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By-Townsend, Ronald D.

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This booklet is designed to direct elementary and junior high teachers of science in assessing and comparing their professional goals and practices with those of their colleagues and with current objectives and teaching behaviors recommended by specialists and researchers in science education and curriculum development. Each of 36 statements related to practices in teaching science is documented by a separate bibliography. Other documented sections discuss objectives and current trends. A checklist for teachers to evaluate their teaching practices is also included. (GR)

SE 006 560

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Contemporary Practices in Teaching SCIENCE
Elementary and Junior High School

Authoritative Commentary and Bibliography

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COOPERATIVE EDUCATIONAL RESEARCH LABORATORY, INC.
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Preface

Using this SAMPLER and SUPPLEMENT, teachers of science in elementary and junior high schools can assess and compare their professional goals and practices with those of their colleagues and with current objectives and teaching behaviors recommended by education specialists and researchers in science education and curriculum development.

Created for CERLI by Ronald D. Townsend, the SAMPLER should not be considered an instrument to "test" individual teaching proficiency nor "rate" the science program in a school. Mr. Townsend developed the SAMPLER and SUPPLEMENT to encourage teachers to identify and pursue measurable goals and use practical procedures that might improve science instruction at the elementary and junior high school levels.

At Florida State University (Tallahassee), the author teaches a Practicum Course for pre-intern physics, chemistry and general science teachers in the department of Science Education, the School of Education. Mr. Townsend has taught at Highland Park High School (Illinois) and at Maine Township High School (Park Ridge, Illinois) where he directed the Science Seminar. In 1964-1965, he was an Educational Consultant in Physics for the Ford Foundation's Turkish National Science High School Project in Ankara, Turkey.

In developing the SAMPLER and SUPPLEMENT, Ronald Townsend consulted with and was advised by Dr. Paul Westmeyer, Head of the Department of Science Education, School of Education, Florida State University, Tallahassee.

Contents

Sampler

Contemporary Practices in Teaching Science in Elementary and Junior High School

THE COOPERATIVE EDUCATIONAL RESEARCH LABORATORY, INC.
540 West Frontage Road, Box 815, Northfield, Illinois 60093
Developed by Ronald D. Townsend, Florida State University, Tallahassee

Published: Summer, 1968

NOTE to USERS: This instrument should not be used to "test" individual teaching proficiency nor "rate" a school's science program but rather to encourage teachers to identify and pursue measurable goals and use practical procedures that might improve science instruction at the elementary and junior high school levels.

Date__________________

Teacher's Name____

1. School Corporation______________________________________

2. Type of School: (Check one only)

☐ (1) Elementary, grades 1-6
☐ (2) Elementary, grades 1-8
☐ (3) Junior High School, grades 7, 8, 9
☐ (4) Community School, grades 1-12

3. Types of classroom in which science is taught:

☐ (1) Laboratory
☐ (2) Standard

4. Circle the grade level(s) at which you teach science:

1 2 3 4 5 6 7 8 9 10 11 12

5. Average science class size:__________

6. Average hours per week of science instruction for each class:__________

7. Years experience teaching:__________ 8. Years experience teaching science:__________

Check the number of college courses you have taken in the following:

		(1)	(2)	(3)	(4)
	Courses	None	1-3	4-7	8 or more
9.	Physics				
10.	Chemistry				
11.	Biology				
12.	Earth Science				
13.	General Science				
14.	Mathematics				

15. What professional journals do you read regularly?

______________________ ______________________
______________________ ______________________
______________________ ______________________

Your Goals in Science Teaching

In order to get the most out of this SAMPLER, you must establish a set of criteria with which you can compare your practices in science instruction to those cited in the SUPPLEMENT. To establish such criteria, list the goals for which you strive in your science instruction. Concisely state these objectives as *measurable* changes sought in students rather than ambiguous unmeasurables like an "understanding" and "appreciation" of science.

For example: you can measure a student's proficiency in classifying and ordering objects, recording and analyzing data, or forming and stating hypotheses. But until you describe the student behavior manifesting "understanding" or "appreciation," it is almost impossible to evaluate the attainment of your goals.

16. ______________________________

17. ______________________________

18. ______________________________

19. ______________________________

20. ______________________________

21. ______________________________

22. ______________________________

23. ______________________________

24. ______________________________

25. ______________________________

Your stated objectives and perhaps some new ones included in the SAMPLER represent specific criteria with which to examine and evaluate your science teaching practices.

Practices in Teaching Science

Some of the following practices have been widely used while others have had limited trials; but all represent methods used in science instruction in current types of reported practices in junior high schools and elementary science classrooms in recent years.

In Column I:

If you use this practice when appropriate and consider it as one of your major teaching techniques, check *Frequently.*

If you use this practice but not frequently enough to consider it as one of your major teaching techniques, check *Sometimes.*

If you do not use this practice or seldom use it, check *Rarely* or *Never.*

MARK ONLY ONE ITEM IN COLUMN I.

In Column II:

If you agree that the practice is good, check *Usually Sound.*

If you think the practice is sound only in certain circumstances, check *Sometimes Sound.*

If you think the practice is not good, check *Usually Unsound.*

If you are undecided or think the practice is questionable, check *Open to Question.*

MARK ONLY ONE ITEM IN COLUMN II.

The Practices

	COLUMN I			COLUMN II			
	I follow this practice: (check only one answer)			I think this practice is: (check only one answer)			
	Fre-quently	Some-times	Rarely or Never	Usually Sound	Some-times Sound	Usually Unsound	Open to Question
26, 27 Use the same readability formula and/or method for selecting science books for your class as used for other reading material.							
28, 29 Adhere to the content and sequence of the specific science textbook used for your class in your school and use reading assignments in the text as the primary method of science instruction.							
30, 31 Use the services of a science education specialist to help plan and implement the science part of your school's instructional program.							
32, 33 Use a team-teaching approach to science by either combining classes or exchanging classes so that each teacher instructs in that area of science in which he or she feels most competent.							
34, 35 Set aside a specific time each week for the study of science, postponing questions on science until the allotted period to maintain the integrity of science as a separate discipline.							
36, 37 Teach your students the fundamental concepts of amount, mass, volume, surface, and time in the early primary grades because they are basic to later science instruction.							
38, 39 Base your instruction of physical fundamentals on the intuitive feelings your students have on conservation of matter. Examples: A tall, thin container may contain the same amount of water as a short, wide container. A piece of clay contains the same amount of "stuff" regardless of its shape.							

	COLUMN I I follow this practice: (check only one answer)			COLUMN II I think this practice is: (check only one answer)			
	Frequently	Sometimes	Rarely or Never	Usually Sound	Sometimes Sound	Usually Unsound	Open to Question
40, 41 Determine what you want the students to be able to do in science at the end of the school year; then determine the pre-requisite skills needed and the order in which they build on one another to establish the sequence of your course.							
42, 43 Present scientific information to the students by the lecture-discussion method.							
44, 45 Conduct demonstrations in front of the class so that your students will learn the scientific approach to investigating the world around them.							
46, 47 Present a scientific theory to your students and then conduct an experiment to prove the validity of the theory.							
48, 49 As a means of science instruction, let the students identify and state the problem to be investigated. Then let the students initiate and implement their own means and methods for investigating the problem. Finally, allow the students to analyze their own data and arrive at their own conclusions.							
50, 51 Set up situations in which your students are encouraged to formulate new questions; restate problems in their own words, and create new ideas.							
52, 53 Give your students detailed and specific instructions for each step that must be taken in conducting an experiment, in analyzing the results, and in drawing the correct answers and conclusions.							

	COLUMN I			COLUMN II			
	I follow this practice: (check only one answer)			I think this practice is: (check only one answer)			
	Frequently	Sometimes	Rarely or Never	Usually Sound	Sometimes Sound	Usually Unsound	Open to Question
54, 55 Allow your students to approach science problems and projects individually and to progress at their own rate of investigation and attainment.							
56, 57 Use televised science programs as a source of science information and instruction.							
58, 59 Use field trips and/or science resource people as an integral part of your science instruction program.							
60, 61 Have your students bring in for study and discussion newspaper and magazine articles on scientific and technological applications, such as rockets, atom smashers, computers, etc.							
62, 63 Use films (full reel or single concept cartridge), filmstrips, overhead projectors, and/or recordings in connection with your science instruction.							
64, 65 Use programed material, either in printed form or with a "teaching machine" as a method of teaching science to your students.							
66, 67 Teach your pupils science from a qualitative, descriptive point of view. Postpone the quantitative aspects of science and measurement until as high school students they reach a higher level of sophistication in mathematics.							
68, 69 Encourage long-term science projects conducted either by the class or by groups. *Example:* Keep a weather chart over a period of one or two months.							

	COLUMN I: I follow this practice: (check only one answer)			COLUMN II: I think this practice is: (check only one answer)			
	Frequently	Sometimes	Rarely or Never	Usually Sound	Sometimes Sound	Usually Unsound	Open to Question
70, 71 Encourage your students to ask questions about science and try to answer these questions with explicit, nonambiguous answers. (Even if you must wait to reply until you have looked up the correct answer.)							
72, 73 Present your students with the concept of "model building." Construct mental or physical models as possible explanations for observed behavior of nature. *Example:* The kinetic theory of gas molecules randomly bouncing around is a model for the explanation of the behavior of gases.							
74, 75 Point out to your students the complexity of science and the need for the most intelligent to continue in scientific studies.							
76, 77 Combine your teaching of arithmetic and mathematical relationships with your instruction on scientific concepts and their relationships.							
78, 79 Include the introduction of scientific information in your reading and English assignments. Have the students read scientific articles and present written and oral reports on specific science topics.							
80, 81 Teach your students science and social studies together as a unified program of instruction showing the interdependency of the development of society and scientific progress.							
82, 83 Starting with various simple notions, teach basic physics or biology or chemistry in the early grades. Examples: Not "how a seesaw works" but the relationship between force and energy; not "how to feed a rabbit" but the process of metabolism.							

	COLUMN I			COLUMN II			
	I follow this practice: (check only one answer)			I think this practice is: (check only one answer)			
	Fre-quently	Some-times	Rarely or Never	Usually Sound	Some-times Sound	Usually Unsound	Open to Question
84, 85 Rather than emphasizing content, impress upon your students the joy of learning how to learn through scientific investigation.							
86, 87 Try to identify the science-oriented and science-gifted students, and give them extra projects and science assignments.							
88, 89 Ask your students to memorize definitions of scientific words.							
90, 91 Test the scientific achievement of your students by their ability to answer specific questions in terms of established scientific facts.							
92, 93 Ask your students to memorize classification schemes and definitions in biology as a scientific approach to nature study.							
94, 95 Evaluate your students' achievemnts in problem solving by testing them on problems very similar to those assigned as homework and/or worked in class.							
96, 97 By increased permissiveness in scientific investigation, teach and test your students on increased "creativity" rather than achievement in either factual information or structural relationship in a particular discipline.							
98, 99 Accentuate the intrinsic rewards of self-learning and making scientific discoveries rather than the pressure of grade and finding specific numerical answers.							

Supplement

Authoritative Commentary and Bibliography

(To complement the *Sampler of Contemporary Practices in Teaching Science, Elementary and Junior High School)*

Introduction

In this SUPPLEMENT, summary statements synthesize four types of professional articles identified by the following symbols:

(AO) authoritative opinion reports on restricted trial practices or logical suggested practices

(CD) articles on curriculum development projects currently in a state of change due to continuous evaluation and revision

(R) research articles on controlled measurable practices

(T) teachers' articles about practices they have tried and intuitively found successful

Among the categories listed above, type T represents the most abundant source though the subjective method of evaluation dilutes its comparative validity. For this reason, there are fewer T articles cited in the SUPPLEMENT's bibliographies of professional literature.

Many factors influence a teacher's practices: courses in science and in methods; experiences in the laboratory; local elements such as class size, equipment, facilities, science program. In order to evaluate these practices, goals must be precisely defined. In order to compare, select, and improve science teaching practices, an individual first must decide what changes in the students he hopes his instruction will effect.

In this context, the SAMPLER initially deals with stated objectives (16-25) and the SUPPLEMENT provides an opportunity to compare these individual objectives with those identified as recent and measurable goals for science instruction at the elementary and junior high school levels.

Objectives

According to Gagne (1), Blackwood (2), Jacobson (3), and Mager (4), before making an effective choice of media or method the goals of an instructional program need to be clearly defined. Furthermore — Gagne (1), Mager (4), Hurd (5), and Brandwein, Watson, and Blackwood (6) stress that these objectives should be stated in terms of changes sought in the student's behavior as a result of the instruction.

Eight of the 11 major curriculum development (CD) projects[1] (7-14) cited in the SUPPLEMENT include the identification of behavioral objectives in their evaluation procedures. Tannenbaum, Stillman, and Piltz (15) believe that defining objectives in terms of student behavior — though extremely difficult to do — is basic to effective evaluation.

Although several lists of behavioral objectives for elementary and junior high school science (Blackwood [2], Jacobson [3], Walbesser [16], Fischler [17]), Reiner [18]), are available, an individual's evaluation of the practices enumerated in the SAMPLER will be more meaningful in terms of his own science teaching objectives.

In order to formulate objectives in specific terms of pupil behavior and the performance expected of a student if the objective has been achieved, the following questions (which resemble those posed by Tannenbaum, Stillman, and Piltz [15]) may serve as useful guidelines:

a. What problem-solving abilities is the student expected to achieve?

b. Can he describe observations and formulate hypotheses about the observed phenomena?

c. Can he plan experiments to test his hypotheses?

d. What information is the student expected to acquire?

e. What skills is he supposed to display?

f. Can he perform measurements and manipulate science equipment?

g. How is he expected to reveal his attitudes? By deferring judgment when he observes a demonstration? By considering the reliability of a source of information?

h. What applications of his knowledge is the student expected to make?

---

[1]Because they are frequently cited in this SUPPLEMENT the 11 curriculum projects will be identified only by name in the bibliographies. See page 47 for a list of project directors from whom further information can be requested.

1. (AO) Gagne, Robert M., "Psychological Issues in Science—A Process Approach", Lecture to AAAS tryout Teachers, Washington, D. C., 1964, and San Francisco and Chicago, 1965.

2. (AO) Blackwood, Paul E., *Science Teaching in the Elementary Schools: A Survey of Practices*, U. S. Department of Health, Education and Welfare, Office of Education, U. S. Government Printing Office, Washington: 1965.

3. (AO) Jacobson, Willard J. (Ed.), "The Science Man Power Projects K-12 Science Program", *The New School Science*, A Report to School Administrators on Regional Orientation Conferences in Science, AAAS Misc. Publ. No. 63-6.

4. (AO) Mager, Robert F., *Preparing Instructional Objectives*, Palo Alto, California: Fearon Publishers, Inc., 1962.

5. (AO) Hurd, Paul DeHart, "Toward a Theory of Science Education Consistent with Modern Science", *Theory into Action . . . in Science Curriculum Development*, A Service Document of the National Science Teachers Association, 1964.

6. (AO) Brandwein, Paul F., Watson, Fletcher G., and Blackwood, Paul E., *Teaching High School Science: A Book of Methods*, New York: Harcourt, Brace, & Co., 1958.

7. (CD) AAAS Commission on Science Education.

8. (CD) Elementary-School Science Project.

9. (CD) Elementary Science Advisory and Research Project.

10. (CD) Elementary Science Study.

11. (CD) Michigan Science Curriculum Committee Junior High School Project.

12. (CD) Oakleaf Individualized Elementary School Science.

13. (CD) School Science Curriculum Project.

14. (CD) Science Curriculum Improvement Study.

15. (AO) Tannenbaum, Harold E., Stillman, Nathan, and Piltz, Albert, *Evaluation in Elementary School Science*, U. S. Department of Health, Education, and Welfare, Office of Education, U. S. Government Printing Office, Washington: 1964.

16. (AO) Walbesser, Henry H., "Curriculum Evaluation by Means of Behavioral Objectives", *Journal of Research in Science*, Vol. 1, Dec., 1963, pp. 296-301.

17. (AO) Fischler, Abraham S. (Harvard Univ.), "Science for Grades 7, 8, and 9," *School Science and Mathematics*, Vol. 61, April, 1961, pp. 271-285.

18. (AO) Reiner, Wm. B., "Meeting the Challenge of Recent Developments in Science in Assessing the Objectives of Modern Instruction." *School Science and Mathematics*, Vol. 66, No. 4, (April, 1966), pp. 335-341.

26, 27 Use the same readability formula and/or method for selecting science books for your class as used for other reading material.

Piltz (1) found that science textbooks being used in 1961 in elementary schools varied greatly in content, sequence, and readability at all levels. The readability difference between science books of different publishers and lack of reading growth (easier to read at the beginning to more difficult at the end of the book) was further brought out by Mallinson (2, 3) and Ottley (4).

Even though Herrington and Mallinson (5) found more consistency with readability formulas than with reading experts, they suggest that the teacher must rely on personal judgment when choosing a science textbook.

Brown (6) questions the validity of the Dale-Chall (7) Formula in determining the readability of science textbooks, since its 3000 familiar word list was compiled in 1948 and many new technical terms are now in the vocabulary of elementary school students. He suggests that teachers determine if the philosophy of science applied by a textbook is consistent with the concepts they want to teach and if their students can read the book. Consistent with this view is the study by Kerns (8) in which elementary school students were found to have a conceptual understanding of twenty science words.

1. (R) Piltz, Albert, "Review of Science Textbooks Currently Used in Elementary Schools", *School Science and Mathematics*, Vol. 61, May, 1961, p. 648.

2. (R) Mallinson, George G., "The Reading Difficulty of Textbooks for General Physical Science and Earth Science", *School Science and Mathematics*, Vol. 54, Nov., 1954, pp. 612-616.

3. (R) Mallinson, George G., "The Readability of High School Science Texts," *The Science Teacher*, Vol. 18, Nov., 1951, pp. 253-256.

4. (R) Ottley, LeRoy, "Readability of Science Textbooks for Grades 4, 5, & 6", *School Science and Mathematics*, Vol. 66, No. 3, April, 1965, pp. 363-366.

5. (R) Herrington, Wilma L. & Mallinson, George G., "An Investigation of Two Methods of Measuring the Reading Difficulty of Materials for Elementary Science", *Science Education*, Vol. 42, Dec., 1958, pp. 385-390.

6. (AO) Brown, Walter R., "Science Textbook Selection and the Dale-Chall Formula", *School Science and Mathematics*, Vol. 66, No. 2, Feb., 1965, pp. 164-167.

7. (R) Dale, Edgar & Chall, Gene S., "A Formula for Predicting Readability", *Educational Research Bulletin*, No. 27, Jan., 1948, pp. 11-20.

8. (R) Kerns, Leroy R., "A Study of the Differences of Comprehension That Pupils in Colorado Elementary Schools Have of Twenty Selected Science Words", Univ. of Col., 1963, EdD., Supervisor-Harold M. Anderson.

28, 29 Adhere to the content and sequence of the specific science textbook used for your class in your school and use reading assignments in the text as the primary method of science instruction.

As we have seen in the research and opinion associated with *Practice No. 26, 27,* there is little consistency or sequence between or within most science textbooks for the elementary and junior high school levels. Morrisett (1) concludes that new and important material is not widely included in present textbooks and that sequencing from simple ideas to the more complex is not apparent.

Weaver (2) adds to the tirade against using a single textbook as your only source of science instruction with a long list of ambiguous and/or completely wrong statements from twelve textbook series used in science for elementary schools.

Blackwood (3) points out that if one of the goals of science instruction is for "children to learn to use the methods of investigation, study, inquiry, exploration, and discovery used by scientists" then many opportunities should be provided for children to explore their environment directly through observation, experimentation, and measurement. The ". . . inherent need of adolescents to perform experiments . . ." in junior high school science is emphasized by Norton (4).

1. (AO) Morrisett, Lloyd, "Curriculum: Education and Research, the Changing Pattern of Curriculum Construction", *Learning About Learning,* Jerome Bruner (Ed.) U. S. Department of Health, Education, and Welfare, Cooperative Research Monograph No. 15, 1966.
2. (R) Weaver, Alan D., "Misconceptions in Physics Prevalent in Science Textbook Series for Elementary Schools", *School Science and Mathematics,* Vol. 65, No. 3, March, 1965, pp. 231-240.
3. (AO) Blackwood, Paul E., *Science Teaching in the Elementary Schools: A Survey of Practices,* U. S. Department of Health, Education, and Welfare, Office of Education, U. S. Government Printing Office, Washington: 1965.
4. (AO) Norton, Jerry L., "The Need for An Activity Centered Science Program", *Science Education,* Vol. 47, No. 3, April, 1963, pp. 285-291.

30, 31 Use the services of a science education specialist to help plan and implement the science part of your school's instructional program.

The need and reasons for using science specialists in elementary schools was presented by Kleinman (1). Higher student achievement when the science specialists taught rather than merely counseling the regular teachers was shown only under certain conditions by Gibb and Matala (2) and left further in doubt by the conflicting studies of Ginther (3) and Payne (4). With the rapid increase of knowledge and techniques in all fields, the need for the help of science specialists in some form by the already overburdened teacher of the self-contained classroom is not disputed.

Suggested by Zacharias (5), amplified by Machlup (6), and implemented by Hoffart (7) was the plan of letting good high school physics students teach elementary school students short blocks of science material. Both sets of students gain from such an arrangement, and the elementary school teacher has scientific help in the self-contained classsroom. Smith (8) reports a similar plan was tried with much success with advanced physics students teaching science resource units to fourth graders at University of Illinois.

1. (AO) Kleinman, Gladys S., "Needed: Elementary School Science Consultants", *School Science and Mathematics*, Vol. 65, No. 8, Nov., 1965, pp. 738-745.

2. (R) Gibb, E. Glenadine and Matala, Dorothy M., "A Study of the Use of Special Teachers in Science and Mathematics in Grades 5 and 6", *School Science and Mathematics*, Vol. 61, Nov., 1961, pp. 569-572.

3. (R) Ginther, John R., "Achievement in Sixth-Grade Science Associated with Two Instructional Roles of Science Consultants", *The Journal of Educational Research*, Vol. 57, Sept., 1963, pp. 28-33.

4. (R) Payne, Arlene, "Achievement in Sixth Grade Science Associated with Two Instructional Roles of Science Consultants: Second Report, *"The Journal of Educational Research*, Vol. 57, March, 1964, pp. 350-354.

5. (AO) Zacharias, Jerald R., "Learning by Teaching", *ESI Quarterly Report*, Spring/Summer, 1966, pp. 5-8.

6. (AO) Machlup, Stefan, "Learning by Teaching: A Pilot Program", *ESI Quarterly Report*, Spring/Summer, 1966, pp. 9-12.

7. (R) Hoffart, Ervin H., "More About Learning by Teaching", *ESI Quarterly Report*, Spring/Summer, 1966, pp. 13-15.

8. (R) Smith, Allen, "The Utilization of Advanced Physics Students in the Fourth Grade", *School Science and Mathematics*, Vol. 66, No. 2, Feb., 1966, pp. 135-137.

32, 33 Use a team-teaching approach to science by either combining classes or exchanging classes so that each teacher instructs in that area of science in which he or she feels most competent.

Shaplin (1, 2) defines team teaching as ". . . two or more teachers given responsibility, working together, for all or a significant part of the instruction of the same group of students" and further estimates that by 1967 three out of ten elementary schools may be using this method of instruction in some way.

Fischler and Shoresman (3) believe that the goals of science instruction can be better achieved by team-teaching than in the self-contained classroom and present possible models and methods for evaluation of team-teaching.

The most enthusiastic cheers where team-teaching was actually tried in connection with science instruction seem to be centered on the junior high school. Berzofsky and Ousler (4) and Thayer (5) emphasize the necessity for cooperative planning and relay the added inducement that even the teachers learn more than in the one-teacher science class. These views were echoed by Carruth and Hichborn (6) who claim that team-teaching improved the science instruction so much for the low and average ability groups that it will be extended in their school to all seventh grade students.

1. (AO) Shaplin, Judson T., "Description and Definition of Team Teaching", *Team Teaching*, New York: Harper and Row, 1964.

2. (AO) Shaplin, Judson T., "Teach Teaching: An Idea in Action", *The Shape of Education for 1964-65*, Vol. 5, National Education Association, Washington, D.C., 1964, p. 33.

3. (AO) Fischler, Abraham S. and Shoresman, Peter B., "Team Teaching in the Elementary School: Implications for Research in Science Instruction", *Science Education,* Vol. 46, No. 5, Dec., 1962, pp. 406-415.

4. (T) Berzofsky, Max and Ousler, Joseph C. Jr., "Organizing Team Teaching in Science", *Science Teacher,* Vol. 31, Oct., 1964, pp. 30-32.

5. (T) Thayer, Mildred N., "Experimental First Year", *Science Teacher,* Vol. 31, Oct., 1964, pp. 33-34.

6. (T) Carruth, Harold R. and Hichborn, Robert P., "Trying Team Teaching in Science", *Science Teacher,* Vol. 32, Nov., 1965, pp. 29-30.

34, 35 Set aside a specific time each week for the study of science, postponing questions on science until the allotted period to maintain the integrity of science as a separate discipline.

Victor and Lerner (1) state that "Science teaching and learning are always more effective when the learning begins with a problem that arouses the curiosity and interest of the children". One source of such "challenging problems" according to Hurley (2) is the child's own proposal.

Hurd (3) admonishes curriculum specialists in science to " . . examine the writings and research in a wide range of fields: economics, sociology, public policy, and manpower as well as the current status of science." It would seem likely also that children living in our science-centered culture should be encouraged to inquire into the interrelations of the various differences rather than be forced to separate them. Looking at the reports on *Practices 78-83* may even give some credence to the idea of using science as the core around which the elementary and junior high school curricula can be built.

1. (AO) Victor, Edward and Lerner, Marjorie S., *Readings in Science Education for the Elementary School,* New York: The MacMillan Co., 1967.

2. (AO) Hurley, Beatrice, "Some Ways of Helping Children to Learn Science", *Science for the Eights-to-Twelves,* Bulletin No. 13A of the Association for Childhood Education International, 1964.

3. (AO) Hurd, Paul DeHart, "Toward a Theory of Science Education Consistent with Modern Science", *Theory into Action . . . in Science Curriculum Development,* National Science Teachers Association, Washington, D. C.

(See bibliographies under *Practices 78-83.*)

36, 37 Teach your students the fundamental concepts of amount, mass, volume, surface, and time in the early primary grades because they are basic to later science instruction.

Some aspects of science such as observation, differences, change, and variance (Weaver and Coleman [1] and Thier, Powell and Karplus [2]) can be taught at the first grade level or even before (Cox [3]). This can only be done by the use of tangible objects with which the children can interact and move and not in the abstract terms of later development as pointed out by Piaget (4).

Inbody (5) sums up the approach that must be taken in teaching science to children in the primary grades: "Instruction based on an adult's conception of logic may be pointless to a child, for an obvious contradiction to an adult may seem like a unique event to a youngster".

1. (R) Weaver, Edward K. and Coleman, Sara G., "The Relationship of Certain Science Concepts to Mental Ability and Learning of First Grade Children", *Science Education,* Vol. 47, Dec., 1963, pp. 490-494.
2. (R) Thier, Herbert D., Powell, Cynthia Ann, and Karplus, Robert, "A Concept of Matter for the First Grade", *Journal of Research in Science Teaching,* Vol. 1, 1963, pp. 315-318.
3. (T) Cox, Louis T. Jr., "Working with Science in the Kindergarten", *Science Education,* Vol. 47, No. 2, March, 1963, pp. 137-144.
4. (R) Piaget, J., *The Child's Conception of the World,* Paterson, New Jersey: Littlefield, Adams and Co., 1963.
5. (R) Inbody, Donald, "Children's Understandings of Natural Phenomena", *Science Education,* Vol. 47, No. 3, April, 1963, pp. 270-278.

38, 39 Base your instruction of physical fundamentals on the intuitive feelings your students have on conservation of matter. Examples: A tall, thin container may contain the same amount of water as a short, wide container. A piece of clay contains the same amount of "stuff" regardless of its shape.

The work of Piaget and Inhelder (1, 2, 3, 4) has shown that until they reach certain stages of mental development, children do not comprehend the fact that area, volume, and mass are conserved even when changed in appearance and that the reasoning of children changes radically as they mature to adolescence. These findings have been confirmed by Lovell (5, 6, 7), Lunzer (8), and Elkind (9, 10). These, plus the fallacy of a child's logic even over observation as in the free-fall experiment by Cunningham and Karplus (11), make the students' intuition seem a poor basis upon which to build a curriculum.

1. (R) Piaget, J., *The Child's Conception of the World,* Paterson, New Jersey: Littlefield, Adams and Co., 1963.
2. (R) Piaget, J. and Inhelder, B., *The Child's Conception of Space,* London: Routledge and Kegan Paul, 1963.

3. (R) Piaget, J.; Inhelder, B.; and Szemenska, A., *The Child's Conception of Geometry*, New York: Harper and Row, 1964.

4. (R) Inhelder, B. and Piaget, J., *The Growth of Logical Thinking from Childhood to Adolescence*, New York: Basic, 1958.

5. (R) Elkind, D., "Quantity Conceptions in Junior and Senior High School Students", *Child Development*, Vol. 32, 1961, pp. 551-560.

6. (R) Elkind, D., "Children's Discovery of the Conservation of Mass, Weight, and Volume: Piaget Replication Study II", *Journal of Genetic Psychology*, Vol. 98, 1961, pp. 219-227.

7. (R) Lovell, K., "A Follow-Up Study of Inhelder and Piaget's The Growth of Logical Thinking", *British Journal of Psychology*, Vol. 52, 1961, pp. 143-153.

8. (R) Lovell, K.; Healey, D.; and Rowland, A. D., "Growth of Some Geometrical Concepts", *Child Development*, Vol. 33, 1962, pp. 751-767.

9. (R) Lovell, K.; Mitchell, B.; and Everett, I. R., "An Experimental Study of the Growth of Some Logical Structures", *British Journal of Psychology*, Vol. 53, 1962, pp. 175-188.

10. (R) Lunzer, E. A., "Some Points of Piagetian Theory in the Light of Experimental Criticism", *Journal of Child Psychology and Psychiatry*, Vol. 1, 1960, pp. 191-202.

11. (R) Cunningham, John and Karplus, Robert, "The Free-Fall Demonstration Experiment", *American Journal of Physics*, Vol. 30, No. 9, Sept., 1962, pp. 656-657.

40, 41 Determine what you want the students to be able to do in science at the end of the school year; then determine the pre-requisite skills needed and the order in which they build on one another to establish the sequence of your course.

Gagne (1) poses the question "What do we want the student to be able to do?" and suggests a sequencing of objectives as a logical approach to curriculum development. Hess (2) also points to a "psychological sequence" in curricular planning. Several of the elementary and junior high school science curriculum projects (AAAS) [3], ISCS [4], IPS [5], SCIS [6]) have organized their materials in a tightly sequenced clear progression toward precise, predetermined objectives. Atkin (7) is concerned about sequencing of curriculum materials in terms of the children's mental progress, the content story line, and feedback from teacher experience.

1. (AO) Gagne, Robert, "A Psychologist's Counsel on Curriculum Design", *Journal of Research in Science Teaching*, Vol. 1, No. 1, 1963.

2. (AO) Hess, Robert, "The Latent Resources of the Child's Mind", *Journal of Research in Science Teaching*, Vol. 1, No. 1, 1963.

3. (CD) AAAS Commission on Science Education.

4. (CD) Intermediate Science Curriculum Study.

5. (CD) Introductory Physical Science.

6. (CD) Science Curriculum Improvement Study.
7. (CD) Atkin, J. Myron, "Some Evaluation Problems in a Course Content Improvement Project", *Journal of Research in Science Teaching,* Vol. 1, No. 2, 1963.

42, 43 Present scientific information to the students by the lecture-discussion method.
44, 45 Conduct demonstrations in front of the class so that your students will learn the scientific approach to investigating the world around them.

Although some of the teacher's guides suggest some topics for discussion and outline, in detail, and some teacher demonstrations, every one of the eleven major curriculum development projects mentioned in this pamphlet considers its materials to be laboratory centered with activities for the students as the main vehicle. To say the trend in science instruction is away from the lecture and even from the teacher-performed experiment is an understatement. To list the places where this is emphasized would be to copy the bulk of the references in any index of science education.

1. (CD) AAAS Commission on Science Education.
2. (CD) Elementary School Science Project.
3. (CD) Elementary Science Advisory and Research Project.
4. (CD) Elementary Science Study.
5. (CD) Intermediate Science Curriculum Study.
6. (CD) Introductory Physical Science.
7. (CD) Michigan Science Curriculum Committee Junior High School.
8. (CD) Minnesota Mathematics and Science Teaching Project.
9. (CD) Oakleaf Individualized Elementary School Science.
10. (CD) Science Curriculum Improvement Study.
11. (CD) School Science Curriculum Project.

46, 47 Present a scientific theory to your students and then conduct an experiment to prove the validity of the theory.

Without listing the projects again (See *Practices 42-45),* the trend is away from the laboratory as a place to prove a theorem and toward using student experiments to answer questions or solve problems as indicated by Blough and Huggett (1) and Kambly and Suttle (2). It is suggested by Jones (3) that learning techniques of investigation as well as factual information may result. If this is true, then the chance for what Bruner (4) calls "massive general transfer" may take place, and the ability to learn will be enhanced in other disciplines.

1. (AO) Blough, Glenn O. and Huggett, Albert J., *Elementary-School Science and How to Teach It,* New York: The Dryden Press, 1952.

2. (AO) Kambly, Paul E. and Suttle, John E., *Teaching Elementary School Science Methods and Resources,* New York: The Ronald Press Co., 1963.

3. (T) Jones, Mary E., "A Study of the Possible Learnings Resulting from Science Experimentations by a Class of First Grade Children". *Science Education,* Vol. 43, No. 4, Oct., 1959, pp. 355-374.

4. (AO) Bruner, Jerome S., *The Process of Education,* Cambridge, Mass.: Harvard University Press, 1961.

48, 49 As a means of science instruction, let the students identify and state the problem to be investigated. Then let the students initiate and implement their own means and methods for investigating the problem. Finally, allow the students to analyze their own data and arrive at their own conclusions.

In 1958, Atkin (1) observed that children from permissive science classes could hypothesize much better than those from the teacher-controlled class. In 1964, Atkin (2) saw one of the two threads in curriculum revision to be the development of children's thinking ability. The benefits of discoveries one makes for himself are extolled by both Schwab (3) and Bruner (4). Suchman (5) outlines the joy of children when allowed to inquire by autonomous activity. He states that "Concepts resulting from inquiry have greater significance to the child because they have come from his own acts of searching and data processing".

Davies (6) found that eighth grade general science students could on their own initiative use the inductive development of scientific abstraction from a variety of individual concrete experiences, selected by the students, to formulate basic science concepts.

Jones (7) found that student initiated experiments in the first grade produced skills, concepts, and attitudes more advanced in scope and concept than commonly used in first grade textbooks.

1. (R) Atkin, J. Myron, "A Study of Formulating and Suggesting Tests for Hypotheses in Elementary School Science Learning Experiences", *Science Education,* Vol. 42, Dec., 1958, pp. 414-422.

2. (AO) Atkin, J. Myron, "Some Evaluation Problems in a Course Content Improvement Project", *Journal of Research in Science Education,* Vol. 1, June, 1963, pp. 129-132.

3. (AO) Schwab, J. J., "The Teaching of Science as Enquiry", *The Teaching of Science,* Cambridge, Mass.: Harvard University Press, 1962.

4. (AO) Bruner, J. S., "The Act of Discovery", *Harvard Educational Review,* Vol. 31, 1961, pp. 21-32.

5. (R) Suchman, J. Richard, "The Illinois Studies in Inquiry Training", *Journal of Research in Science Teaching,* Vol. 2, No. 3, 1964, pp. 230-232.

6. (T) Davies, Eton M., "Introducing the Inductive Method", *The Science Teacher,* Vol. 29, December, 1962, pp. 52-55.

7. (R) Jones, Mary E., "A Study of the Possible Learnings Resulting from Science Experimentation by a Class of First Grade Children", *Science Education,* Vol. 43, Oct., 1959, pp. 355-374.

50, 51 Set up situations in which your students are encouraged to formulate new questions, restate problems in their own words, and create new ideas.

Brandwein (1) claims the most excellent of teaching skills to be those which confront the students with objects, events, and questions that improve their ability to design a critical investigation. Atkin and Karplus (2), Thier, Powell, and Karplus (3), and Gagne (4) all believe the teacher must furnish some background and intellectual framework within which autonomous discovery can take place.

Ausubel (5) maintains that available procedures and methods for handling data can be skillfully arranged and simplified for children ". . . in such a way as to make ultimate discovery almost inevitable".

Buell (6) and Fish and Saunders (7) reported situations where teacher guidance had led to "self-judging" and "self-correcting" by the students of their *own* inquiry strategies.

Neal (8) found that given guidance in developing habitual use of the methods of scientific inquiry, students in grades 1-6 can: 1. identify and state problems, 2. formulate plans to collect and evaluate data, 3. formulate hypotheses, 4. formulate conclusions or concepts, 5. apply concepts and methods to new situations.

1. (AO) Brandwein, Paul, *Substance, Structure and Style in the Teaching of Science,* New York: Harcourt, Brace and World, 1965.

2. (AO) Atkin, J. Myron and Karplus, Robert, "Discovery or Invention?" *The Science Teacher,* Vol. 29, September, 1962, pp. 45-51.

3. (AO) Thier, Herbert D.; Powell, Cynthia Ann and Karplus, Robert, "A Concept of Matter for the First Grade", *Journal of Research in Science Teaching,* Vol. 1, Dec., 1963, pp. 315-318.

4. (AO) Gagne, Robert M., "The Learning Requirements for Enquiry", *Journal of Research in Science Teaching,* Vol. 1, No. 1, 1963, pp. 149-153.

5. (AO) Ausubel, David P., "Learning by Discovery: Rationale and Mystique", *National Association of Secondary School Principals,* Vol. 45, Dec., 1961, pp. 18-57.

6. (T) Buell, Robert R., "Inquiry Training in the School's Science Laboratories", *School Science and Mathematics*, Vol. 65, No. 3, March, 1965, pp. 287-291.

7. (T) Fish, Alphoretta S. and Saunders, T. Frank, "Inquiry in the Elementary School Science Curriculum", *School Science and Mathematics*, Vol. 66, No. 1, Jan., 1966, pp. 13-22.

8. (T) Neal, Louise A., "Techniques for Developing Methods of Scientific Inquiry in Children in Grades One Through Six", *Science Education*, Vol. 45, No. 4, Oct., 1961, pp. 313-320.

52, 53 Give your students detailed and specific instructions for each step that must be taken in conducting an experiment, in analyzing the results, and in drawing the correct answers and conclusions.

(See research and professional writings for *Practices 48, 49* and *50, 51.)*

54, 55 Allow your students to approach science problems and projects individually and to progress at their own rate of investigation and attainment.

Both the Elementary Science Advisory and Research Project (1) and ESS (2) represent their programs as highly individual and experimental where the children choose experiments and materials with which to work, develop their own goals or problems, and determine the manner and pace at which they will work.

A much more structured and sequenced approach, ISCS (3) for grades 7, 8, and 9, allows the children to progress through this laboratory centered course at their individual rates.

Individual or group open-ended laboratory experiments directed toward interdisciplinary ideas are presented by the MSCC-JHSP (4) project in a modified version of self-pacing.

The Oakleaf Individualized Elementary School Science (5) project provides concept development through individualized laboratory experiences.

1. (CD) Elementary Science Advisory and Research Project.
2. (CD) Elementary Science Study.
3. (CD) Intermediate Science Curriculum Study.
4. (CD) Michigan Science Curriculum Committee Junior High School Project.
5. (CD) Oakleaf Individualized Elementary School Science.

56, 57 Use televised science programs as a source of science information and instruction.

The literature on this practice is abundant but inconclusive. For the most part the teachers Brunberg (1), Nasca (2), Suchy (3), and Montag, Dubridge, and Samuels (4) praise the efficiency and merits of TV teaching of science in the elementary and junior high schools. They warn, however, to involve the students in activities along with the TV method of instruction.

The researchers Brish (5), Deutschman (6), Barrington (7), Tannenbaum (8), and Jacobs (9) are less enthusiastic about present practices due to mixed results in statistical studies. They point to many factors as possible causes in these results and encourage science educators toward the potential possibilities in this very efficient method of instruction. They seem especially encouraged about the use of closed-circuit television in laboratory demonstrations.

A study by The Ford Foundation (10) found in researches comparing television-taught and non-television-taught pupils in elementary and high schools that the television-taught achieved more in 165 comparisons and the non-television-taught achieved more in 86 comparisons. Jewett (11) and Guba (12) list specific areas for further research on the effects and effectiveness of television teaching.

1. (T) Brunberg, David, "Closed-Circuit Television—A Success in Science Instruction", *California Education,* Vol. 2, No. 9, May, 1965, pp. 7-8.

2. (T-R) Nasca, Don, "Science Recall and Closed Circuit Television Instruction", *The Journal of Educational Research,* Vol. 59, No. 2, Oct., 1963, pp. 77-79.

3. (T) Suchy, Robert R., "Radio and Television in Science and Mathematics", *National Association of Secondary School Principals Bulletin,* Vol. 50, Oct., 1966, p. 125.

4. (T) Montag, Betty Jo, Dubridge, Walter, and Samuels, William, "TV vs. Overcrowding in General Science", *The Science Teacher,* Vol. 31, April, 1964, pp. 51-58.

5. (R) Brish, W. M., "CCTV For Science", *Yearbook of Education,* 1960.

6. (R) Deutschman, T. J.; Barrow, L. C. & McMillan, A., "Efficiency of Different Methods of Communication", *AVCR,* No. 3, 1962.

7. (R) Barrington, H., "A Survey of Instructional Television Researches", *Educational Research,* Vol. 8, Nov., 1965, p. 8.

8. (R) Tannenbaum, R., "Instruction Through Television", *Encyclopedia of Educational Research,* 1960.

9. (R) Jacobs, J. N. and Grate, J., "Teaching Sixth Grade Science by TV", *Elementary School Journal,* Nov., 1962.

10. (R) The Ford Foundation Report, 1961, "Teaching by Television", *Ford Foundation and Fund for Advancement of Education,* 1961.

11. (AO) Jewett, Robert E., "The Effects of Television Teaching on the Classroom Teacher", *Educational Research Bulletin,* Vol. 40, No. 6, Sept., 1961.

12. (AO) Guba, Egon G., "Measuring the Effectiveness of Instructional Television", *Educational Research Bulletin,* Vol. 40, Sept., 1961, p. 153.

58, 59 Use field trips and/or science resource people as an integral part of your science instruction program.

The use of field trips and science resource people is not new but, unfortunately, rarely used as part of elementary and junior high school science instruction. Jacobson (1) says ". . . field experiences should be an integral part of science programs for the early adolescent." Well planned field trips with discussion both before and after to stimulate observation and analysis according to Tannenbaum, Stillman, and Piltz (2) ". . . are particularly valuable for teaching elementary science since many natural phenomena are understood better when they are seen."

Schulz (3) and the NSTA subcommittee on Local Action Programs suggest that local scientists be involved in the school's science curriculum to 1. "work with teachers to learn the capabilities and limitations of children and youth", 2. "provide counsel on the accuracy of curriculum materials", and 3. "assist teachers in understanding how scientists think and work."

Fischler (4) combines field trips and the help of science resource people by encouraging field trips to factories, laboratories, farms, and government agencies and by suggesting that scientists and engineers be invited frequently to contribute as a class studies various phases of science.

Josephson (5) recommends field trips for first graders and suggests techniques for growth in problem solving, observation, and reporting ability by this instructional method.

1. (AO) Jacobson, Willard J., "Science for the Early Adolescent", *School Science and Mathematics,* Vol. 62, 1962, pp. 365-373.

2. (AO) Tannenbaum, Harold E.; Stillman, Nathan; and Piltz, Albert, *Evaluation in Elementary School Science,* Office of Education, U. S. Department of Health, Education, and Welfare, 1964.

3. (AO) Schulz, Richard W., (Chairman), Subcommittee on Local Action Programs of the NSTA Curriculum Committee, "Planning a Local Action Program for Implementing Curriculum Development in Science", *Theory into Action . . . in Science Curriculum Development,* A Service Document of the National Science Teachers Assoc., 1964, pp. 32-40.

4. (AO) Fischler, Abraham S., *Modern Junior High School Science,* New York: Bureau of Publications, Teachers College, Columbia University, 1961.

5. (T) Josephson, Ruth A., "A Study of the Value of Field Trips for the Teaching of Natural History in the First Grade Curriculum of the Fox Point-Bayside School, Fox Point, Wisconsin", Masters Thesis, Ithaca, New York, Cornell University, 1952.

60, 61 Have your students bring in for study and discussion newspaper and magazine articles on scientific and technological applications, such as rockets, atom smashers, computers, etc.

Wittlin (1) presents the case and need for 1. public nurseries and kindergartens equipped with modern toys and books, 2. libraries of objects and learning aids in every school, and 3. specialized science teachers all leading to the scientific literacy of our future citizens. Polla, O'Hearn, and Gale (2) claim that science education at all levels must prepare all citizens to become an integral part of our modern society regardless of future occupation. They list a long bibliography with references to scientific literacy.

Bradley and Earp (3) showed that a person accustomed to working with elementary school age children, familiar with their vocabulary and concept level, but limited in science background could rewrite articles from the *Scientific American* magazine in such a way as to be readable and profitable to sixth grade pupils. Robinson (4) claims the desirable effects of teaching with science articles include: an enrichment of course contents, better development of science understanding by all kinds of students, and an improvement on the part of some students in attitude toward the course and interest in science articles.

1. (AO) Wittlin, Alma S., "Scientific Literacy Begins in the Elementary School," *Science Education,* Vol. 47, No. 4, Oct., 1963, pp. 331-342.
2. (AO) Pella, Milton O.; O'Hearn, George T.; Gale, Calvin W.; "Referents to Scientific Literacy", *Journal of Research in Science Teaching,* Vol. 4, No. 3, 1966, pp. 199-208.
3. (R) Bradley, R. C. and Earp, N. Wesley, "A Method of Producing Up-to-Date Science Material for Elementary Children", *Journal of Research in Science Teaching,* Vol. 4, No. 2, 1966, pp. 102-105.
4. (T) Robinson, Jack H., "Effects of Teaching with Science Articles", *Science Education,* Vol. 47, No. 1, Feb. 1963, pp. 73-83.

62, 63 Use films (full reel or single concept cartridge), filmstrips, overhead projectors, and/or recordings in connection with your science instruction.

Jacobson (1) says of good teachers that they will use ". . . a variety of teaching and learning materials: tradebooks and textbooks, films and filmstrips, radio and television, magazines and mimeographed materials." Tannenbaum, Stillman, and Piltz (2) in extending their discussion on the benefits of field trips observe that many phenomena do not lend themselves to personal experiences; and films, tapes, and similar devices are often valuable substitutes. Slade (3) emphasized this point with a meteorological example.

Hobbs (4) gives examples of keeping students up-to-date on the affairs of the National Aeronautics and Space Administration, and Reed and Ridgway (5) show the versatile practicality of the overhead projector.

1. (AO) Jacobson, Willard J., "The Science Manpower Project's K-12 Science Program", *The New School Science,* A Report to School Administrators on Regional Orientation Conferences in Science, AAAS Misc. Publ. No. 63-6.

2. (AO) Tannenbaum, Harold E.; Stillman, Nathan; and Piltz, Albert, *Evaluation in Elementary School Science,* Office of Education, U. S. Department of Health, Education, and Welfare, 1964.

3. (T) Slade, Mark, "Liberating a Complex Idea", *Educational Screen and Audiovisual Guide,* Vol. 44, January, 1965, pp. 20-21.

4. (T) Hobbs, Kenneth B., "The Space Age and Audiovisual Materials", *Educational Screen and Audiovisual Guide,* Vol. 41, July, 1962, pp. 366-369.

5. (T) Reed, Nancy J. and Ridgway, Joseph W., "Becoming the Pace Setters", *Educational Screen and Audiovisual Guide,* Vol. 43, May, 1964, p. 250.

64, 65 Use programed material, either in printed form or with a "teaching machine" as a method of teaching science to your students.

Skinner (1), Leahy (2), Anderson and Edwards (3), and Reiner (4) all extol the benefits of programed instruction in the form of machine, gadget, special book or cards as allowing self-teaching of many individuals in one class at different levels and rates of learning while being individually guided by one teacher. Thus the teacher will be allowed greater freedom for creative teaching in both remedial work for the slower students and enrichment for the talented ones.

The whole September issue of *Scientific American* magazine was devoted to the place of computers in our society. Suppes (5), speaking about "Computer Assisted Instruction", pointed to the potentials and pitfalls of CAI and the impact it may have on teachers' roles, changing curriculum and research in learning and instruction. The use of CAI to present the ISCS (6) seventh-grade materials complemented the concurrent classroom trial in providing a formative evaluation of written text and laboratory materials. According to Snyder, Flood, and Stuart (7), this CAI presentation focused on the interaction of the student and materials by reducing classroom variables and thus allowing for a closer scrutiny of the conceptual framework and sequencing of the ISCS curricular materials.

Leahy and Siegel (8) caution that programed instruction is only one of the tools of science education and the laboratory must remain at the heart of science instruction. They predict that programed instruction will release both the student and teacher for more laboratory work. The efficiency and effectiveness of combining programed instruction with laboratory experiences was borne out by Hedges and MacDougall (9) with fourth graders and by Nasca (10) with eighth grade students.

1. (AO) Skinner, B. F., "Teaching Machine", *Science,* Vol. 128, Oct., 1958, pp. 969-997.

2. (AO) Leahy, Daniel J., "Implications of Automatic for the Teaching of Science", *Science Education,* Vol. 46, No. 4, Oct., 1962, pp. 304-309.

3. (AO) Anderson, Kenneth E. and Edwards, Allen J., "The Educational Process and Programmed Instruction," *Science Education,* Vol. 47, No. 1, Feb., 1963, pp. 21-27.

4. (AO) Reiner, William B., "Programed Learning—A Useful Tool for the Science Educator", *The Science Teacher,* Vol. 29, Oct., 1962, pp. 26-33.

5.(AO-R) Suppes, Patrick, "The Use of Computers in Education", *Scientific American*, Sept., 1966, pp. 207-220.

6. (CD) Intermediate Science Curriculum Study.

7. (R-T) Snyder, William R.; Flood, Paul N.; and Stuart, Michael, "use of CAI in Evaluation of the ISCS Seventh-Grade Course", *Intermediate Science Curriculum Study Newsletter*, June, 1967.

8. (AO) Leahy, Daniel and Siegel, Bertram N., "The Science Teacher and Programed Instruction", *The Science Teacher*, Vol. 29, Oct., 1962, pp. 40-45.

9. (R) Hedges, William D. and MacDougall, Mary A., "Teaching Fourth Grade Science by Means of Programed Science Material with Laboratory Experiences, Phase III" *Science Education*, Vol. 49, No. 4, Oct., 1965, pp. 348-358.

10. (R) Nasca, Donald, "Effects of Varied Presentations of Laboratory Exercises Within Programed Materials on Specific Intellectual Factors of Science Problem Solving Behavior", *Science Education*, Vol. 50, No. 5, Dec., 1966, pp. 437-457.

66, 67 Teach your pupils science from a qualitative, descriptive point of view. Postpone the quantitative aspects of science and measurement until as high school students they reach a higher level of sophistication in mathematics.

In Piaget's (1) experiments with the development of quantity conceptions in children, he found that abstract responses to mass, weight, and volume appeared in a regular sequence that was related to age. These findings were reconfirmed by Elkind (2). Scott (3) applied these results, with success, to teaching and testing students in grades 3, 4, 5, and 6.

A strictly quantitative, detailed sequence of projects is proposed by Swartz (4) to be presented at various levels of elementary school science. He stresses the quantitative treatment, *appropriate* to the grade level, of phenomena which can be immediately observed and measured by the student. Githens (5) proposes a quantitative approach to physical science as a "... general education course, helpful to anyone, . . . regardless of destiny in life." Souers (6) lists activities designed to show the need for standards of measurement and to familiarize students with basic metric units through laboratory experiments and problem solving.

1. (AO) Piaget, J., *The Child's Conception of Numbers*, London: Routledge and Kegan Paul, 1952.

2. (AO) Elkind, David, "The Development of Quantitative Thinking: A Systematic Replication of Piaget's Studies", *The Journal of Genetic Psychology*, Vol. 98, 1961, pp. 37-46.

3.(AO-T) Scott, Lloyd, "A Study of the Case for Measurement in Elementary School Mathematics", *School Science and Mathematics*, Vol. 66, No. 8, pp. 714-722.

4. (CD) Swartz, Clifford, "Elementary School Science by a Quantitative Approach", *Journal of Research in Science Teaching*, Vol. 2, No. 4, 1964, pp. 349-355.

5. (CD) Githens, Sherwood, Jr., "Quantitative Physical Science for the Ninth Grade", *Journal of Research in Science Teaching,* Vol. 2, No. 4, 1964, pp. 345-358.

6. (T) Souers, Charles V. and Winslow, Donald R., "Ideas to Stimulate Lessons in Measurement for Upper Elementary and Junior High School Students", *School Science and Mathematics,* Vol. 66, No. 6, June, 1966, pp. 532-534.

68, 69 Encourage long-term science projects conducted either by the class or by groups. Example: Keep a weather chart over a period of one or two months.

Accepting the objectives of science instruction which develop investigative skills in your students (see the researches and professional articles under OBJECTIVES) and accepting the proposition that through their own inquiries and discoveries (see *Practices 48, 49* and *50, 51)* your students will acquire these skills, leads to the conclusion that solving problems by means of long-term or short-term scientific investigations is an effective means of science education. Lists of such problems and projects can be found in books by Hone, Joseph, Victor, and Brandwein (1), Blough and Schwartz (2), and Kambly and Suttle (3). Lists of other sources are given by Stollberg (4). Student projects for the more able students are described by Woodburn (5).

1. (AO) Hone, Elizabeth B; Joseph, Alexander; Victor, Edward; and Brandwein, Paul F., *A Sourcebook for Elementary Science,* Harcourt, Brace, and World, 1962.

2. (AO) Blough, Glenn O. and Schwartz, Julius, *Elementary School Science and How to Teach It,* New York: Holt, Rinehart and Winston, 1964.

3. (AO) Kambly, Paul E. and Suttle, John E., *Teaching Elementary School Science,* New York: The Ronald Press Company, 1963.

4. (AO) Stollberg, Robert, "Materials for Elementary School Science", *The National Elementary School Principal,* Sept., 1953, pp. 256-273.

5. (AO) Woodburn, John H., *Encouraging Future Scientists: Student Projects,* National Science Teachers Association, Future Scientists of America Bulletin, Washington: National Education Association, 1958.

70, 71 Encourage your students to ask questions about science, and try to answer these questions with explicit, non-ambiguous answers. (Even if you must wait to reply until you have looked up the correct answer.)

Because "the correct answer" has become such an ambiguous term in this age of rapidly changing scientific theories and concepts, science educators such as Hurd (1) are emphasizing education based upon skills in finding out rather than a bulk of information that may soon become obsolete. As Blackwood (2) says, "Children will ask questions about their environment and should be given help (not answers) in finding answers to these questions". Rogers (3) claims we need more emphasis on ". . . where scientific knowledge comes from, how it is gained, codified, reinterpreted . . . and more estimates rather than too much concern for precise measurements . . ." Tyler (4) adds to this by saying the student must understand science as ". . . a continuing process of inquiry, not as a set of firm answers to particular questions". Hurd sums this up by pointing the student to see that scientific knowledge has a ". . . certain dynamic quality and that it is likely to shift in meaning and status with time."

1. (AO) Hurd, Paul DeHart, "Toward a Theory of Science Education Consistent with Modern Science", *Theory into Action . . . in Science Curriculum Development,* A Service Document of the National Science Teachers Association, 1964.

2. (AO) Blackwood, Paul E., *Science Teaching in the Elementary Schools: A Survey of Practices,* Office of Education, U. S. Department of Health, Education, and Welfare, 1965.

3. (AO) Rogers, Eric M., "The Research Scientist Looks at the Purpose of Science-Teaching", *Rethinking Science Education,* The Fifty-ninth Yearbook of the National Society for the Study of Education, Part I, Chicago: The University of Chicago Press, 1960, pp. 19-22.

4. (AO) Tyler, Ralph W., "The Behavioral Scientist Looks at the Purposes of Science-Teaching", *Rethinking Science Education,* The Fifty-ninth Yearbook of the National Society for the Study of Education, Part I, Chicago: The University of Chicago Press, 1960, pp. 31-33.

5. (AO) Hurd, Paul DeHart, "Science Education for Changing Times, Summary", *Rethinking Science Education,* The Fifty-ninth Yearbook of the National Society for the Study of Education, Part I, Chicago: The University of Chicago Press, 1960, pp. 33-37.

72, 73 Present your students with the concept of "model building". Construct mental or physical models as possible explanations for observed behavior of nature. Example: The kinetic theory of gas molecules randomly bouncing around is a model for the explanation of the behavior of gases.

Burkman (1) in writing about the ISCS (2) project cites "Model Building" and "the Structure of Matter" as the organizing threads for the eighth-grade program. Livermore (3) presents one of the "Integrated Processes" of AAAS (4) as "Formulating Models". Karplus (5) speaks of the student's "Conceptual Framework" gained through the SCIS (6) courses, and Atkin (7) describes the 3rd book of ESSP (8) as containing "Conceptual Models for Observed Motion".

Wittrock (9) and Mogar (10) found that the elementary school child's conception of physical relationships can be enhanced by instruction on mental and physical models and he can ". . . learn, retain and transfer the rudiments of the Kinetic Molecular Theory".

Dennis (11) attempted to determine the most effective level for presenting concepts relating to the Kinetic Theory of Matter to elementary school children. Anderson (12) found that elementary school children were able to formulate mental models to explain their observations of natural phenomena and that this ability increased with the age and I.Q. of the children tested.

1. (CD) Burkman, Ernest, "Summer Writing Conference Announced", *Intermediate Science Curriculum Study Newsletter,* June, 1967.
2. (CD) Intermediate Science Curriculum Study.
3. (CD) Livermore, A. H., "The Process Approach of the AAAS Commission on Science Education", *Journal of Research in Science Teaching,* Vol. 2, No. 4, 1964, pp. 271-282.
4. (CD) AAAS Commission on Science Education.
5. (CD) Karplus, Robert, "The Science Curriculum Improvement Study", *Journal of Research in Science Teaching,* Vol. 2, No. 4, 1964, pp. 293-303.
6. (CD) Science Curriculum Improvement Study.
7. (CD) Atkin, J. Myron, "University of Illinois Elementary-School Science Project, 1964", *Journal of Research in Science Teaching,* Vol. 2, No. 4, 1964, pp. 328-329.
8. (CD) Elementary School Science Project.
9. (R) Wittrock, M. C., "Response Mode in the Programing of Kinetic Molecular Theory Concepts", *Journal of Educational Psychology,* Vol. 54, 1963, pp. 89-93.
10. (R) Mogar, Mariannina, "Children's Causal Reasoning About Natural Phenomena", *Child Development,* Vol. 31, 1960, pp. 59-65.
11. (R) Dennis, David M., "The Introduction of Concepts in Kinetic Molecular Theory to Children", *Journal of Research in Science Teaching,* Vol. 4, No. 2, 1966, pp. 106-111.
12. (R) Anderson, Ronald D., "Children's Ability to Formulate Mental Models to Explain Natural Phenomena", *Journal of Research in Science Teaching,* Vol. 3, No. 4, 1965, pp. 326-332.

74, 75 Point out to your students the complexity of science and the need for the most intelligent to continue in scientific studies.

Emphasizing the complexities of science may drive many elementary school students away from any science study, but emphasizing the simple investigative skills of student-inquiry, according to Suchman (1), motivates the child toward conceptual growth.

Two basic precepts of science educators are stated by Blough, Blackwood, Hill, and Schwartz (2):

> "A program in elementary science should be provided for *all* children".

> "The development of scientific attitudes is basic in a good elementary science program".

The needs for improved attitudes toward science by an educated citizenry are posed by Castel and Yager (3) in discussing the interaction between science and culture. Gruber (4) sums up the overall effects that a teacher may have on student attitude and interest in science with the following statement: "Choose the image of science you want to give your students. In the last analysis, your image of science will depend upon your image of man".

1.(AO-R)Suchman, J. Richard, "The Elementary School Training Program in Scientific Inquiry", University of Illinois, 1962.

2. (AO) Blough, Glenn O.; Blackwood, Paul E.; Hill, Katherine E.; and Schwartz, Julius, "Developing Science Programs in the Elementary School", *Rethinking Science Education,* The Fifty-ninth Yearbook of the National Society for the Study of Education, Part I, Chicago: The University of Chicago Press, 1960, pp. 112-135.

3. (AO) Castel, J. Doyle and Yager, Robert E., "Science as Mind-Affected and Mind-Effecting Inquiry", *Journal of Research in Science Teaching,* Vol. 4, pp. 127-136.

4. (AO) Gruber, Howard E., "Education and the Image of Man", *Journal of Research in Science Teaching*, Vol. 1, No. 2, 1963, pp. 162-169.

76, 77 Combine your teaching of arithmetic and mathematical relationships with your instruction on scientific concepts and their relationships.

Schaaf (1) finds many scientific concepts closely related to mathematical concepts (e.g.—ratio, variable, constant, function, proportion, measurement, error, precision, etc.) and believes that if introduced in grades 7-9 with mathematics the two disciplines would receive mutual benefits. Souers (2) and Gorman (3) both present actual trials of teaching mathematics and science as a combined course. Grove and Grove (4) tried the same experiment in elementary grades as did the MINNEMAST (5) project as reported by Rosenbloom (6). The School Mathematics Study Group (7) reversed the process of applying mathematics to science by teaching mathematics through Science.

Poll (8) extends the goals of science education by proposing a combination course of science, mathematics, social studies, and English to provide the student with a "learning environment" where he can order some measure of his own learning experience.

1. (R) Schaaf, William L., "Scientific Concepts in the Junior High School Mathematics Curriculum", *School Science and Mathematics*, Vol. 65, No. 7, Oct., 1965, pp. 614-624.

2. (T) Souers, Charles V., "An Integrated Math-Science Activity for Process Teaching at the Jr. High School Level", *School Science and Mathematics*, Vol. 66, No. 1, Jan., 1966, pp. 3-5.

3. (T) Gorman, Frank H., "An Experiment in Integrating Seventh and Eighth Grade Science and Mathematics", *Science Education*, Dec. 27, 1943, pp. 130-134.

4. (R-T) Grove, Ethel L. & Grove, Ewert L., "An Experiment in the Integration of Mathematics and Science", *School Science and Mathematics*, June, 1952, pp. 467-470.

5. (CD) Minnesota Mathematics and Science Teaching Project.

6. (R) Rosenbloom, T. C., "The Minnesota Mathematics and Science Teaching Project", Journal of Research in Science Teaching, Vol. 1, Sept., 1963, pp. 276-280.

7. (CD) School Mathematics Study Group, "Mathematics through Science", Part 1: "Measurement and Graphing" Part 2: "Graphing, Equations, and Linear Functions" Part 3: "An Experimental Approach to Functions", Pasadena: A. C. Vroman, Inc., 1963.

8. (AO) Poll, Ernest N., "Diversified Learning Situations—A Student Choice", *School Science and Mathematics*, Vol. 65, No. 1, Jan., 1965, pp. 62-67.

78, 79 Include the introduction of scientific information in your reading and English assignments. Have the students read scientific articles and present written and oral reports on specific science topics.

Higgens (1) outlines the mutual benefits and obvious interaction between science and English in communication, clarity of meaning, and accuracy in reporting and verbal reasoning. Smith (2) points to the increasing number of people whose jobs are dependent upon science that uses a specialized vocabulary and whose processes are explained in technical verbiage in a plea for teaching reading of and with science. Podendorf (3) cites a consensus of opinion by the Council for Elementary Science International that science through reading is one way to give children the tools of knowledge which can be applied in scientific investigation. Mattila (4) sees hope in the fact that some elementary schools are recognizing the value of specific instruction in reading as related to science and incorporating this into their curriculum. Ediger (5) suggests two directions for reading in the area of elementary school science: 1. motivation to read and interest in reading from environment and laboratory observations leading to questions, and 2. purposeful activities for the pupils to gain meaning and understanding from the reading in the area of elementary school science.

1. (AO) Higgens, John J., "Hard Facts", *English Language Teaching*, Vol. 21, No. 1, Oct., 1966, pp. 55-60.

2. (AO) Smith, Nila B., "Reading in Subject Matter Fields", *Educational Leadership*, Vol. 2, No. 6, Mar., 1965, pp. 382-385.

3. (AO) Podendorf, Illa, "Accent on Thinking in Science in the Sixties in the Classroom Through Reading and Research", *Science Education,* Vol. 46, No. 2, Mar., 1962, pp. 184-186.

4. (AO) Mattila, Ruth H., "Accent on Thinking Through Reading at the Intermediate and Upper Grade Levels", *Science Education,* Vol. 46, No. 2, Mar., 1962, pp. 174-179.

5. (AO) Ediger, Marlow, "Reading in the Elementary School Science Program", *Science Education,* Vol. 49, No. 4, Oct., 1965, pp. 389-390.

80, 81 Teach your students science and social studies together as a unified program of instruction showing the inter-dependency of the development of society and scientific progress.

Collin (1) points out only one of the many places where the fast moving events of our culture (in this case, NASA's goals and contributions to science) are having a direct impact on science education. Hurd (2) emphasizes the need for students (future citizens) to understand the relation of basic research to applied research and the interplay of this applied technology and human affairs. In our society today, these are of utmost importance in forming public policy.

McAulay (3) poses the possibility of science becoming the core of the elementary curriculum and being correlated with other courses, such as social studies. In Baltimore (4) public schools, elementary school science is already being included with social studies and the areas of health and safety, and Hunt (5) tells of a trial program in junior high school where a three-teacher team taught a combination science and social studies course to seventh grade students.

Blough, Blackwood, Hill, and Schwartz (6) state that of all subjects social studies is the one most closely allied to elementary school science.

Also see the researches and professional articles under Practice 60, 61.

1. (AO) Collin, Everett E., "The Implications of Space Exploration to Science and Mathematics Education", *School Science and Mathematics,* Vol. 65, No. 7, Oct., 1965, pp. 701-710.

2. (AO) Hurd, Paul DeHart, "Science Education for Changing Times, Summary". *Rethinking Science Education,* The Fifty-ninth Yearbook of the National Society for the Study of Education, Part I, Chicago: The University of Chicago Press, 1960, pp. 33-38.

3. (AO) McAulay, J. D., "Elementary Education—Five Straws in the Wind", *Phi Delta Kappa,* Vol. 41, June, 1960, pp. 394-396.

4. (T) Baltimore, *A Guide to Elementary Education,* Baltimore, Maryland: Baltimore Public Schools, 1955.

5. (R) Hunt, Edward G., "Team Teaching in Junior High School Science and Social Studies", University of Connecticut, 1963, Ph.D.

6. (AO) Blough, Glenn O.; Blackwood, Paul E.; Hill, Katherine E.; and Schwartz, Julius, "Developing Science Programs in the Elementary School", *Rethinking Science Education,* The Fifty-ninth Yearbook of the National Society for the Study of Education, Part I, Chicago: The University of Chicago Press, 1960, pp. 112-135.

82, 83 Starting with various simple notions, teach basic physics or biology or chemistry in the early grades. *Examples:* Not "how a seesaw works" but the relationship between force and energy; not "how to feed a rabbit" but the process of metabolism.

Blough, Blackwood, Hill, and Schwartz (1) maintain that elementary school science much too often is merely a watered-down version of high school biology, physics, chemistry, or astronomy. Although elementary school science must develop the structure and methods of discovery from these organized sciences, it must be based on the needs of the children and their investigation of their immediate environment to meet present day and future needs. Wohlwill (2) and Ausubel (3) both quote Piaget (4) in presenting a case for science education to progress from completely concrete activities in the early grades toward more and more abstractions as the student matures until he can mentally master the abstract concepts called for in biology, physics, chemistry, geology, and astronomy.

Even at the sixth grade level, Beitzel (5) found in an attempt to teach chemistry that the students preferred the topics involving laboratory activities much more than the abstractions of equations.

1. (AO) Blough, Glenn O.; Blackwood, Paul E.; Hill, Katherine E.; and Schwartz, Julius, "Developing Science Programs in the Elementary School", *Rethinking Science Education,* The Fifty Ninth Yearbook of the National Society for the Study of Education, Part I, Chicago: The University of Chicago Press, 1960, pp. 112-135.

2. (AO) Wohlwill, Joachim F., "Cognitive Development and the Learning of Elementary Concepts", *Journal of Research in Science Teaching,* Vol. 2, No. 3, 1964, pp. 222-226.

3. (AO) Ausubel, David P., "The Transition from Concrete to Abstract Cognitive Functioning: Theoretical Issues and Implications for Education", *Journal of Research in Science Teaching,* Vol. 2, No. 3, 1964, pp. 261-266.

4. (R) Piaget, J., *The Child's Conception of the World,* Paterson, New Jersey: Littlefield, Adams and Co., 1963.

5. (T) Beitzel, Richard E., "The Preparation and Evaluation of a Technically Oriented Experiment-Centered Sixth Grade Chemistry Unit", The State University of Iowa, 1963, Ph.D.—Chairman—T. R. Porter.

84, 85 Rather than emphasizing content, impress upon your students the joy of learning how to learn through scientific investigation.

Poincare (1), a French mathematician and philosopher, described the true and often misunderstood motive of science: "The scientist does not study nature because it is useful; he studies it because he delights in it, and he delights in it because it is beautiful." He explains this beauty as ". . . that profounder beauty which comes from the harmonious order of parts and which a pure intelligence can grasp."

This awe at being able to understand something of the simplicity of nature sounds much different from comprehending some of the complexities of our advanced technologies. And, indeed, it is different. As is emphasized again and again in the research and professional articles cited in this pamphlet, to teach science in the elementary and junior high schools is to teach children to observe, investigate, analyze, and discover the beautiful order of nature. The engineering of the technological applications may come later for those college students who are interested and inclined toward this important aspect of our civilization. But the job of the elementary and junior high school teacher is one of making sure that *all* aware of the more fundamental processes of science.

As Barnard (2) points out, "Were it not that nature works in essentially simple fashion, there could be no science."

1. (AO) Poincare, Henri, *The Value of Science,* Translated by George Bruce Halsted, New York: Science Press, 1907.

2. (AO) Barnard, J. Darroll, "The Role of Science in our Culture", *Rethinking Science Education,* The Fifty-ninth Yearbook of the National Society for the Study of Education, Part I, Chicago: The University of Chicago Press, 1960, pp. 1-17.

86, 87 Try to identify the science-oriented and science-gifted students, and give them extra projects and science assignments.

Martinson (1) believes "Identification of gifted children and provision of appropriate programs for them would maximize each child's potential for intellectual development, and untold benefits would accrue to both the individuals and society." Gallagher and Rogge (2), in citing many researches, believe that the identification of gifted children by means of individual I.Q. tests and achievement tests can be extended by new measuring instruments to yield a broader definition of giftedness itself.

Brandwein (3), MacCurdy (4), and Neivert (5) agree on at least one aspect of developing future scientists once the gifted and interested student has been identified, and that is the need for special opportunities for these students to become actively involved in some form of scientific investigation.

Evans (6) describes one of many new ways for gifted and interested students to gain enrichment through summer programs and camps devoted to the science and arts.

1. (AO) Martinson, Ruth A., "Issues in the Identification of the Gifted", *Exceptional Children,* Vol. 33, No. 1, Sept., 1966, pp. 13-16.

2. (R) Gallagher, James J. and Rogge, William, "The Gifted", *Review of Educational Research,* Vol. 36, No. 1, Feb., 1966, pp. 37-55.

3. (AO) Brandwein, Paul, *The Gifted Student as Future Scientist,* New York: Harcourt, Brace and Co., 1955.

4. (R) MacCurdy, Robert Douglas, "Characteristics of Superior Science Students and Their Own Subgroups", *Science Education,* Vol. 40, Feb., 1956, pp. 3-7.

5. (R) Neivert, Aylvia S., "Identification of Students with Science Potential", Unpublished Doctor's Dissertation, Teachers College, Columbia University, 1955.

88, 89 Ask your students to memorize definitions of scientific words.

Asking students to memorize definitions of scientific words or asking them to be able to use them in directions or reports of active investigation seems to be what Wittlin (1) calls the difference between ". . . adequacy or excellence in terms of scientific literacy."

Rather than determining the children's achievements in science by their ability to "parrot-back" definitions of words, Navarra (2), Schenke (3), West (4), and Hill (5) all periodically recorded by various means the behavior of the individual children while involved in the activities of their respective science programs. This allowed an assessment of the progress the children made through the school year and their increased use of the scientific terms in reading, communicating with peers, and in writing reports. Garone (6) found this latter method of periodic reports especially useful in progress evaluation.

1. (AO) Wittlin, Alma S., "Scientific Literacy Begins in the Elementary School", *Science Education,* Vol. 47, No. 4, Oct., 1963, pp. 331-342.

2. (R) Navarra, John G., *The Development of Scientific Concepts in a Child,* New York: Bureau of Publication, Teachers College, Columbia University, 1955.

3. (R) Schenke, Lahron, "Information Sources Children Use", *Science Education,* Vol. 40, Apr., 1956, pp. 232-237.

4. (R) West, Joe Y., *A Technique for Appraising Certain Observable Behavior of Children in Science in Elementary Schools,* New York: Bureau of Publications, Teachers College, Columbia University, 1937.

5. (R) Hill, Katherine E., *Children's Contributions in Science Discussion,* New York: Bureau of Publications, Teachers College, Columbia University, 1947.

6. (R) Garone, John, "Acquiring Knowledge and Attaining Understanding of Children's Scientific Concept Development", Unpublished Doctoral Project, Teachers College, Columbia University, 1951.

90, 91 Test the scientific achievement of your students by their ability to answer specific questions in terms of established scientific facts.

If by facts you mean the recall of specific "isolable" bits of information, you are testing for what Bloom (1) calls the lowest step in the hierarchy of educational objectives.

Blough, Hill, Jacobson, and Piltz (2) claim the primary concern in evaluating should be to determine the nature of the changes in students behavioral abilities. "It is not enough for the pupil to be able to recite facts. Facts should make a difference in behavior."

If you wish the teaching of science to yield benefits for your students in other areas and in later years, Bruner (3) says that the teaching and learning of structure, rather than simple mastery of facts is at the center of such transfer.

Novak (4) claims that students taught the processes of investigative science and the formulation of concepts learn as much or more facts and retain them longer than those taught with emphasis on fact learning.

1. (AO) Bloom, Benjamin S. (Ed), *Taxonomy of Educational Objectives,* New York: David McKay Company, 1956.
2. (AO) Blough, Glenn O.; Hill, Katherine E.; Jacobson, Willard; and Piltz, Albert, "Teaching and Evaluating Science in the Elementary School", *Rethinking Science Education,* The Fifty-ninth Yearbook of the National Society for the Study of Education, Part I, Chicago: The University of Chicago Press, 1960, pp. 136-151.
3. (AO) Bruner, Jerome S., *The Process of Education,* Cambridge: Harvard University Press, 1966, pp. 17-32.
4. (AO) Novak, Joseph D., "Science in the Junior High School", *School Science and Mathematics,* Vol. 61, Dec., 1961, pp. 701-706.

92, 93 Ask your students to memorize classification schemes and definitions in biology as a scientific approach to nature study.

Carpenter (1) and Hanfmann and Kasanin (2) found that classification, schemes, and concepts are more efficiently learned, retained, and verbalized by the student when the student has an opportunity to manipulate and study objects than when he learns the verbiage by rote memorization. Ramsey and Wiandt (3) found that a more complete coverage of science topics was permitted by individual science projects and the memorization of schemes and definitions came about naturally as needed for each new topic the students met.

As pointed out in *Practice 92, 93,* ability to recall facts is not so important but rather what the student can do within the intellectual framework of acquired (not just memorized) facts. Bruner (4) believes the child can be helped to pass progressively from the thinking by using objects to the more abstract thinking by using schemes and concepts; not by the logic of expository teaching but by letting the child learn by doing.

1. (R) Carpenter, Finley, "The Effect of Different Learning Methods on Concept Formation", *Science Education,* Vol. 40, No. 4, Oct., 1956, pp. 282-285.

2. (R) Hanfmann, E., and Kasanin, J., "A Method for the Study of Concept Formation", *Journal of Psychology,* Vol. 3, 1937.

3. (R) Ramsey, Irvin L., and Wiandt, Sandra Lee, "Individualizing Elementary School Science", *School Science and Mathematics,* Vol. 67, No. 5, May, 1967, pp. 419-427.

4. (AO) Bruner, Jerome S., *The Process of Education,* Cambridge: Harvard University Press, 1966, pp. 33-54.

94, 95 Evaluate your students' achievements in problem solving by testing them on problems very similar to those assigned as homework and/or worked in class.

There are probably as many approaches to solving scientific problems as there are scientists trying to solve them. If the teacher explains his own method of problem-solving, according to Bruner (1), the student becomes a "passive listener." If the student is guided into developing and practicing his own methods of problem-solving, his discoveries are themselves both motivators and rewards.

Goodnow and Pettingrew (2) and Hunter (3) found that solving problems of a certain set tends to improve a student's skill with problems which fit that set (i.e., of a similar nature). Adams (4) found that a group trained on repeated presentations of the same problem was more proficient in solving a new problem of the same set than a group trained on a number of different problems.

Weir (5), using a game-type activity, indicated that younger subjects developed problem-solving skills at a more rapid rate.

This all seems to say that in teaching science in the elementary and junior high school, if problem-solving by students is your goal, give them much practice investigating and solving problems in the laboratory.

1. (AO) Bruner, Jerome S., *On Knowing, Essays for the Left Hand,* Cambridge: Harvard University Press, 1962.

2. (R) Goodnow, J. J. and Pettingrew, T. F., "Effect of Prior Patterns of Experience Upon Strategies and Learning Sets", *Journal of Experimental Psychology,* Vol. 49, June, 1955, pp. 381-389.

3. (R) Hunter, I. M. L., "The Influence of Mental Set on Problem-Solving", *British Journal of Psychology,* Vol. 47, Feb., 1956, pp. 63-64.

4. (R) Adams, Jack, "Multiple Versus Single Problem Training in Human Problem-Solving", *Journal of Experimental Psychology,* Vol. 48, July, 1954, pp. 15-18.

5. (R) Weir, Morton W., "Developmental Changes in Problem-Solving Strategies", *Psychological Review,* Vol. 71, Nov., 1964, pp. 473-490.

96, 97 By increased permissiveness in scientific investigation, teach and test your students on increased "creativity" rather than achievement in either factual information or structural relationship in a particular discipline.

According to Bruner and Clinchy (1), problem-solving can be divided into two possible approaches: 1. analytic and 2. intuitive. The second may be enhanced by teaching students to look for clues and short-cuts in an inquiry approach to problem-solving. Baldwin (2) calls intuition a "disciplined guess" that has both freedom and constraint balanced in "creative thinking." Baldwin further asserts that, in varying amounts, this "creativity" can be developed in young children by means of games pointed toward constructive goals of discovery.

Spaulding (3) found that by responding to social and emotional qualities rather than student achievement in one case or by formal teacher controlled group-instruction in the other, teachers had a negative effect on the flexibility and originality of their students.

Bruner (4) sums up what is meant by teaching for creativity with a plan to ". . . train the students in the use of their mind." Perhaps the best way to do this is by the example of creative and innovative teaching.

1. (AO) Bruner, Jerome S., and Clinchy, Blythe, "Towards a Disciplined Intuition", *Learning About Learning,* a conference report, Jerome S. Bruner (Ed.), Bureau of Research, Office of Education, U. S. Department of HEW, Washington: U. S. Government Printing Office, 1966.

2. (AO) Baldwin, Alfred, "The Development of Intuition", *Learning About Learning,* a conference report, Jerome S. Bruner (Ed.), Bureau of Research, Office of Education, U. S. Department of HEW, Washington: U. S. Government Printing Office, 1966.

3. (R) Spaulding, Robert L., "What Teacher Attributes Bring Out the Best in Gifted Children? *Gifted Child Quarterly,* Vol. 7, Winter, 1963, pp. 150-156.

4. (AO) Bruner, Jerome S., "Character, Education, and Curriculum", *Learning About Learning,* a conference report, Jerome S. Bruner (Ed.) Bureau of Research, Office of Education, U. S. Department of HEW, Washington: U. S. Government Printing Office, 1966.

98, 99 Accentuate the intrinsic rewards of self-learning and making scientific discoveries rather than the pressure of grade and finding specific numerical answers.

Bruner (1) notes that self-discovery and investigation by children lead them from learning for extrinsic reasons to learning for intrinsic rewards. Bruner and Caron (2) conducted studies of over-achievers in early grades who sought parental or teacher approval. Tests showed these children to develop more slowly in analytic ability.

The intellectual and esthetic values of scientific discovery are stressed by Shamos (3) and Kline (4) as important in a child's complete education.

The scientist's point of view concerning the act of discovery is expressed by Snow (5) when he says "Anyone who has ever worked in any science knows how much esthetic joy he has obtained. The literature of scientific discovery is full of this esthetic joy."

1. (AO) Bruner, Jerome S., "The Act of Discovery", *Harvard Educational Review,* Vol. 31, No. 1, 1961, pp. 21-32.

2. (R) Bruner, Jerome S. and Caron, A. J., "Cognition, Anxiety, and Achievement in the Preadolescent", *Journal of Educational Psychology,* 1967.

3. (AO) Shamos, Morris H., "Science and Common Sense", *The Science Teacher,* Vol. 29, No. 5, Sept., 1962, pp. 7-11.

4. (AO) Kline, Morris, "The Liberal Education Values of Science", *The Science Teacher,* Vol. 32, No. 8, Nov., 1965, pp. 22-24.

5.(AO-R)Snow, Charles P., "Appreciations in Science", *Science,* Vol. 133, Jan. 27, pp. 256-259.

Current Trends

Authoritative opinion, extensive research, collaborative efforts of scientists and experts in child development working with teachers on curriculum development, and teachers' increasing awareness that all future citizens in our science-oriented society need to acquire scientific knowledge and develop problem-solving skills have affected teaching practices in elementary and junior high schools.

Among the trends that now characterize these contemporary practices, the following represent emerging and specific criteria and approaches.

Rationale:

From general ambiguous goals to specific testable objectives of desired changes in students' behavior.

From science for a few to the necessity of science for all.

From teaching science as a topic to teaching students to observe, inquire and discover; in other words, to use their minds.

Curriculum:

From science as a separate discipline to science as the core of an interdisciplinary course involving social studies, mathematics and reading.

From a qualitative to a more quantitative approach.

From courses based on content and adult logic to courses based on student needs and maturity.

Materials:

From one textbook as the primary instructional tool to the use of television, field trips, resource personnel, films, film-loops, records, overhead projectors, etc.

From science texts written by a few authors to science courses (text, teacher's guide, experiments and teaching aids) developed with trials and evaluation by a large group of scientists, psychologists, education specialists, and teachers in a cooperative effort.

From "atomistic" packages of content to sequenced materials with each new skill building upon previously acquired skills.

Techniques:

From content lectures by teachers to process-centered student investigations.

From proving theories by experiments to experiments which lead students toward discovering scientific relationships.

From the self-contained classroom teacher to special science consultants and/or special science teachers and some team teaching.

From all students moving through a course at the same rate to a self-pacing individualized study of science topics—often through the use of programed materials.

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Appendix
Curriculum Development Projects Cited in the SUPPLEMENT

AAAS Commission on Science Education
John R. Mayor and Arthur H. Livermore
American Association for the Advancement of Science
1515 Massachusetts Ave., N.W.
Washington, D. C. 20005

Elementary-School Science Project
J. Myron Atkin
University of Illinois
805 West Pennsylvania Avenue
Urbana, Illinois 61801

Elementary Science Advisory and Research Project
Prof. David Hawkins
Elementary Science Advisory Center
Ketchum 306W, University of Colorado
Boulder, Colorado 80302

Elementary Science Study
Charles Walcott
55 Chapel Street
Newton, Mass. 02160

Intermediate Science Curriculum Study
Prof. Ernest Burkman
Kellum Hall Basement
Florida State University
Tallahassee, Florida 32306

Introductory Physical Science
Uri Habor-Schaim
Educational Services Incorporated
55 Chapel Street
Newton, Mass. 02160

Michigan Science Curriculum Junior High School Project
Dr. W. C. Van Deventer
Department of Biology
Western Michigan University
Kalamazoo, Michigan 49001

Minnesota Mathematics and Science Teaching Project
James H. Werntz, Jr.
720 Washington Ave., S.E.
Minneapolis, Minnesota 55414

Oakleaf Individualized Elementary School Science
Dr. John Bolvin
Learning Research and Development Center
160 N. Craig Street
University of Pittsburgh
Pittsburgh, Pennsylvania 15213

School Science Curriculum Project
Richard F. P. Salinger
805 West Pennsylvania Avenue
University of Illinois 61801

Science Curriculum Improvement Study
Robert Karplus
Physics Department
University of California
Berkeley, California 94720

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