MAJOR ELEMENTARY SCIENCE PROGRAM MODELS: LOOKING BACK FOR THE SOURCE OF WISDOM

Efforts began earlier, but it was the launching of the Soviet satellite Sputnik in 1957 that caused the most serious attempts at science curriculum reform. During the twenty-five years after Sputnik, $2 billion was spent to support mathematics and science education in elementary and secondary schools. The main goal then, as many believe it should be now, was to prepare future scientists and engineers, mostly out of a concern for national defense. As important as this goal is, we now know that defense issues rise and fall in urgency and that “this is a goal that is appropriate for only 3 percent of high school graduates, and a goal where we have traditionally spent 95 percent of our time, efforts, resources and attention” (Yager, 1984, p. 196).

The Alphabet Soup

The decade after Sputnik is known for its alphabet soup elementary science programs (see Table 11w.1). Three programs developed during that decade are worth mentioning now because of their goals, their effects on children’s learning, and the eventually improved quality of modern textbooks and other curriculum materials. Several of the assumptions the programs were based on have been supported over time by a growing body of research, while other assumptions have fallen from favor. The programs we refer to here are known as SAPA, SCIS, and ESS.

Science—A Process Approach (SAPA), Science Curriculum Improvement Study (SCIS), and the Elementary Science Study (ESS) were regarded as innovative programs in their day. Designed and field-tested during the 1960s and then revised during the 1970s, these experimental programs had several features in common:

• They were developed by teams of scientists, psychologists, educators, and professional curriculum specialists rather than written by single authors or single expert specialists.

• Federal funds were widely available for development, research, field testing, dissemination, and teacher inservice training.

• Each project was developed from particular assumptions about learning drawn from prominent theories and used to form a specific framework for each project. Behavioral and cognitive-development psychology had major influences.

• Each project was developed from what were assumed to be the ways children learned best. Specific teaching approaches were emphasized and were used to help children learn the ways and knowledge of science and to develop the attitudes of scientists.
Active pupil learning was assumed to be very important. Each project provided hands-on learning experiences for all children because it was assumed that manipulatives help children learn best.

The projects did not provide a standard textbook for each child. In fact, a workbook for recording observations was as close as some children came to anything that resembled a textbook.

There was no attempt to teach all that should be known about science. Specific science processes or content areas were selected for each project, thus narrowing the field of topics to a specialized few.

Attention was given to the basic ideas of science, the concepts and theories, with the intention of increasing the number of citizens who would seek careers in science and engineering.

The programs were conveniently packaged. Equipment was included with curriculum materials. This made the programs easier to use and reduced teacher preparation time by eliminating the need to gather diverse equipment.

Mathematical skills were emphasized. The programs were more quantitative than qualitative. Emphasis was placed on student observation, careful measurement, and the use of appropriate calculations to form ideas or reach conclusions.

Science was taught as a subject by itself and was not associated with social studies, health, or reading. At times, science was treated as a pure subject that was believed to have inherent value for all children.

The teacher’s role changed. Teachers used such less direct methods of teaching as inquiry and functioned as questioners and guides for students. They

<table>
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<th>TABLE 11W.1 Examples of Alphabet Soup Elementary Science Programs</th>
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<td>SAPA (Science—A Process Approach), American Association for</td>
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<tr>
<td>the Advancement of Science Commission on Science Education,</td>
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<td>1963</td>
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<td>COPES (Conceptually Oriented Program in Elementary Science),</td>
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<td>ESSP (Elementary School Science Project), University of</td>
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<td>California, Berkeley, 1962</td>
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<td>University, 1964</td>
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<tr>
<td>ESS (Elementary Science Study), 1964</td>
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<td>IDP (Inquiry Development Program), 1962</td>
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<td>MinneMAST (Minnesota Mathematics and Science Teaching</td>
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<td>Project), 1966</td>
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<td>SSCP (School Science Curriculum Project), 1964</td>
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<td>SCIS (Science Curriculum Improvement Study), 1961</td>
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<td>SQAIESS (Study of a Quantitative Approach in Elementary</td>
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<td>School Science), 1964</td>
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<td>USMES (Unified Sciences and Mathematics for Elementary</td>
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<td>Schools), 1973</td>
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<tr>
<td>WIMSA (The Webster Institute for Mathematics, Science and</td>
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<td>the Arts), 1965</td>
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avoided lecturing or more didactic forms of direct instruction. The teacher was not to be an expert who spoke what children should memorize.

SAPA, SCIS, and ESS are landmark elementary science programs, still available today. As shown in Figure 11w.1, they differ essentially on two factors: the amount of structure or flexibility each contains in its design for classroom use and the emphasis each gives to science content, attitudes, or thinking processes. Let us explore each program briefly to understand better the legacy that has brought positive influences to the options available in elementary science education today.

**Science—A Process Approach (SAPA)**

**SAPA's Prime Assumptions.**

Children need to learn how to do science, and this means acquiring the skills essential to learning and understanding science information. These knowledge-acquiring skills are called cognitive [thinking] skills or process skills and are similar to the procedures used by scientists to acquire new knowledge. Process skills may be compared to the program [of] a computer. Computers are incapable of handling information without a program to provide directions; the human mind does not cope effectively with incoming information in the absence of learning strategies (a program). (Hurd, 1968, pp. 11–12)

The American Association for the Advancement of Science’s Commission on Science Education assumed that a sequential program was necessary for developing a child’s intellect. In 1963, a team of scientists, psychologists, elementary teachers, and curriculum specialists developed plans and materials for trial versions of what became Science—A Process Approach. The program is based on two assumptions: first, that prepared materials must consider the intellectual development of the child, and second, that a total program must use a se-
sequential approach for the long-range development of the child’s intellectual skills. The first assumption worked well. Materials that were developed on the child’s ability level were appropriate. Incremental advances in the complexity of the materials seemed to help children develop intellectually. However, the long-term sequential approach proved too rigid to use without difficulty in schools where children attend school irregularly or transfer in mid-year.

**Description of SAPA.** SAPA is the most structured of the three programs we explore here. Its structure arises from behavioral psychology. The underlying psychological assumptions were that any skill can be broken down into smaller steps and that children need to learn lower-level skills before they can learn more advanced skills. Predictably, the original version of SAPA developed into a set of skills to be mastered through a complex, highly structured hierarchy (see Figure 11w.2) and step-by-step teaching.

Skill development takes precedence over science subject matter in SAPA. Even after revision and the development of SAPA II, the content of science is important only as it serves as a vehicle for developing thinking processes. The complex task of inquiry, therefore, is broken into a series of smaller, easier-to-acquire skills. All skill development is expected to arise from a child’s direct experiences performing prescribed learning tasks, usually with concrete manipulable objects. Hands-on learning involves children in doing science the way many scientists say they do it themselves—carefully planned step-by-step procedures.

SAPA science process skills are divided into two types: basic and integrated skills. In the primary grades (K-3) children develop these basic process skills: observing,
using space/time relationships, classifying, using numbers, measuring, communicating, predicting, and inferring. In the intermediate grades (4–6) children use the basic process skills as a foundation for developing more complex skills: controlling variables, interpreting data, formulating hypotheses, defining operationally, and experimenting.

The knowledge explosion in the sciences helps SAPA justify its approach; it is a unique program that emphasizes science skills over content. Creators of SAPA believe that it is impossible for individuals, including scientists, to keep up to date in all the sciences and that it is also unrealistic to expect children to learn everything about science. SAPA’s intention is to equip each child with the thinking skills that can be used to solve problems they find in the future.

SAPA is a complete K–6 program. The learning activities in the revised SAPA II are packaged in a series of 105 ungraded learning modules, with approximately 15 modules per traditional grade level. Each module is devoted to a specific skill. SAPA II arose in 1975 from extensive field testing, program evaluation, and materials revisions, and it is an improvement over the original design. Clusters of modules help teachers overcome the rigid sequence of skills used in the original flowchart approach (Figure 11w.2). SAPA II strives to reflect important changes in science education, is more flexible than the original design, reflects a greater emphasis on environmental topics, and attempts more pupil individualization. Students have no books, yet copy masters are available; modular teacher guides are used in place of a teacher’s textbook guide.

Each learning module has the same features and structure (Figure 11w.3). The cover of each module presents the specific process skill that is emphasized within. The module title identifies the science content selected, and behavioral objectives specify what each child should be able to do at the end of the module. The sequence chart inside the cover shows the relationship and fit of the module’s objectives with those of related modules (refer to Figure 11w.2). A complete rationale justifies the purpose and describes the benefits of the module’s activities for children and their intellectual development. The instructional procedure gives an overall introduction and describes each specific learning activity. Materials needed are listed with each activity, and modules contain about three to six activities. Each module contains a section, generalizing the experience, for extension of the learning activities. Evaluation is emphasized strongly in SAPA. An appraisal section describes class performance options for evaluation, and the competency measure section fully describes evaluation tasks that can be used with individual children. Specific questions and suggested answers are given. Competency measure tasks are keyed to the specific module objectives.

SAPA Program Effects. Did SAPA make a difference? James Shymansky et al. (1982) and Ted Bredderman (1982) say yes. Shymansky et al. specifically report that students learning science in the SAPA program outperformed children who learned from traditional science programs by seven statistically significant percentile points on measures of achievement. (Traditional programs were defined
as those whose development followed pre-1955 models, emphasized the information of science, and used laboratory activities to verify or to supplement lessons. This difference may not seem great, but take a closer look. Let us suppose that two classes of elementary students take the same standardized achievement test in science and all differences are controlled except the program that they learn science from. One class learns from the traditional textbook approach that is designed to teach science facts through reading and memorization; the other class learns from a program—SAPA—that does not stress facts or science information but instead focuses on doing science and developing thinking skills. The result? Let us say that the average student score from the traditional science program class is at the fiftieth percentile on a test designed to measure knowledge of science facts. Then by comparison, the average student in the SAPA class achieves at the fifty-seventh percentile on the same test—a distinct and significant achievement gain. The SAPA students knew more facts.

SAPA has several other factors going for it even more important than the performance of the average children from our example. In each case, these findings arose from research and careful study the findings are real, not imagined. SAPA students scored fifteen percentile points higher than non-SAPA students on measures of attitude toward science. On tests of process skills, SAPA students scored thirty-six percentile points higher than children from traditional programs. In such other areas as related study skills (reading and mathematics), creativity, and Piagetian tasks, SAPA children scored higher by 4, 7, and 12 percentile points, respectively. Many of the assumptions that undergird SAPA appear to produce differences, just as its developers envisioned.

Science Curriculum Improvement Study (SCIS)

SCIS’s Prime Assumptions.

In a world where there is so much to learn and know, concepts provide an intellectual economy in helping to organize large amounts of information. [T]his is the way concepts serve scientists and it is also the way concepts can improve children’s learning. There is too much to be known, even by children, to expect it can be learned by rote and as isolated facts. But a large amount of information can be organized into a few concepts. Systems of related concepts can then be built to form principles or rules whereby children are able to interpret and explain new observations and experiences. . . . One advantage of having children form concepts is that new information can be more easily related to that already known. The result is the likelihood that both the new information and related concept will have greater meaning, and understanding will be increased. If on the other hand, new information cannot be brought into an organized form, there is a likelihood that the new information will confuse rather than aid understanding. . . . [E]ach new relevant observation acquires meaning because it becomes associated with many previous experiences. (Hurd, 1968, pp. 9–10)

The Science Curriculum Improvement Study (SCIS) was developed to help elementary school children form a broad conceptual framework for under-
standing science. Teams of scientists, educators, and psychologists began work in 1961 to produce the first of what eventually became three SCIS versions: SCIS and SCIIS were developed by the same team and SCIS II by another. The most recent version is called SCIS3+. SCIS materials are available through Delta Education of Nashua, NH; http://www.delta-ed.com. The related versions are described here and are generically called SCIS.

The conceptual curriculum is organized around the structure of science as scientists see it. Specific concepts are chosen for their wide application and potential usefulness in each child’s future. The unique challenge of SCIS is to provide a program that will help children explore science, guide children’s thinking, and help children to form concepts and link them together within SCIS’s conceptual structure.

**Description of SCIS.** SCIS is a sequential program that emphasizes both process and content, making SCIS rather middle of the road according to Figure 11w.4. The instruction is less structured than in SAPA. Specific teaching approaches complement the program’s intention: to reach pupils at their current level of development as they form the intended science concepts.

The original version of SCIS introduced concepts that were new to elementary science. These concepts were linked together to form such units of study as properties, relativity, systems, interactions, variation and measurement, and ecosystems. Understanding these concepts yielded the primary goal of SCIS: scientific literacy. The program is divided into two parts: a physical/earth science sequence and a life/environmental science sequence. Each grade level’s program contains concepts and essential processes prerequisite for study at the next grade level (see Figure 10.4).

The SCIS concepts represent different levels of abstraction. For example, the first level pertains to matter, living things, variation, and conservation of matter. The second level includes concepts of interaction, causal relations, relativity, and geometric relations. The third level concepts pertain to energy, equilibrium, steady state, and the behavior, reproduction, and speciation of living things. The levels continue through to level six, dealing with concepts more appropriate for students at higher elementary grades. These concepts are somewhat complex when compared to simpler collections of facts; therefore, in SCIS instruction receives special attention.

SCIS gives children direct, concrete experiences. The teacher’s role is to help children acquire and use their observations to form the broad conceptual ideas of science—to guide, not to tell. The instructional method has three distinct phases and is known as the learning cycle (Karplus, 1964):

- Phase 1, exploration in an activity-oriented setting, permits the children to explore the learning materials or phenomena.
Using Space/Time Relationships

- Describing changes in position of objects relative to one's own position and to that of another observer.
- Applying a rule that the speed with which an object changes position is the distance moved per unit of time.
- Naming the time to the nearest minute or second on a clock with a second hand.
- Distinguishing between the speed with which an object changes position and the distance it moves.
- Distinguishing between the speed with which an object changes position and the time required for its arrival at a given point.
- Demonstrating a test for deciding whether an object has changed its position.
- Describing the comparative rate of change of position of two objects in relative terms.
- Identifying motion of various objects as fast or slow.

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Determining Sequences Within the Program

One convenient order for using the modules is the numerical sequence with which they are coded. If that order is followed, children will have the opportunity to develop skills in a sequence in which success is highly probable. Frequently it is necessary or desirable to alter the sequence when several teachers share materials, weather conditions interfere, or other scheduling problems arise. It is not necessary to use the modules in numerical sequence so long as the children have mastered the prerequisites before a module is begun.
**Excerpts from a SAPA II Module**

### SCIENCE . . .

**Surveying Opinion**

**44 Predicting/b**

**Sequence**

1. **CONSTRUCTING a bar graph to show the relationship between two variables and constructing predictions and tests of predictions based on data presented in a bar graph.**  
   *THIS MODULE, Predicting/c*

2. **CONSTRUCTING a bar graph to represent a given collection of data.**  
   *THIS MODULE, Predicting/b*

3. **DESCRIBING a method for collecting and organizing simple data.**  
   *THIS MODULE, Predicting/b*

4. **CONSTRUCTING a bar graph to show amounts of collected litter and constructing predictions and tests of predictions based on data presented in the graph.**  
   *MODULE 50, Predicting/d*

5. **Constructing a chart on which to show growth of plants from seeds.**  
   *MODULE 55A, Observing/m*

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**Rationale**

It is essential that contributing evidence upon which a prediction is based be collected, organized, and recorded in a clear and usable way. The activities in this module provide children with experience in making predictions based on data recorded in a survey of children in the school, thus using the children’s natural interest in collecting, interviewing, and surveying.

You must be sure to point out carefully the limitations on the dependability of predictions based on an opinion survey. Emphasize that accurate predictions are difficult in the early phases of the survey, and are impossible if they are based on only small bits of information. As more data are added, trends or patterns are often noticeable. These trends can be used to make more reliable predictions...

Because favorite kinds of snacks are the subject matter of this module, the results of the surveys are unpredictable and may vary considerably with locale, time of year, the children’s previous experience, and other factors. Remember that although the children will be very much interested in the results of the survey, these results are merely a means to an end. The objective is to provide experience in making predictions based on available evidence...

In **Activity 3**, the children survey other groups in the school. Take advantage of the excitement that such surveys create and the opportunity they provide for improvement of communication skills, but be sure to plan the surveying procedures carefully with the other teachers involved...

**Vocabulary:** predict, prediction, survey, opinion, tally, poll, polling

**Instructional Procedure**

Ask the children what the word *predict* means to them. They may have several suggestions. For example, they may recall that when they studied *Shadows,* Using *Space/Time Relationships* e, Module 29, they were asked to predict the two-dimensional shapes of the shadows of a three-dimensional object...

The children should also recall the predictions they made from the bar graphs they constructed in Using *Graphs,* Predicting c, Module 38.

Perhaps some child will mention that the weather man predicts the weather. Another may recall a time of national elections when there were predictions about which candidate would win.

Remind them that predicting is telling what you think is going to happen based on experience...

If possible, bring periodical or newspaper examples of polls that have been taken. A copy of a survey made within the school would be useful too. Discuss the value of surveys. Use questions as these: What is an opinion? What is a survey? How is the information obtained when we survey opinion? Suggest that the class make its own survey...

**Materials:** Surveys, several examples from periodicals or newspapers.

**Activity 1**

Give each child a piece of paper and a pencil. With no preliminary discussion ask the children to write down the names of three of their favorite kinds of snacks. Be sure that they do this independently. Then collect their papers.

Tell the children that you have just taken a *poll* of their favorite snacks. Ask which snack the children think was named the most times. After several children have expressed their ideas, ask why they think a particular snack was the most popular. Suggest that their ideas are largely guesses because, at this point, they have little or no evidence to use as a basis for making predictions...

**Materials:** Writing paper, 1 sheet for each child, Pencils, 1 for each child

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A Process Approach II

Objectives  At the end of this module the child should be able to:
1. Describe a method for collecting and organizing simple data.
2. Construct a bar graph to represent a given collection of data.
3. Construct a prediction based on an examination for the data presented in a graph or collection of graphs.

Activity 2
Ask the children for their ideas about organizing the data so that each child can have a copy of the results. There should be a number of suggestions. Try to accept one of them.

If the children do not suggest a feasible plan, use the following procedure. Give each child one paper marked during the previous activity, a clean sheet of paper, and a pencil. Call on the children to read from their marked papers. When a snack is first mentioned, tell everyone to write it down and put a tally mark next to it; each time it is mentioned again, have everyone put another mark next to the snack. Several children will probably have listed specific candy bars, flavors of ice cream, and so forth. Have the children tally all such listings under general headings, such as “candy” and “ice cream.” Some children may list two items such as “cookies and milk.” In this case put one tally next to “cookies” and another next to “cookies and milk.” In this case put one tally next to “candy” and another next to “milk.”

For the purpose of discussion, ask the children to imagine that milk was named more often than any other kind of snack, and that it was listed 20 times. Also ask them to imagine that candy was named 6 times and ice cream was mentioned 4 times. Figure 1 shows how these data may be graphed...

Generalizing Experience
Some children may be much more interested in this series of activities than are others. You should provide opportunities for the most interested children to continue with the surveys and to report the tallies to the others in the room...

Ask the children to make additional surveys about snack preferences. For example, have them ask a teenager, their mother or father, or some other friend to list three favorite kinds of snacks. You will get greater cooperation from the parents if you send a note with the child describing the project and the importance of the information. The children should get data from the same number of adults as there are members in their room. Tell the children that they should make their predictions beforehand and discuss the reasons for them. Then have them make the tabulation and discuss the results. If you find that more practice in graphing is desirable, you could have the children graph these data before they discuss the results...

Approval
Divide the children into two groups, each containing about the same number of boys and girls. Ask everyone to write on a piece of paper the names of their three favorite flavors of ice cream. Have the children in one group tabulate their own data, and ask the other group to do the same. Be sure the groups do not overhear each other’s results.

Task 1 (Objective 1): Say to the child, In planning for the school picnic, the P.T.A. members want to get an idea of how many hamburgers, hot dogs, and cold-meat sandwiches to make. Tell me how they could get the information they need. The child should describe a method of surveying some of the children in the school.

Task 2 (Objective 2): Say, A poll in Miss Brown’s room of 30 children gave the following data about preferences: hamburgers, 15 children; hot dogs, 10 children; cold-meat sandwiches, 5 children. Give the child the data on a piece of paper or write the information on the chalkboard. Then give him a piece of graph paper and say, Make a graph showing the number of times each kind of food was chosen. The child should include the following entries on the graph: a proper title that identifies the subject of the graph, a scale of numerals on the vertical number line, the name of the teacher whose children were surveyed—perhaps included in the title, the proper labeling of the horizontal base line and vertical number line, bars drawn to the correct height to show the number of choices. If the child makes any errors in constructing the graph, correct them before continuing.

Task 3 (Objective 3): Ask the child, Could you use your graph to predict exactly how many times hamburgers would be chosen by the children in another room? The child should indicate that an exact prediction probably cannot be made.

Task 4 (Objective 3): Show the child the two picture cards of graphs—one showing a graph that represents the choices made by the children in Mr. Smith’s room, the other showing a graph that represents the choices made by the children in Miss Jones’ room. Read the labels below the horizontal base line of each graph. Say, Look at the three graphs—the one you made and the two I have just given you. Make a prediction about which kind of food the children in Mrs. White’s class will select most often. The child should say, “Hamburgers.”

Task 5 (Objective 3): Ask, Why did you make that selection? The child should identify a pattern that supports his or her answer.
Phase 2, invention, does not leave children to their own devices but guides them toward the concepts by gathering their observations and using them to invent ideas that help the children organize and understand their experiences.

Phase 3, application, helps the children discover relationships and broaden their experiences by giving them opportunities to use the newly formed concepts in new contexts.

Although most of the attention is given to academic skills through concept formation, SCIS also gives attention to student attitudes and thinking skills. The skills developed in the program are similar to those developed in SAPA: Students carefully observe, record their observations, make comparisons, recognize similarities, use measurements, and develop vocabulary as they discuss their experiences and form meaningful concepts.

Each grade level of SCIS is packaged conveniently, and most grades have two modular kits: one for physical/earth science and one for life/environmental science. Each kit contains all the equipment and materials needed for teaching the specific unit and accommodates classes of up to thirty-two children. Materials are carefully selected to provide the specific experiences each child needs to form the selected concepts; some materials are consumable and need regular replacement. Print materials include wall charts, game boards, card decks, and visual transparencies. Student manuals (record books) are provided for each grade level except kindergarten. Children use the manuals to record their observations and complete investigations that help to evaluate their progress. An evaluation packet provided for each unit helps the teacher determine
each child’s concept formation, skill, and attitude development. Living materials are needed for approximately half of the school year; these materials are provided for a fee at the time specified by the teacher. Extending Your Experiences (EYE) cards for concept expansion, review, remediation, and special projects can be used with individual children, small groups, or an entire class.

The teacher’s guide is exceptionally well organized. Guides contain a concise lesson plan, the synopsis, lists of materials, background information, tips for advance preparation, specific teaching suggestions, helpful illustrations, descriptions of optional activities, and descriptions of ways to do concept and process evaluation. All of these materials are packaged with a complete kit for every unit.

Each unit of the new SCIS3+ materials includes correlation of all activities to the National Science Education Standards, Benchmarks for Science Literacy Project 2061, age-appropriate related literature, and related software titles.

SCIS Program Effects. What kinds of effects did SCIS have on children? Again, we can look to James Shymansky and his fellow researchers (1982) for some answers. In achievement tests, students in SCIS programs scored 34 percentile points above children from traditional science programs. Of the three programs we describe in this chapter, SCIS had the greatest effect on pupil achievement, outdistancing SAPA and ESS by 30 and 27 percentile points, respectively.

Concurrently, SCIS produced gains of 21 percentile points in science process skills and 34 percentile points in children’s creativity when compared to traditional programs. Smaller improvements were measured in pupil attitudes, related study skills such as reading and mathematics, and Piagetian tasks. An unexpected benefit of SCIS is reported by Renner and Marek (1988). The first-grade unit, material objects, was compared to a commercial first-grade reading readiness program. Children in the experimental group studied material objects without reading readiness, and children in the control group studied traditional reading readiness materials without material objects. Both groups were equivalent and were pretested with the Metropolitan Reading Readiness Test and then posttested six weeks later. The SCIS experimental group outscored the control group in all areas—word meaning, listening, matching, alphabet, numbers, and total score—except copying (Renner & Marek 1988, pp. 193–196). Apparently the thinking skill development in the SCIS program was much more potent than direct reading readiness instruction. The assumptions that SCIS developers made about children’s learning appear to be valid, given the extent of gains in achievement, process skills, and other important aspects of learning.

The Elementary Science Study (ESS)

ESS’s Prime Assumptions.

The central question is whether whatever a child learns is more meaningful and is retained longer if he works his own way through a topic [discovery] or if it is taught him by assertion. Proponents of the discovery approach cite the following
values in its favor: (1) Children are motivated by the satisfaction they receive from finding out things for themselves, and satisfaction is recognized as an important attitude in stimulating learning; (2) since children are more personally involved with information and ideas in a discovery approach, deeper understanding of subject matter results and forgetting is reduced; (3) discovery procedures help children develop strategies of inquiry, or process skills . . . ; and (4) transfer of learning is improved.

[Discovery in ESS means that] children explore freely with the materials of a topic until they begin to ask questions of their own. These questions form the basis for further investigation. Teacher direction is at a minimum and the pupils are permitted to pursue their own lines of inquiry in a capitalization on the natural curiosity and ability of children to profit from self-directed experiences. Given this freedom, each child can delve into features of a problem that are interesting and important to him. Discovery learning in this approach is seen as increasing motivation and improving the intuitive meaning of observations. (Hurd, 1968, pp. 18–19)

The developers of ESS believed that the elementary school should provide children with abundant time to explore and to examine relationships between humans and the physical and living world. Terms like free discovery and guided discovery arose from the teaching methods used with ESS. David Hawkins, developer of ESS, used the term messing about to describe the class time students should spend in unguided exploration activities—the initial learning phase of ESS. Developers believed that learning must provide children with interesting and enriching experiences and that abundant, varied activities must be available. A number of psychologists supported the ESS goals by stressing the importance of free, unstructured periods of exploration during the initial phases of learning. Also, psychologists affirmed that children learn at different rates, have different interests, and learn different things from the same learning activity. These views support the notion that learning must be individualized—a feature of ESS.

Description of ESS. The main goal of ESS for teachers is to provide students with a wide variety of learning materials, which are packaged into unit booklets. Some topics stress experiences with skills fundamental to learning, such as weighing, graphing, and using instruments, while other topics emphasize science concepts. All have been field-tested and revised during development so that they continue to motivate children and foster positive attitudes toward science.

ESS originally contained fifty-six different units with a suggested range of grade levels. Now about thirty-eight different units are in print (see Figure 11w.5 for some examples). Each unit takes several weeks to complete and contains material useful for a K–9 science program. Although no prepackaged course of study exists, the units can be easily adapted to fit most existing curricula. Each unit stretches across a range of grade levels and can be used in any sequence, un-
like SAPA and SCIS. Each unit strives to develop science concepts and thinking skills simultaneously. The rationale is that children acquire mental strategies for organizing their observations as they form science concepts based on those same experiences. This belief is consistent with Piagetian developmental psychology and the learning theory of Jerome Bruner (1962).

The questions children ask are highly valued in ESS. In fact, this is the main intent of the ESS materials: that children will raise all kinds of questions about their experiences and try ways to work with the materials that have not been pre-planned by the teacher. As a consequence, teachers have to expect that children will talk with other children as they compare observations and form explanations about what they experience.

ESS has a flexible structure and emphasizes attitudes as the discovery method is used by children to learn science content. The kits consist of low-cost materials and provide the kinds of direct experiences favored by program developers. As the units vary, so do the kits. Some kits are meant for entire classes of thirty students, but most are for smaller numbers: groups of about six, or individual students for certain activities (see Figure 11w.5). Each kit and teacher’s guide can be purchased separately, giving more freedom and flexibility when selecting curriculum materials for the science program than either SAPA or SCIS. Some ESS units may be used by purchasing only the teacher’s guide without the expense of a commercial kit.

A teacher’s guide accompanies the pupil kit. The guide contains background information and teaching tips that are suggestions rather than specific directions. Notes on classroom management share examples of the kinds of questions that teachers could ask children and examples of the kinds of answers children may give or the types of questions children may ask. Other suggestions help the teacher become a guide or adviser of inquiry rather than a provider of information. This teacher role ensures that the responsibility for learning is shifted to the child, as each is stimulated to devise her or his own way of acquiring and making meaning out of information from the exploration (see Figure 11w.6).

ESS has no student textbooks. Worksheets, pictures, and supplementary brief booklets, called readers, accompany some of the units, while brief film loops provide learning experiences not easily acquired otherwise. There is considerable variation among the many ESS units, but this variation serves a fundamental purpose: to promote unguided exploration that motivates children to pursue topics of interest. ESS assumes that this kind of experience will help each child develop useful learning skills and that knowledge gained from this approach is meaningful and long lasting.

**ESS Program Effects.** ESS strives to help children learn science and thinking skills through positive attitudes. Does this work? Again we can refer to the report of James Shymansky and his fellow researchers (1982) (see Table 11w.2). Yes, to an extent ESS is successful. Achievement gains were less than with SCIS and SAPA, yet children who learned science by ESS did outperform their age-mates.
in traditional science programs by an average of 4 percentile points. Attitude improvements were impressive: average ESS scores were 20 percentile points above the averages of children from traditional programs, by far the largest advance of the three programs we compare in this chapter. Substantial increases in creativity and process skill development were shown by 26 and 18 percentile point gains, while completion of Piagetian tasks was 2 percentile points above those of traditional programs. Achievement gains were not as great as the theoretical assumptions of ESS might suggest, yet these assumptions were not completely wrong given the other substantial gains children made from the ESS program.

SAPA, SCIS, and ESS have shown some superior characteristics and effects when compared with traditional science programs. Yet each program is based on a different design and a different teaching approach, and for different reasons. Developers of the programs made different assumptions but shared some in common as well. What are the characteristics of effective science teaching that should be included in a science program?

WHAT WORKS?

Take a look in a large number of elementary classrooms where science is taught and what do you see? Perhaps you observe what Donald Wright reports: “Fifty to 80 percent of all science classes use a single text or multiple texts as the basis for instruction. . . . For students, knowing is more a function of reading, digesting, and regurgitating information from the textbook or lab manual than it is of analyzing, synthesizing, and evaluating” (Wright, 1980, p. 144).

Furthermore, you may have an impression that a direct, authoritative, prescriptive approach with the same pace for everyone and where the 3 Rs are emphasized is actually the best way to teach science. As added support for this view you could refer to the fact that the three NSF-sponsored programs we have just mentioned have never been used by more than 30 percent of the school districts in the United States; also, only 7 percent of K–6 teachers have ever attended an NSF-sponsored meeting (Weiss, 1978). Certainly if the gov-

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*No studies reported

ernment spent millions to develop these programs, they would be used if they actually worked, right? Wrong.

What the three programs we compare all have in common is a hands-on curriculum and teaching approach. Despite what is widely believed and practiced, the hands-on, minds-on learning approach is superior to the traditional approach. James Shymansky and his colleagues (1982) tell us that synthesis of the abundant research shows conclusively that children in a hands-on science program achieve more, like science more, and improve their problem-solving skills more than children who learn from traditional textbook-based programs. The hands help the minds grow by constructing meaning. These conclusions endured resynthesis even though original statistics have been revised to yield results of greater precision (Shymansky, et al., 1990).

Ted Bredderman (1982) adds support to this view. Bredderman’s research is provided as a part of Project Synthesis, a massive research effort funded by the National Science Foundation to determine the effects of past experimental programs so that present and future science education goals could be revised. Bredderman’s research collected the results from sixty studies that involved 13,000 students in 1,000 elementary classrooms over fifteen years. He analyzed the results of these studies carefully through meta-analysis procedures to sort out conflicting findings reported in the literature. His conclusion clearly shows what works:

With the use of activity-based science programs, teachers can expect substantially improved performance in science process and creativity; modestly increased performance on tests of perception, logic, language development, science content, and math; modestly improved attitudes toward science and science class; and pronounced benefits for disadvantaged students. (Bredderman, 1982, pp. 39–41)

Hands-on, minds-on learning makes the difference. Exploring, investigating, and discovering are essential to meaningful learning and effective science teaching. When children solve problems and make discoveries, they are learning how to learn and constructing meaning for themselves. Jerome Bruner (1961) points out the benefits for children as they make discoveries through active learning:

• Children’s intellectual potency is increased; their powers of thinking improve.
• Children’s rewards for learning shift from those that come from the teacher or someone else to those that are found inside themselves from the satisfaction they feel.
• Children learn the procedures and important steps for making discoveries and find ways to transfer these to other learning opportunities.
• What children learn takes on more meaning, and they remember it longer.

While all three programs surveyed here report successes, they also have limitations. From the research that has been synthesized, it seems prudent to mix emphases on science content and process skills for the most potent
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Children learn what seeds are, how seeds grow and change, and how seeds differ from other small objects. Activities, including observing and recording growth, may be done as a class or in small groups.

This practical unit is an introduction to measurement. Children determine length, area, and volume with a variety of tools and materials.

After the initial challenge of balancing the beam, children learn the importance of weight and its position on the beam in relation to the fulcrum point. Further explorations reveal that weight is not a function of volume. Other activities include sorting, counting, and balancing odd-shaped boards on a half-half fulcrum.

With 250 blocks in six colors and shapes, children progress from casual play to creating elaborate mosaic designs, they also use mirrors to create new patterns. Math content includes measurement, symmetry, counting, shape, and proportion.

With the set of 330 unpainted, hardwood blocks the children move from free play activity to concepts of size, shape, one-to-one correspondence, and conservation of volume.

Observation of the changes from egg to tadpole to frog gives students direct experience with the concept of a life cycle.

Children assemble the 7 piece puzzle into various configurations, including the basic 4-inch square. They soon discover basic geometric relationships between the pieces and through visual experience learn to deal with problems analytically.

Manipulation of the blocks, cubes, and people pieces provides experience in classification, class and relationship, and logical thinking processes.

Children explore the effects of circular motion by making designs and observing liquids and solid objects placed on revolving discs. Predictions and error stimulate discussion and further experimentation.

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**Scope and Sequence Chart**

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**Physical Science**

This durable organism provides children with concrete evidence of a life cycle and effects of environmental conditions on living things.

Through the handling of individual letters and formulation of words in the type holders, children learn the basics of printing. They also develop an appreciation of the printed word as a means of communication.

Students build structures with materials chosen to create structural problems. They learn to deal with properties such as size, strength of materials, and design configuration.

Students discover that buoyancy of an object is a property of both the object and the liquid. Investigations involve different materials and shapes placed in liquids of varying densities.

Children discover how to make clay float, and develop predicting, weighing, and measuring skills while learning about volume displacement and buoyancy.

Children observe characteristics of common liquids when these liquids are poured into one another or dropped on different surfaces. New ways to transfer liquids are developed.

Through use of scientific method, students progress from identification of harmless, common white powders to more advanced analysis of properties.

Activities with ice introduce the students to the effects that heat, insulation, shape, and conductivity have on melting rates. Thermometers are used to measure freezing and melting points.

Children discover the many individual characteristics of a mineral which make it different from others. Rock sorting and chart making develop useful classification skills.

**Math**
teaching and learning combination. Yet researchers like Ted Bredderman and James Shymansky and his colleagues warn against abandoning the traditional textbook-based programs in complete favor of SAPA, SCIS, ESS, or the like. Instead, they recommend incorporating the useful methods and materials into existing science programs as a step toward improvement.

What are we to do? First, realize that some of the effective science programs remain. Several schools still use SAPA, SCIS, and ESS. Parts of these can be added to existing school programs to provide children with more hands-on
learning opportunities. Next, be aware that there have been substantial improvements in recent editions of textbooks and that new generations of curriculum supplements have been developed. These supplements may be available through your university or state department of education. Both of these types of resources have capitalized on several features that made the alphabet soup programs successful. For example, we find more frequent use of student learning activities with a focus on specific conceptual outcomes, better organization of teaching materials, and convenient packaging of curriculum materials; we can attribute these improvements to the effects of the hands-on, minds-on programs.

Programs like ESS, SAPA, and SCIS definitely filled a void that existed when elementary science textbooks were nothing more than a lesson in reading. Without national science standards, many science textbooks tried to cover everything with very little depth. The alphabet soup science programs proved that hands-on and minds-on could go hand-in-hand.

It would seem that the lessons learned would follow up the grades from the primary and intermediate science textbooks into the middle schools texts. In a recent study by the American Association for the Advancement of Science (AAAS) this did not prove to be the case. The AAAS Project 2061 Middle Grades Science Textbooks Evaluation completed in 1999 found that out of nine middle school science textbooks none were ranked satisfactory on a number of rating criteria. The study identified key ideas from the National Science Education Standards in the earth, life and physical sciences and from Benchmarks for Science Literacy from AAAS. The study identified categories on which to judge the science content within those key areas. It looked at how well the textbook (1) provided a sense of purpose and conveyed that in a clear manner; (2) took into account student ideas by addressing commonly held beliefs about the key idea; (3) engaged the students with relevant phenomena; (4) developed and used scientific ideas; (5) promoted student thinking about phenomena, experiences, and ideas; (6) assessed student progress; and (7) enhanced the learning environment. The textbooks studied were all found unsatisfactory. In most cases they covered too many topics, providing very little depth in any of them. The only middle school material deemed satisfactory in this study was actually a supplement titled Matter and Molecules, created at Michigan State University in 1988. A detailed look at the books involved in the study and the results can be found through the American Association for the Advancement of Science Web site at http://www.project2061.org.

A study of this nature indicates that there is still much confusion as to what science and how much of it should be taught at the K–8 level. As evidenced by this study, the National Research Council’s National Science Education Standards and the American Association for the Advancement of Science’s Project 2061 are slowly becoming the standard to guide textbook construction. Many state science curricula are using these as their guide. We now know that if the elementary science program is to serve all children well, specific assumptions must
guide program development and science teaching. Science must be taught so that children construct meaning from direct science experiences and expand their problem-solving and thinking skills. Furthermore, the subject matter must provide opportunities for children to develop personally; to learn about the many interrelationships among science, technology, and our society; to grow intellectually through inquiry; and to be exposed to the history and nature of science.

Each science program can evolve from its present condition to a level where relevant learning opportunities are provided for all children. The following list of assumptions and supported research is associated with effective science programs. The list is gleaned from research supported by the National Science Foundation and the National Science Teachers Association’s recommendations for exemplary elementary science programs. These assumptions reveal some of the impact of historically significant science programs and predict the future trends science programs will face. We suggest that you keep these assumptions handy and let them help you plan more effective science instruction as well as advise your school principal or curriculum committee.

**Supported Assumptions About Effective Elementary Science Programs**

1. National Science Foundation experimental elementary science programs and sponsored new approaches to teacher preparation have been successful, even though a low percentage of schools (30 percent) have used the programs and an even smaller percentage of teachers (7 percent) have received direct training.

2. Effective elementary science programs keep pace with changes in science, society, knowledge, and trends in schooling.
3. Most current elementary school science programs do not serve all children well. Effective programs have meaning for diverse audiences.

4. Effective science programs strive to promote children’s personal development; to help children explore the interrelationships among science, technology, and society; to continue academic preparation through inquiry; and to build awareness of the history and nature of science.

5. Effective programs have no single author but are developed by teams with teacher involvement. Extensive classroom testing and program revision are necessary and must be done frequently.

6. Students learn successfully in different ways; multiple views on learning add diversity and help to balance the effective science program.

7. Programs that emphasize conceptual learning appear to be most effective overall and produce the greatest and most enduring gains in achievement when conception is a learner’s construct.

8. Multiple teaching methods are useful, and hands-on learning opportunities are necessary for all children. Overall, inquiry methods and learning cycles are useful methods for helping children learn science concepts.

9. What is taught—the substance of science—must be useful and relevant for each child. Publications such as the National Science Education Standards help guide content selection.

10. Packaging the program is helpful and reduces teachers’ preparation time. New generation science curriculum supplements have several common features that add impact to the materials. They identify relevant themes, define purposes or objectives, give background information, list materials needed, state procedures for teaching, identify essential vocabulary, offer ideas for evaluation or lesson expansion, and so on.

11. The history and nature of science makes it possible to integrate topics into other subject lessons. Science’s diversity enriches other parts of the school curriculum and adds to its power as a literacy subject.

12. A less direct, teacher-as-guide instructional role is effective because students are encouraged to assume greater responsibility for their own learning.

13. Conceptual learning takes time and should not be rushed; effectiveness rather than time efficiency should be the driving force of the curriculum.

14. Learners in constructivist science programs achieve more, like science more, and improve their problem-solving skills more than children who learn from traditional textbook-based programs. Innovative newer generations of science textbooks incorporate many of the features of the effective experimental programs.

15. Effective science programs promote children’s intellectual development by improving their thinking through inquiry and problem-solving processes.

16. Materials and learning activities must match the child’s level of development to have the greatest impact.

17. Students receive intrinsic rewards from the personal discoveries they make through firsthand learning experiences with manipulatives.
Part 1: Simple Circuits

Beginning Circuits

Before Starting to Teach

Materials you will need:
- 2 8-inch pieces of #20 bare copper wire
- 2 8-inch pieces of #22 plastic-covered copper wire
- 3 #48 (PB) bulbs
- 3 D batteries
- 1 wire stripper

The following suggestions will guide your initial exploration. If you take enough time to try your own ideas as well, you will be ready for the variety of ideas your students are sure to propose.

Try to light one of the bulbs, using a piece of bare wire and a battery. Some people have taken 20 minutes to light the bulb the first time, so do not worry if yours does not light right away. See how many different ways you can devise to make the bulb light. It is helpful to make sketches of your various attempts, including those that do not work.

Using the plastic-covered wire, light a bulb. You will have to remove the covering from the ends. The wire stripper is designed to remove the plastic cover without cutting the wire. You can adjust the knob so that the wire opening will cut only the plastic.

In the Classroom

Materials you will need for each child:
- 1 8-inch piece of #22 plastic-covered copper wire
- 1 #48 (PB) bulb
- 1 D battery

For each group:
- 1 wire stripper

To have available:
- extra supplies of the above materials

It is suggested that the students work in groups of two to four. Although they don’t need to share equipment for the initial activity, they will soon need to do so.

Each student should have a box or paper bag in which to keep his materials at the end of each class period. It has worked well for children to keep the materials originally passed out to them for the duration of the unit. They use these materials, as well as others to be distributed later, continually. Whether or not the children take equipment home to work with is up to you.

LEAD-OFF QUESTION

Can you make the bulb light with one battery and one wire?

Some children will take 20 minutes to light the bulb, while others will take only five. Once one child in a class manages to make the bulb light, his method catches on quickly. Probably only five or six will light the bulb on their own. The rest will follow a neighbor’s lead.

As the bulbs are lighted, assure the children that there are different ways to light bulbs, and have them look for more. Invite them up to the chalkboard to draw the various ways they have tried. Ways in which the bulb does not light are just as important and should be drawn on the board, too.

It is extremely important to give children this time for free investigation with the equipment, so that they can pursue whatever questions occur to them. Their questions at this early stage will provide good leads for later work. After doing these first experiments, some children may bring household bulbs into the class. One such class connected seven batteries to a 50-watt bulb and still saw no light. Then a girl felt that the bulb was warm; they added another battery or two and were rewarded by a slight glow. One battery was removed, and the bulb dimmed. The class then went on to compare the number of batteries required to light bulbs of various sizes.

FOLLOW-UP QUESTION

How many different ways can you light the bulb?

ACTIVITIES CHILDREN MAY TRY

- Using two or more batteries, light the PB.
- Find out how many bulbs can be lit with one battery.
- Find out how brightly a bulb will shine when three, four, or eight batteries are used.
- Find out how many batteries it takes to burn out a bulb.
- Use plastic-covered wire, light a PB.
- Use more wire to see if a PB will still light.

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• Find out which will wear out first, if contact between a battery and a PB is maintained for a long time. How long does it take?
• Attach a wire from one end of the battery to the other. See how the battery feels after five minutes in this situation and after an hour.
• See if the battery will light a bulb after an hour.

Note: When investigating the different ways that will light the bulbs, children often discuss the question, "Does turning the battery around make another way?" The fact that a battery works both ways is an exciting discovery to many.

POSSIBLE DISCUSSION QUESTIONS

After three or four sessions with these materials, the children will be ready to come together as a class to share their experiences. One way to begin such a discussion is to draw some circuits on the board and ask if the class can predict whether the bulbs in the arrangements will light. Below are examples of some circuits you may want to discuss.

A bulb can be lit essentially in four ways, using one wire and one battery. (Actually, turning the wire around could be considered to be creating new ways, too.)

In each case, the bulb lights with the same brightness. Asking a child about the brightness of different arrangements helps him to see that brightness is a way to tell something about a circuit.

Since the battery lights the bulb with equal brightness, regardless of which way it is facing in the circuit, children may wonder why some batteries are marked with a "+" (positive) and a "−" (negative) at the top and the flat end respectively. If the bulb can't tell one end from the other, why do we bother about designating the poles positive and negative? This question will be answered when the children start working with more than one battery. At that time, the students will see that with two or more batteries in a circuit, the direction of each is important.

The "flow" of electricity usually comes up sooner or later. Does the electricity flow in circuits from the positive to the negative end of the battery or vice versa? This is a very difficult question to answer experimentally. It is further complicated by the fact that when different materials are used in circuits, different things happen. Students who are quick to explain simple circuits in terms of a particular direction of flow might profit from a question such as: "Are you sure? What difference would you notice if the flow were actually the reverse?" Since the students have noticed that the bulb works equally well on both ends of the battery, they should begin to realize that the particular direction of electricity flow doesn't matter in this situation.

When students start lighting more than one bulb with one battery, or one bulb with more than one battery, a great many possibilities for further investigation emerge.

The changes in brightness of the bulb can be accounted for, if you recognize that the bulb is acting like a meter, giving a measure of how much or how little of "something" is in the wire. If children can group the results of their experiments in such a way that they see relationships between, and common elements in, activities that dim and activities that brighten a bulb, they are on the way to understanding what is happening.

Predicting Sheet 1

Prediction Sheet 1 illustrates twelve situations closely related to many of the activities your children may have investigated in the first section.

After a child has thought about each circuit and marked the sheet accordingly, discuss some of his predictions with him. What reasons are given for a particular answer? When a child predicts incorrectly or cannot describe a convincing basis for his prediction, recommend that he test his prediction by making the circuit. He may then be able to give a clearer explanation for some results.
18. The science students learn from effective programs helps them transfer their learning to other circumstances better, get more meaning, and remember what they learn longer.