these, 132 institutions, 40 percent of the total, reported having graduate science education programs, per se.

TABLE 1

Number of Science Education Programs and Craduates
1959-1979

	Bachelor's		Master's		Doctoral	
	Programs	Graduates	Programs	Graduates	Programs	Graduates
1959	78	1,204	32	201	23	41
1964	78	1,296	63	464	31	83
1969	79	1,340	111	976	59	171
1974	86	1,406	125	1,047	66	220
1979	90	970	126	885	67	244

Table 1 contains data which show that the number of Baccalaureate, Master's, and Doctoral programs each increased in the two decades between 1959 and 1979. The increase was negligible, however, between 1974 and 1979 at the institutions providing data.

An examination of the number of graduates in each degree program shows that the number of Bachelor's and Master's degree recipients increased until 1974 and then declined sharply by 1979. In the case of Baccalaureate recipients the 1979 number is the smallest in more than twenty years, and the number of Master's degree recipients in 1979 falls below the 1969 level. By contrast, the number of doctoral recipients continues to increase up to and including 1979. The rate of increase from 1969 to 1979, however, is slower than it was from 1959 to 1969.

The second phase of the study consisted of a more detailed review of programs at the 35 institutions with the largest doctoral enrollments and research productivity. These 35 institutions will be referred to as graduate research centers for science education. Through a mail questionnaire and telephone interviews, information was obtained from each of these institutions (Butts and Yager, 1981). Tables 2-8 provide data on these 35 graduate research centers.

TABLE 2

Doctoral Graduates at Major Centers
1960-1980

	Graduates	Centers
1960	34	11
1965	75	21
1970	179	31
1975	204	34
1980	162	33

Table 2 shows that the number of doctoral programs at the graduate research centers and the number of their graduates peaked in 1975. During the decade from 1960-1970, there was a five-fold increase in production of doctorates and a three-fold increase in the number of programs at these institutions. The decade from 1970-1980 witnessed a net gain of two programs and the decade ended with a net decline in annual production of doctorates.

Combining data from Tables 1 and 2 shows another phenomenon that may be surprising to many. These data are merged in Table 3. Since the data in Table 1 were from the years 1959, '64, '74, and '79 and the corresponding data in Table 2 were from one year later, care must be used in interpreting the picture that is presented. The data on doctorates awarded in 1969-70 provide a clear example of the "error" in combining these data, but a trend seems to emerge and requires further examination.

TABLE 3

Production of Science Education Doctorates

	1959-60	1964-65	1969-70	1974-75	1979-80
Total Number of Doctoral Programs (From Table 1)	23	31	59	66	67
Number of Major Graduate Research Centers (From Table 2)	11	21	31	34	33
Number of Doctoral Programs Not at Graduate Research Centers	12	10	28	32	34
Total Number of Doctorates (From Table 1)	41	83	171	220	244
Doctoral Graduates at Major Centers (From Table 2)	34	75	179	224	162
Number of Doctorates Prepared at Other than Graduate Research Centers	7	8	(8)	16	82

In 1959-60, about 80 percent of the science education doctorates were prepared at graduate research centers while by 1979-80 less than two-thirds were prepared at these institutions. Moreover, by 1980 two major graduate research centers, Harvard and Stanford, had ceased to offer science education doctorates, thus reducing the number of science education graduate research centers to 33 while the total number of institutions graduating science education doctorates had increased to a record high of 67.

Given the available data, it is not clear if this represents a trend toward the preparation of increasing numbers of science education doctorates at institutions other than graduate research centers while programs at the centers decrease in size or if it is merely an anomaly in the data. It is a question which merits further investigation as is the question of how doctoral education at graduate research centers compares with doctoral education at other institutions.

Table 4 illustrates changes in the course requirements over the twenty year period at the 35 graduate research centers. Semester hour requirements have changed somewhat during the period. Science requirements have grown slightly so that science education doctoral recipients are earning roughly the equivalent of a Master's degree in science courses. Coursework in the "nature of science" continues to be a relatively small component of doctoral programs. Course requirements in education have grown substantially in two decades.

TABLE 4

Composition of Doctoral Programs in Semester Hours
35 Largest Graduate Centers

	Discipline			
	Science	Science Education	History/ Philosophy/ Sociology	Curriculum/ Instruction
1960	24	15	4	7
1965	26	16	4	7
1970	29	16	4	11
1975	29	16	4	11
1980	29	16	4.5	11

Guidelines for the Doctorate were established in 1966 and revised in 1974 by the Association for the Education of Teachers of Science (Butts, 1977). Each of these guidelines called for specific features of a desirable program but the effects of such standards are not perceivable given the broad categories used in this survey. In general, doctoral programs have tended to become more demanding in terms of specific course requirements.

Table 5 provides further information regarding the number of science education personnel employed at the 35 centers. It is apparent that the number of faculty and assistants increased dramatically during 1960-75, with the most dramatic increase during the 1965-70 period. The numbers of faculty members and graduate assistants employed, however, decreased significantly during the 1975-80 period. The decline in number of personnel parallels similar declines in enrollments in science education at the Bachelor's, Master's, and Doctoral levels.

TABLE 5

Number of Science Education Personnel
35 Largest Graduate Centers

	Faculty	Assistants
1960	53	43
1965	96	82
1970	161	155
1975	182	169
1980	168	150

Table 6 provides information concerning external funding for enrichment programs for secondary school students, in-service teacher education, and research/curriculum development in science education at the 35 centers. It is apparent that the amount of external support for gifted students and for teacher in-service activities peaked in 1970, although the number of grants continued to increase for a time thereafter. The amount of the average grant clearly declined during a period of rapid inflation. Currently, the total dollar amount in these two categories is at a twenty-year low. A review of data on in-service program support illustrates the drastic drop in external funding during the five years between 1975 and 1980 as well as the overall decrease between 1960 and 1980. These changes reflect changes in the public's support for such activities nationally.

TABLE 6

External Funding for Science Educators
35 Largest Graduate Centers

	High Ability Secondary School Students		Teacher In-Service Programs		Research/Curriculum Development	
	Total Funding	#Grants	Total Funding	#Grants	Total Funding	#Grants
1960	$ 65,000	2	$1,321,000	15	$ 136,000	4
1965	880,000	6	1,456,000	27	400,000	9
1970	997,000	8	2,030,100	37	1,449,000	17
1975	245,000	14	1,518,000	40	1,229,000	22
1980	102,000	5	520,000	15	1,192,000	26

Although the figures for research and development indicate decline during the 1975-80 period, the number of grants has increased and the average size of grant has increased over two decades. It is also interesting to note that the funds for research and development have surpassed other kinds of external support for the science education centers since 1975.

Table 7 illustrates trends of institutional support for science education at the 35 centers. Except for support of graduate assistants, levels of internal support have increased over the twenty-year period. The salary and general budget increases have tended to mask the decline in the total number of faculty supported during the past few years. Although salaries (for faculty and support staff) have increased, the end of the twenty-year period marks a slowdown in the rate of increase. The severe cut in funds available for graduate students in science education is striking. The relatively slight increases for equipment and supplies at a time of significant inflation indicate another alarming trend.

TABLE 7

General University Support for Science Education
35 Largest Graduate Centers

	Faculty	Graduate Students	Support Staff	Equipment/ Supplies
1960	$620,000	$131,000	$34,000	$14,000
1965	1,051,000	314,000	110,000	64,000
1970	2,163,000	683,000	157,000	110,000
1975	2,976,000	1,652,000	214,000	139,000
1980	3,991,000	895,000	268,000	173,000

Table 8 provides information regarding employment trends for the doctoral graduates at the 35 centers during the 1960-80 period. The number of new doctoral recipients employed as science educators at colleges and universities increased dramatically between 1960 and 1970. The number of graduates employed as college science teachers (at community colleges, four-year colleges, and universities) increased from 1960 through 1975, with the greatest increase occuring between 1965 and 1970. In 1960 it was rare for doctoral graduates to return to K-12 public schools to work as teachers, supervisors, curriculum directors, or general administrators, but in 1970 it became common to do so and, in 1975, the public school became an important source of employment for doctoral graduates. Current figures suggest that this employment pattern diminished in importance between 1975 and 1980, probably because of declines in enrollment and financial crises in K-12 schools.

TABLE 8

Employment Patterns for Doctoral Graduates
35 Largest Graduate Centers

	Science Education	Science	Public Schools (K-12)	Other (Health, Government, Industry)
1960	10	1	0	0
1965	26	3	2	4
1970	96	32	17	12
1975	76	40	45	17
1980	51	26	26	15

The number of doctoral graduates finding employment in industry, health fields, governmental units, and public centers (e.g., museums, field stations, etc.) has increased. Such employment did not occur twenty years ago, or at least none was reported by the respondents. The 1980 figures do, however, show a slight decline in such fields compared with data from 1975.

Another factor related to doctoral enrollments and doctoral employment is the large number of non-U.S. citizens enrolled at the major centers. Although this was not a specific question in the questionnaire used to develop the data, telephone contacts during this time period revealed that foreign students represent over half of the total doctoral enrollments at some well-established centers. With such changes in the profile of graduate enrollment, the U.S. doctoral employment picture is clouded to an as yet undetermined degree. Most of the international students return to their homelands as college instructors of both science and science education, while others are employed in leadership positions in government.

This study of science education in U.S. graduate centers identified several trends for the discipline during a twenty-year period, 1960-80. Major trends include:

1. Science education programs increased rapidly in both number and size from 1960-70 and more slowly from 1970-75. This growth included the number of faculty employed, number of graduates at all levels, amount of internal support, and amount of external support.

2. Financial support increased between 1960 and 1975 and has declined since then. The areas most seriously affected are (a) externally funded projects and (b) graduate student support. The decline in these areas, in turn, has resulted in a decrease in the number of Americans enrolled in doctoral programs at many centers while the number of foreign students has grown. Foreign students are usually provided with support by their government or another sponsor as a condition of entry into the United States.

3. Faculty members at the 35 graduate research centers are homogeneous in age, sex, background, professional experience, and professional responsibilities. At the time of the survey there were 168 science educators at these institutions, of whom thirty were over 55 years of age and eight were under 35 years of age. Eighty-eight percent were male. Nearly all had been secondary science teachers prior to obtaining the doctorate and entering higher education. Nearly all had received their doctorates from one of the 35 graduate research centers.

4. On the surface, graduate programs have changed somewhat over the past two decades. More science and more education credits are required now than earlier. However, the survey did not illuminate qualitative changes in programs over the past two decades. At some centers, perhaps at many, a greater emphasis is placed on the development of research skills now than in the past. At some institutions, students are required to show a high level of competence in statistics and research design as well as capability in ethnographic research or other research paradigms.

5. As the number of faculty decreases at the graduate research centers, specialization also tends to decrease. This is coupled with a general decrease in the autonomy of science educators as more programs are changed from separate science education departments to sub-units within larger departments. As a result, science educators tend to spend more time teaching an increasing range of topics and faculty research time has become more limited.

6. Programs at graduate research centers tend to be isolated from one another. Few examples of cooperative research among these centers exist and

professional dialogue tends to be limited to traditional mechanisms such as journals and annual meetings of professional organizations.

7. Research is conducted by graduate students more frequently than by faculty members. Moreover, this research tends to be developed as a part of dissertation requirements and, frequently, the studies are not part of a planned program of research focused on systematically elucidating a particular topic or broad question. As a consequence, research findings have limited impact on practice and new researchers acquire neither the competence nor the propensity to develop a program of research. Moreover, not all doctoral recipients publish research results and few continue their research after completing the dissertation.

8. Science education as an academic pursuit is plagued by the lack of a coherent conceptual framework to guide research and practice. This difficulty arises, in part, because science education is an eclectic field which draws on concepts from many fields such as epistemology, philosophy of science, sociology, psychology, curriculum theory, and the many science disciplines. Thus, science education is more closely related to applied fields like agriculture, medicine, or engineering than to academic disciplines such as chemistry or psychology. During the past decades this may have helped science education respond to changes in federal policy as reflected in fiscal support of curriculum development and implementation. As federal leadership is sharply curtailed, however, the lack of clear direction and focus in the science education community becomes more salient and problematic.

IMPLICATIONS FOR SCIENCE TEACHERS

With the decline of federal influence shaping science education, it is possible that relationships between school science teachers and university science educators* can ente a new phase. For two decades, the science education communities at both the university and school levels have been responding to policies established "from above." Without that external force, school and university personnel can and should come together on an equal footing to address the many serious problems which science educators face today--for instance, questions of preparing young people for life in a technological society.

Among the vehicles for action are professional organizations at the state, regional, and national levels. These organizations provide an important forum where school science teachers and university science educators can work together to address and find solutions to some of the pressing problems of science education. At present, many professional organizations are formulating plans and strategies for redefining and improving science education in light of new issues and the myriad of changes in societal needs and external support. The potential is high for improving science education through these organizations. If the promise is to be fulfilled, however, practitioners, classroom teachers and other school personnel must join with university science educators to strengthen organizational efforts through active participation and

*The term "university science educators" is used to identify faculty members at tertiary institutions while "school science teachers" refers to elementary and secondary personnel involved in science instruction and program planning. The terms "educator" and "teacher" are not intended to imply any hierarchical difference and none should be inferred.

commitment. This period of change calls upon teachers to become active in state, regional, and national organizations where they can have a voice in shaping the future of science education.

The data in this study show a picture of declining enrollments and declining resources that is familiar to many school science teachers. If science educators at universities and science teachers in schools are to maintain viable programs, we must (a) seek new audiences for our work, (b) adapt our programs so that they meet perceived needs of potential clients, (c) convey information to potential clients that will convince them that courses and programs will benefit them, and (d) reformulate our goals so that our programs serve a wider audience.

In seeking new audiences, we should make sure that we attract into science those students who have traditionally not enrolled such as females, minorities, and children from low-income families. One high school physics teacher in a neighboring school recently increased enrollments from two to five sections simply by making a conscious effort to recruit females into physics. In many schools it is clear that upper level high school courses like physics and chemistry provide fertile ground for expansion by recruitment.

Most people are aware of the importance of science in society today and in the future. Many, however, are unable to make the connection between what is taught in science courses and the societal needs they perceive. This applies to prospective clients of both school and university programs. We should, therefore, consciously adapt our programs to make a clear connection between the expectations and needs of students and the content of our courses. For example, students in chemistry or biology should be helped to transfer knowledge of these subjects to an understanding of environmental issues (most pertinently, local issues); and practicing teachers should be helped to transfer knowledge from science education courses to actual classroom problems such as teaching science effectively to students who typically do not enroll in courses beyond those required.

If we hope to maintain our enrollments, we must do more to publicize our courses and programs than we have in the past. The overall pool of students is decreasing in many parts of the country. Therefore, we must "advertise" to obtain a larger portion of this pool if we are to maintain or increase enrollments.

In the process of attracting students and adapting programs, we must reexamine the goals of our programs. Our society presents new challenges to us and our students every day. At the same time, our collective understanding of science-based societal issues and the learning process is expanding. For these reasons, the science education community should be actively reformulating the goals, objectives, and approaches for science instruction at elementary and secondary levels as well as in university programs for prospective and practicing teachers. Such reformulation cannot be conducted at one level or by one set of people. It will likely be carried out in local districts, state education departments, universities, as well as in professional organizations. As different groups adapt ideas about science content and the applications of it to a variety of local and regional needs, science education may become more diversified than it has been in the past and better able to meet the needs of students who, as citizens, will be called upon to make choices and decisions on issues and questions which have a scientific basis.

Graduate science education in universities has been the major emphasis of the study reported here. The data presented have some important implications for science teachers who are considering graduate study leading to a doctorate in science education. The following are some of the issues that potential doctoral applicants may wish to consider:

1. The employment picture for recipients of science education doctorates has changed markedly. Few university science education positions will be available in the next fifteen years unless there is a drastic alteration of governmental policies. Full time positions at community colleges will also be difficult to obtain. Similarly, the present climate of budgeting for elementary and secondary education will provide little call for K-12 science education specialists educated at the doctoral level. In contrast, career opportunities for education specialists in health-related areas appear promising. Perhaps the greatest growth area for science education specialists at the doctoral level can be found in business and industry. At present, these opportunities are promising, but data on these positions are incomplete and it is unclear how rapidly the number of positions will expand. One point is clear, however: doctoral students should explore and prepare for more than traditional school and university careers.

2. Sixty-seven universities in the U.S. offer doctorates in science education. Many of these programs are small and some may not be strong. Prospective candidates should seek information about the nature and quality of the programs they propose to enter, career options for which these programs prepare graduates, and placement of recent program graduates. Moreover, it is important that prospective candidates obtain data from more than one source and check data carefully because much of the information sought is subjective.

3. Doctoral programs in science education should prepare recipients of the degree with knowledge and skills that will enable them to be adaptive and responsive in the future. Quantitative data show that doctoral programs have changed partially, but not substantially, over the last two decades. Since qualitative data were not collected in this study, it is unclear if course content has changed significantly over that time. Most courses seem to be up to date and to provide useful content. For most doctoral candidates, responsibility to professional development will dictate a selection of courses and professors offering significant content and fostering a competence that will be of value during their future professional lives.

4. A doctorate in science education may not enhance income, but it may change the lifestyles of recipients. The doctorate usually provides competence to conduct research and/or skills needed to assume a leadership position. The transition from classroom teacher in a school to a leadership position in a school, university, or industry is a significant one and candidates should be psychologically prepared to make such a transition over a relatively short time span.

Graduate science education is currently at a turning point. New patterns and programs will evolve during this decade as a small and capable group of professionals grapples with many important educational and societal issues. As they enter into planning and problem solving with practitioners from elementary and secondary schools, their work will become more valuable to the society they serve. Both university and school personnel have competence and perspective that will help us understand contemporary issues. Collaborative effort by the two groups will result in better resolutions for the complex issues which we now confront.

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EPILOGUE: NEXT-STEP ACTIONS

These research analyses collectively suggest some next-step actions for educators to take. Such actions could broaden the dimensions of science commonly found in K-12 settings and are consistent with the Desired State conditions described by the Project Synthesis researchers as reported in Volume 3 of NSTA's What Research Says to the Science Teacher. The major research efforts reviewed here are syntheses of several national efforts funded by NSF, NIE, and other agencies. Thus the actions suggested by these reviews represent national prescriptions and priorities, and the reviewers represent both the researchers' peer group and the general public in evaluating these research efforts.

Actions by educators that would serve to implement research findings and set new directions for science education include:

1. Develop easily-used systems to assess day-to-day student behaviors, study the actual use of classroom time, and review strategies of working with individuals and groups of learners.

2. Continue efforts to identify additional dimensions of science and develop situations to exemplify them in classrooms, thereby broadening the goals of science education.

3. Consider long-range indicators of successful curriculum and instruction; identify specific curriculum components, particular teaching strategies, and evaluation mechanisms that coincide with new goals and with the long range indicators.

4. Study the nature of learners, their likes and dislikes, abilities, previous experiences, educational and life goals; then use such information in planning programs and teaching approaches.

5. Display excitement about change, the challenges of the future, and the problems that surround us, for change, challenge, and problems are central ingredients of science.

6. Accept the challenge of being a part of a current and continuing inquiry into the nature of science, the nature of the universe, and the nature of problems emerging from the interaction of the two. Science operates in the present tense and has the power to resolve problems, not just create them; this immediate and positive aspect of science should be made apparent to each student in every science classroom.