8. The model must be applicable via a variety of teaching strategies, including traditional laboratories and new educational technologies.
9. The model must incorporate the traditional processes of scientific inquiry and technological design.
10. The phases of the model must be identifiable by words easily understood and applied by practicing science teachers.

An Instructional Model for Contemporary Science Education

The instructional model proposed here fulfills the criteria described in the previous section. The model has five phases and includes structural elements in common with the original Atkin/Karplus learning cycle. The five phases are engagement, exploration, explanation, elaboration, and evaluation. The middle three phases are fundamentally equivalent to the three phases of the Atkin/Karplus learning cycle. In reading the description of the model proposed here, you should note the variations from the original model and the different appropriate activities and procedures for each phase. These interpretations serve to define the model every bit as much as the skeletal structure of the model.

Curriculum developers and classroom teachers can apply the model at several levels. The model can be the organizational pattern for a year-long program, for units within the curriculum, and for sequences of daily lessons. I recommend, however, that initially developers and teachers use the model clearly and consistently at only one of these levels. Although curriculum developers who are familiar with the model may be able to utilize nested cycles (cycles within cycles) or interwoven cycles (exploring one concept while expanding on another), apprising teachers and students of that nesting or interweaving would neglect the "intelligible and apparent" criterion.

The instructional model is based on a constructivist view of learning. Constructivism is a dynamic and interactive model of how humans learn. Using this approach, students redefine, reorganize, elaborate, and change their initial concepts through self-reflection and interaction with their peers and their environment. Learners interpret objects and phenomena, and internalize those interpretations in terms of their current conceptional understanding. The objective in a constructivist program is to challenge students' current conceptions by providing discrepant events, data that conflict with students' current thinking, or experiences that provide an alternative way of thinking about objects and phenomena. When an activity challenges students' conceptions, there must be an opportunity for students to reconstruct a conception that is more adequate than their original conception. This takes time and a planned sequence of instruction. The instructional model outlined in the next sections provides the time, opportunity, and structure necessary for such learning to occur. Table 8.2 summarizes the instructional model.

Efforts to translate constructivist research into classroom practice is evident in

the use of the 5 Es instructional model. Instructional procedures have been developed to help students through the process of conceptual change (Bruer, 1993; Driver, 1989; Driver et al., 1994; Driver, Guesne, and Tiberghien, 1985; Hewson, 1984; McGilly, 1994; Kyle, Abell, and Shymansky, 1989; Osborne and Freyberg, 1985). Many of these efforts have improved student understanding in the physical sciences (White and Gunstone, 1992; Hewson, 1984; Hewson, 1986; Joshua and Dupin, 1987; Minstrell, 1984; Minstrell, 1989; White, 1985) and the biological sciences (Anderson and Roth, 1987). A pedagogical tool known as concept mapping (Novak and Gowin, 1984) has been used to allow students to articulate their current conceptions. The use of concept mapping has been shown to improve achievement in a variety of subjects (Novak, 1987; Tisher, 1985). Berkheimer and Anderson (1989) and Driver and Oldham (1986) have outlined constructivist approaches to curriculum development. These approaches rely heavily on determining students' prior knowledge and structuring instruction accordingly.

The following sections present brief descriptions of the five phases of the instructional model. Curriculum developers and classroom teachers can apply the instructional model in different disciplines and with varied teaching strategies.

Engagement

The first phase is to engage the student in the learning task. The student mentally focuses on an object, problem, situation, or event. The activities of this phase should make connections to past and future activities. The connections depend on the learning task and may be conceptual, procedural, or behavioral.

Asking a question, defining a problem, showing a discrepant event, and acting out a problematic situation are all ways to engage the students and focus them on the instructional activities. The role of the teacher is to present a situation and identify the instructional task. The teacher also sets the rules and procedures for the activity. The experience need not be long or complex; in fact, it should probably be short and simple.

Successful engagement results in students being puzzled by, and actively motivated in, the learning activity. Here the word *activity* refers to both a constructivist and a behavioral approach, that is, the students are mentally and physically active.

Exploration

Once the activities have engaged students, they need time to explore their ideas. Exploration activities are designed so that all students have common, concrete experiences upon which they continue building concepts, processes, and skills. If engagement brings about disequilibrium, exploration initiates the process of equilibration. This phase should be concrete and meaningful for the students.

The aim of exploration activities is to establish experiences that teachers and students can use later to formally introduce and discuss scientific and technological concepts, processes, or skills. During the activity, the students have time in which they can explore objects, events, or situations. As a result of their mental and

TABLE 8.2 *The 5 Es Instructional Model: Examples of Student Behaviors and Teacher Strategies*

Student Behavior	*Stage of the Instructional Model*	*Teaching Strategy*
Asks questions such as, Why did this happen? What do I already know about this? What can I find out about this? How can this problem be solved? Shows interest in the topic.	**Engage** Initiates the learning task. The activity should make connections between past and present learning experiences, and anticipate activities and organize students' thinking toward the learning outcomes of current activities.	Creates interest. Generates curiosity. Raises questions and problems. Elicits responses that uncover students' current knowledge about the concept/topic.
Thinks creatively within the limits of the activity. Tests predictions and hypotheses. Forms new predictions and hypotheses. Tries alternatives to solve a problem and discusses them with others. Records observations and ideas. Suspends judgment. Tests ideas.	**Explore** Provide students with a common base of experiences within which current concepts, processes, and skills are identified and developed.	Encourages students to work together without direct instruction from the teacher. Observes and listens to students as they interact. Asks probing questions to redirect students' investigations when necessary. Provides time for students to puzzle through problems. Acts as a consultant for students.
Explains possible solutions or answers to other students. Listens critically to other students' explanations. Questions other students' explanations. Listens to and tries to comprehend explanations offered by the teacher. Refers to previous activities. Uses recorded observations in explanations.	**Explain** Focus students' attention on a particular aspect of their engagement and exploration experiences, and provide opportunities to demonstrate their conceptual understanding, process skills, or behaviors. This phase also provides opportunities for teachers to introduce a concept, process, or skill.	Encourages students to explain concepts and definitions in their own words. Asks for justification (evidence) and clarification from students. Formally provides definitions, explanations, and new vocabulary. Uses students' previous experiences as the basis for explaining concepts.

TABLE 8.2 *The 5 Es Instructional Model: Examples of Student Behaviors and Teacher Strategies (continued)*

Student Behavior	*Stage of the Instructional Model*	*Teaching Strategy*
Applies new labels, definitions, explanations, and skills in new, but similar, situations.	**Elaborate**	Expects students to use vocabulary, definitions, and explanations provided previously in new context.
Uses previous information to ask questions, propose solutions, make decisions, design experiments.	Challenge and extend students' conceptual understanding and skills. Through new experiences, the students develop deeper and broader understanding, more information, and adequate skills.	Encourages students to apply the concepts and skills in new situations.
Draws reasonable conclusions from evidence.		Reminds students of alternative explanations.
Records observations and explanations.		Refers students to alternative explanations.
Checks for understanding among peers.	**Evaluate**	Refers students to existing data and evidence and asks, What do you already know? Why do you think . . .?
Answers open-ended questions by using observations, evidence, and previously accepted explanations.	Encourage students to assess their understanding and abilities and provide opportunities for teachers to evaluate student progress.	Observes students as they apply new concepts and skills.
Demonstrates an understanding or knowledge of the concept or skill.		Assesses students' knowledge and/or skills.
Evaluates his or her own progress and knowledge.		Looks for evidence that students have changed their thinking.
Asks related questions that would encourage future investigations.		Allows students to assess their learning and group process skills.
		Asks open-ended questions such as, Why do you think . . .? What evidence do you have? What do you know about the problem? How would you answer the question?

physical involvement in the activity, the students establish relationships, observe patterns, identify variables, and question events.

The teacher's role in the exploration phase is that of facilitator or coach. The teacher initiates the activity and allows the students time and opportunity to investigate objects, materials, and situations based on each student's own ideas of the phenomena. If called upon, the teacher may coach or guide students as they begin constructing new explanations. Use of tangible materials and concrete experiences are essential in the exploration phase.

A portion of the exploration phase should center on cooperative learning (Johnson and Johnson, 1987; Johnson, Johnson, and Holubec, 1986; Johnson, Johnson, and Maruyama, 1983). The opportunity for students to interact, discuss, and even argue in a constructive environment and about goal-centered activities enhances the possibility that their current concepts will be challenged and other ideas will be evident as they reconstruct their ideas (Kuhn, 1992; Vygotsky, 1962, 1978; Smith, Carey, and Wiser, 1985; Champagne, 1987).

Explanation

Explanation means the act or process in which concepts, processes, or skills become plain, comprehensible, and clear. The process of explanation provides the students and teacher with a common use of terms relative to the learning experience. In this phase, the teacher directs student attention to specific aspects of the engagement and exploration experiences. First, the teacher asks the students to give their explanations. Second, the teacher introduces scientific or technological explanations in a direct and formal manner. Explanations are ways of ordering and giving a common language for the exploratory experiences. The teacher should base the initial part of this phase on the students' explanations and clearly connect the explanations to experiences in the engagement and exploration phases of the instructional model. The key to this phase is to present concepts, processes, or skills briefly, simply, clearly, and directly, and then continue on to the next phase.

The explanation phase is teacher-directed. Teachers have a variety of techniques and strategies at their disposal. Educators commonly use verbal explanations, but there are numerous other strategies, such as video, films, and educational courseware. This phase continues the process of mental ordering and provides words for explanations. In the end, students should be able to explain their experiences to each other and to the teacher.

Elaboration

Once the students have an explanation of their learning tasks, it is important to involve them in further experiences that apply, extend, or elaborate the concepts, processes, or skills. Some students may still have misconceptions, or they may only understand a concept in terms of the exploratory experience. Elaboration activities provide further time and experiences that contribute to learning.

Audrey Champagne (1987) discusses an example of the elaboration phase:

> Students engage in discussions and information-seeking activities. The group's goal is to identify and execute a small number of promising approaches to the task. During the group discussion, students present and defend their approaches to the instructional task. This discussion results in better definition of the task as well as the identification and gathering of information that is necessary for successful completion of the task. The teaching model is not closed to information from the outside. Students get information from each other, the teacher, printed materials, experts, electronic databases, and experiments which they conduct. As a result of participation in the group's discussion, individual students are able to elaborate upon the conception of the tasks, information bases, and possible strategies for its [the task's] completion. (p. 82)

Note the use of interactions within student groups as a part of the elaboration process. Group discussions and cooperative learning situations provide opportunities for students to express their understanding of the subject and receive feedback from others who are very close to their own level of understanding.

The elaboration phase also is an opportunity to involve students in new situations and problems that require the application of identical or similar explanations. Generalization of concepts, processes, and skills is the primary goal of the elaboration phase.

Evaluation

At some point, it is important that students receive feedback on the adequacy of their explanations. Informal evaluation can occur from the beginning of the teaching sequence. The teacher can complete a formal evaluation after the elaboration phase. As a practical educational matter, science teachers must assess educational outcomes. This is the phase in which teachers administer tests to determine each student's level of understanding. This also is the important opportunity for students to use the skills they have acquired and evaluate their understanding. The instructional model proposed here is closely aligned with the actual processes involved in the scientific and technological enterprise. In science and technology, the methods of scientific inquiry and strategies of design are excellent means for students to test their explanations and solutions. This is, after all, congruent with science and technology. How well do the students' explanations and solutions stand up to review by peers and teachers? Is there a need to reform ideas based on experience? Table 8.3 provides another summary of the instructional model and suggests parallels to scientific inquiry and technological problem solving.

Some Reflections on the Instructional Model

In my work at BSCS, I have used this instructional model in curriculum materials for the elementary school—*Science for Life and Living: Integrating Science, Technology,*

TABLE 8.3 *The Instructional Model and Contexts for Science and Technology*

A Scientific Context for the Instructional Model	*An Instructional Model*	*A Technological Context for the Instructional Model*
The student has questions about the natural world.	*Engagement:* This phase of the instructional model initiates the learning task. The activity should make connections between past and present learning experiences and anticipate activities and focus students' thinking on the learning outcomes of current activities. The student should become mentally engaged in the concept, process, or skill to be explored.	The student has a problem about a human adaptation to the environment.
The student uses scientific inquiry to answer the questions. Scientific approaches such as stating an appropriate question, making observations, doing an investigation, gathering and analyzing data are all part of this phase in science teaching.	*Exploration:* This phase of the teaching model provides students with a common base of experiences within which they identify and develop current concepts, processes, and skills. During this phase, students may use cooperative learning to explore their environment or manipulate materials.	The student uses different strategies to solve the problem. Engineering approaches, such as recognizing constraints and criteria, analyzing costs, risks, benefits, and designing prototypes are part of this phase of teaching.
The student proposes answers to the questions.	*Explanation:* This phase of the instructional model focuses students' attention on a particular aspect of their engagement and exploration experiences, and provides opportunities for them to verbalize their conceptual understanding or demonstrate their skills or behaviors. This phase also provides opportunities for teachers to introduce a formal label or definition for a concept, process, skill, or behavior.	The student proposes a solution to the problem.

TABLE 8.3 *The Instructional Model and Contexts for Science and Technology (continued)*

A Scientific Context for the Instructional Model	*An Instructional Model*	*A Technological Context for the Instructional Model*
The student applies the proposed answers to new situations in an effort to generalize the explanation.	*Elaboration:* This phase of the teaching model challenges and extends students' conceptual understanding and allows further opportunity for students to practice desired skills and behaviors. Cooperative learning is appropriate used in this stage. Through new experiences, the students develop deeper and broader understanding, more information, and adequate skills.	The student tests the solution in different contexts.
The student and teacher determine the adequacy of the explanation.	*Evaluation:* This phase of the teaching model encourages students to assess their understanding and abilities, and provides opportunities for teachers to evaluate student progress toward achieving the educational objectives.	The student evaluates the solution in terms of the criteria and constraints.

and Health; for the middle school—*Middle School Science and Technology;* and for the high school—*Biological Science: A Human Approach.*

Let me describe several critical issues about instructional models. The first issue has to do with the meaning an activity within the instructional sequence has for students. Students derive personal meaning from three types of experiences. The general terms *physical, psychological,* and *social* describe the types of meaning an experience has for students. An activity can have meaning for students because objects and events are physically close. Objects and events have meaning for individuals simply because they are close and involved. Placing an unknown object in a student's hand increases the meaning of that object for the student. Having hands-on experiences and engaging in problem-solving activities both have a dimension of personal meaning. There is a second dimension of psychological meaning. Some objects and events are interesting and engaging for students. Dinosaurs, plants, and the solar system are all examples of psychologically interesting things for children. Instruction can use the initial interest in these areas to develop concepts, such as time, cycles, and scale. Finally, there is a social aspect of meaning. This is the dimension that most individuals associate with meaning. Educators often equate meaning with relevance or the timeliness of issues. In some cases, science-related social issues, such as population growth, environmental pollution, or resource depletion are meaningful to students. However, assuming these are meaningful to students just because they are timely, and even critically important, is not always a correct assumption from a learning point of view. Obviously, combining all three dimensions of meaning in educational experiences certainly enhances the possibilities of learning.

There is a second critical issue regarding instructional models. An instructional model is probably necessary but not sufficient for the process of conceptual change. That is, the careful structuring and sequencing of activities helps tremendously to bring about conceptual change. There remains, however, a critical interaction among students and between teachers and students that completes the process in the context of classrooms and schools. A carefully structured sequence of activities enhances the possibilities of learning, but it does not ensure learning. The careful probing by teachers, subtly challenging the students, and knowing when to provide a hint or clue that will help the student reconstruct an idea are all interpersonal dimensions of instruction that cannot be adequately accommodated by a set of activities. In short, the burden of learning is too heavy to place solely on an instructional model. The teacher is essential to complete the process of conceptual change.

Finally, the instructional model provides an educational bridge from the students' current conceptions or misconceptions to current scientific concepts. You may note the careful structuring and sequencing that allows students to identify explanations and their adequacy. Although honoring students' ideas, it is also the responsibility of science curriculum and instruction to introduce and help students learn scientific concepts and processes. The design of the 5 Es model is such that this occurs at the midpoint of the instructional sequence. The elaboration

and evaluation phases provide time and opportunity for students and teachers to assess their own understanding against those of science.

Conclusion

This chapter describes an instructional model designed for several BSCS programs. An instructional model brings coherence to different teaching strategies, provides connections among educational activities, helps science teachers make decisions about interactions with students, and contributes to students' development of scientific and technological literacy.

The phases for the instructional model date back to the ideas of Johann Friedrich Herbart, John Dewey, Jean Piaget, and J. Myron Atkin and Robert Karplus. Although the model dates to the ideas of these individuals, it has been modified and updated based on contemporary research and practical issues of science teaching. The instructional model has constructivism as a theoretical foundation but recognizes the critical role of classroom teachers, who must make myriad decisions about their students.

The instructional model consists of five phases designed to facilitate the process of conceptual change. The actual application of the phases in curriculum and teaching may not be as clear and easy as outlined here; still, the model should contribute to better, more consistent, and coherent instruction. The instructional sequences include

- *Engagement.* In the first phase, the teacher designs experiences intended to make connections with current concepts and skills and to bring into question the adequacy of those concepts and skills.
- *Exploration.* In this phase, the teacher uses activities and social interaction (cooperative learning) to help students begin constructing more adequate concepts and developing better skills.
- *Explanation.* In this phase, the students have an opportunity to articulate their ideas, and the teacher helps students clarify their ideas through scientific and technological terms and concepts.
- *Elaboration.* In this phase, the teacher provides activities based on the same concepts and skills, but there is a new and different context. The students must expand or generalize their new conceptions to the different experiences.
- *Evaluation.* In this phase, the teacher uses a variety of assessments to determine the students' conceptual understanding and level of skill development. This phase also is an opportunity for students to test their understanding and skills.

Four general factors support this instructional model: (1) educational research on conceptual change, (2) congruence of the model with the general processes of