Session 3: Comparing Teaching Approaches

The learning cycle model presented during this [redacted] session is based on a 4-phase cycle including: invitation, exploration, concept introduction, and application. There are other models with similar phases and minor variations (some have three main stages, others four or more) but they all share a common vision of how learning takes place.

The learning cycle is an instruction model that is learner-centered and takes into account the learner's prior understandings and need for firsthand experiences. It provokes questions, and enables students to integrate and apply new concepts and information.

It is important to be mindful of the fact that the learning cycle we present is one model that can be used to represent, organize, and categorize main phases in science learning. It is not the only way to conceptualize learning. It should not be seen as a rigid or mechanical model—people and their learning processes are gloriously complex, and depending on the person and the content being learned there is no automatic order or sequence in which these phases must occur. The learning cycle model of instruction can be powerful and enormously helpful in stimulating thinking about how people learn. It is also an important tool in designing lessons that succeed in conveying concepts to students meaningfully and effectively.

To help illustrate the flexible configurations of the learning cycle, we have chosen a chapter from Roger Bybee's book Achieving Scientific Literacy. This chapter, *Improving Instruction*, presents an historical overview of significant schools of thought and subsequent models for how people learn that have emerged over the past century. Often referred to as the "Five E Paper" Bybee presents a five-phase learning cycle quite similar to the model employed in class.

A classic work on learning theory from the 1960's is worth investigating if only to see the foundations for current research and thought. One of the authors, Robert Karplus, was Professor of Physics at UC Berkeley and a former Director of the Lawrence Hall of Science.

Discovery or Invention? Atkin, J.M., Karplus, R., The Science Teacher, Volume 29, Number 5, September 1962, National Science Teachers Association.

in this chapter. In my view, *adapt* is the operative word, and in most cases, adapting will be preceded by *adopting*. That is, most school districts should adopt curriculum materials and then adapt them through professional development.

If science teachers or local school districts are adapting their current materials to address the *Standards*, then the first issue is, How close are the extant units and lessons to specific standards? If the materials generally have features consistent with the philosophy, pedagogy, and content of standards, then adaptation may be fairly easy. If, on the other hand, extant materials show considerable variation from that philosophy, pedagogy, and content, the adaptation may simply be too much and school personnel should consider a science curriculum that most closely aligns with the local and state requirements, national standards, and the interests and talents of science teachers.

Conclusion

This chapter focused on the improvement of the science curriculum. The view of the science curriculum moves beyond the textbook as curriculum or hundreds of hands-on activities. The science curriculum is a designed set of relationships among content, teaching, context, and assessment. Regardless of your approach—revising the old or adopting the new—improving the science curriculum has costs, benefits, and trade-offs. If we continue to improve the science curriculum and maintain the focus on a standards-based systemic reform, then we should begin to realize our goal of scientific and technologic literacy for all students.

8 *Improving Instruction*

The heart of this chapter consists of an instructional model that should help science teachers improve their instructional practices. I am convinced that the ultimate reform of science education will only occur at the level of science classrooms. Recommending an instructional model touches the heart of teaching—the most practical level at which educational reform occurs.

The instructional model used extensively in several BSCS programs, commonly referred to as the 5 Es, consists of the following phases: engagement, exploration, explanation, elaboration, and evaluation. Each phase has a specific function and contributes to the teacher's coherent instruction and the students' constructing a better understanding of scientific and technological knowledge, attitudes, and skills. The model can be used to help frame the sequence and organization of programs, units, and lessons. Once internalized, it also can inform the many instantaneous decisions science teachers must make in classroom situations.

Constructivism is the theoretical foundation for this instructional model. The constructivist view assumes a dynamic and interactionist conception of human learning. Students bring to a learning experience their current explanations, attitudes, and skills. Through meaningful interactions between themselves and their environment, which includes other students and teachers, they redefine, replace, and reorganize their initial explanations, attitudes, and skills. In developing the instructional model, I assumed that the constructive process could be assisted by sequences of experiences designed to challenge current conceptions, attitudes, and skills, and provide time and opportunities for reconstruction to occur.

Historical Perspectives on Instructional Models

The 5 Es model has an orientation and elements identifiable in educational history. This section presents some historical antecedents of the contemporary 5 Es model. The section begins with a general characterization of learning theories and then describes instructional models proposed by individuals, such as Johann Friedrich Herbart, John Dewey, and Jean Piaget, all of which can be viewed as conceptual predecessors to the 5 Es model.

Views of Learning

Historically, educators have explained learning by classifying it into one of three broad categories: transmission, maturation, and construction (see Table 8.1). B. F. Skinner's theories serve as an example of the first category—transmission (Ferster and Skinner, 1957). Arnold Gesell's model exemplifies the second—maturation (Ilg and Ames, 1955). Many science educators would recognize Piaget's ideas as associated with the third category—construction (Piaget, 1975; Piaget and Inhelder, 1969). Piaget viewed development of the intellect as neither direct learning from the environment nor maturation. Rather, he proposed that learning consists of reorganization and reconstruction of psychological structures as a result of interactions between the individual and the environment. The following sections present several examples of individuals whose ideas contributed to contemporary perspectives of teaching and learning.

Herbart's Model

Johann Friedrich Herbart, a German philosopher, influenced American educational thought around the turn of the century. For Herbart, the primary purpose of education was development of character, and the process of developing character began with the student's interest. At a more specific level, Herbart considered concepts to be the fundamental building blocks of the mind, and the function of a concept constituted justification for including a concept in a course of study. In a contemporary sense, Herbart was interested in the creation and development of conceptual structures that would contribute to an individual's development of character. Herbart's philosophy contrasted with another model that proposed that the purpose of education was to exercise the mind (DeBoer, 1991; Tanner and Tanner, 1990).

TABLE 8.1 *Perspectives for Instructional Strategies*

Perspective	*Assumptions about Students as Learners*	*Views of Knowledge*	*Approaches to Teaching*
Transmission	Students must be filled with information and concepts.	Concepts are a copy of reality.	External to internal
Maturation	Students must be allowed to mature and develop.	Concepts emerge.	Internal to external
Construction	Students must be actively involved in learning.	Concepts are constructed.	Interaction between internal and external

Herbart proposed two principal ideas that he used as foundations for teaching: interest and conceptual understanding. The first principle of effective instruction consisted of the student's interest in the subject. Herbart suggested two types of interest, one based on direct experiences with the natural world and the second based on social interactions. Instruction can quite easily use the natural world and capitalize on the curiosity of students. In addition, teachers can introduce objects from the natural world and use them to help students accumulate a rich set of sense impressions. Herbart suggested the observation and collection of living organisms and the introduction of tools and machines. As teachers introduce organisms and objects, they should take into account and make connections to prior experiences (Herbart, 1901).

Herbart's model also suggested that teachers should recognize the social interests of children and interactions with other individuals. A thorough education incorporates social interactions and recognizes their contribution to learning. Thus, an instructional model should incorporate opportunities for social interaction among students, and between students and the teacher.

The second principle of Herbart's model resides in the association of the sense perceptions with generalizations or principles, or the formation of concepts. For Herbart, sense perceptions of objects, organisms, and events were essential, but in and of themselves they were not sufficient for the development of mind. A very important theme in Herbart's model is the coherence of ideas. That is, each new idea must be related to extant ideas. Said in contemporary terms, prior knowledge is the point of departure of instruction.

If we synthesized Herbart's ideas into an instructional model, as others have (see, for example, Compayre, 1907; DeBoer, 1991), we would begin with the current knowledge and experiences of the student and present ideas that easily related to those concepts the student already had. The introduction of new ideas that connected with extant ideas would slowly form concepts. According to Herbart (1901), the best pedagogy allowed students to discover the relationships among experiences. The teachers guided, questioned, and suggested through indirect methods. The next step in the instructional model involved direct instruction, where the teacher systematically explained ideas that the student could not be expected to independently discover. In the final step of Herbart's model, teachers asked students to demonstrate their conceptual understanding by applying the concepts to new situations. Students solved problems, wrote essays, and performed tasks that demonstrated their understanding of the concepts. Herbart's model is one of the first systematic approaches to teaching and has been used in various forms by educators for more than one hundred years (DeBoer, 1991). The following list summarizes Herbart's instructional model.

Preparation	The teacher brings prior experiences to students' awareness.
Presentation	The teacher introduces new experiences and makes connections to prior experiences.

Generalization	The teacher explains ideas and develops concepts for the students.
Application	The teacher provides experiences where the students demonstrate their understanding by applying concepts in new contexts.

Dewey's Model

John Dewey began his career as a science teacher. No doubt, the early influence of science explains the obvious connection between Dewey's conception of thinking and scientific inquiry. In *How We Think,* Dewey (1933 [1910]) outlined what he termed a complete act of thought and described what he maintained were indispensable traits of reflective thinking. The traits included (1) defining the problem, (2) noting conditions associated with the problem, (3) formulating a hypothesis for solving the problem, (4) elaborating the value of various solutions, and (5) testing the ideas to see which provided the best solution for the problem.

In *Democracy and Education,* Dewey (1916) further described the relationship between experience and thinking. He summarized the general features of the reflective experience:

> (i) perplexity, confusion, doubt, due to the fact that one is implicated in an incomplete situation whose full character is not yet determined; (ii) a conjectural anticipation—a tentative interpretation of the given elements, attributing to them a tendency to affect certain consequences; (iii) a careful survey (examination, inspection, exploration, analysis) of all attainable consideration which will define and clarify the problem in hand; (iv) a consequent elaboration of the tentative hypothesis to make it more precise and more consistent, because squaring with a wider range of facts; (v) taking one stand upon the project hypothesis as a plan of action which is applied to the existing state of affairs: doing something overtly to bring about the anticipated result, thereby testing the hypothesis. (p. 150)

Based on this quotation, it seems clear that Dewey implied an instructional approach that was based on experience and required reflective thinking. In contemporary terms, doing hands-on activities in science is not enough. Those experiences also must be minds-on. In Dewey's time, and in the contemporary reform, many individuals regard activity-based, hands-on, process-oriented programs as ends rather than means. According to Dewey, a worthwhile instructional sequence provided students with the opportunity to formulate and test hypotheses and thus engage in the reflective thinking process. Jacques Barzun (1991) states, "All that is new or seems new in Dewey . . . is the recommendation to make early instruction follow the pattern of scientific inquiry"(p. 56).

Dewey's ideas stimulated the progressive movement in American education. By the 1930s, the Progressive Education Association established the Committee on the Function of Science in General Education of the Commission on Secondary School Curriculum. The committees released their report as *Science in General Education* in 1938 (Commission on Secondary School Curriculum, 1937). Dewey's

model of reflective thinking became a consistent theme and instruction model in that report. In a chapter on reflective thinking, the report had a section on "How the Science Teacher May Encourage Reflective Thinking." The section included the following recommendations:

- widening the range of problems that are real and stimulating to the student (p. 313)
- overcoming obstacles to the wide use of reflective thinking (p. 314)
- finding opportunity for students to work intensively on their problems (p. 315)
- working on problems encountered in meeting needs (p. 318)
- helping older students to become aware of the nature of reflecting thinking (p. 320)
- encouraging confidence in scientific methods (p. 324)

Underlying these general recommendations, one detects the model of scientific inquiry and provisions for students to engage actively in that process. The following list summarizes Dewey's instructional model. I synthesized this model from Dewey's statements and from *Science in General Education.*

Sensing perplexing situations	The teacher presents an experience where the students feel thwarted and sense a problem.
Clarifying the problem	The teacher helps the students identify and formulate the problem.
Formulating a tentative hypothesis	The teacher provides opportunities for students to form hypotheses and tries to establish a relationship between the perplexing situation and previous experiences.
Testing hypothesis	The teacher allows students to try various types of experiments, including imaginary, pencil-and-paper, and concrete experiments, to test the hypothesis.
Revising rigorous tests	The teacher suggests tests that result in acceptance or rejection of the hypothesis.
Acting on the solution	The teacher asks the students to devise a statement that communicates their conclusions and expresses possible actions.

Piaget's Model

Piaget's model of equilibration is the part of his overall developmental theory that relates to the process of learning. Equilibration is, in essence, the learning theory for Piaget's developmental psychology. Piaget's major statement on equilibration is *The Development of Thought* (1975). Piaget and others have discussed the equilibration process in their works (Nodine, Gallagher, and Humphreys, 1972; Piaget and Inhelder, 1969).

According to Piaget, intellectual development occurs through an adaptation in response to a discrepancy between the individual's current cognitive structure and a cognitive referent in the environment. Disequilibrium results from a discrepancy. Modification of intellectual structures brings the cognitive system back to equilibrium. The process of equilibration involves both maintenance and change of intellectual structures. That is, old structures continue while they are modified or combined with others to form new structures. Equilibration occurs at three major levels: (1) the total system, which Piaget described as a stage of development, a complete set of cognitive structures that are at equilibrium for a period of time; (2) a subsystem, such as the cognitive structures for classification, conservation, and numeration; (3) specific concepts, like color, objects, and organisms, which may be included in the aforementioned levels of organization.

In Piaget's model, organization and adaptation are the two processes that bring about equilibration. Organization is the maintenance of an internal order of the intellectual structure through the inherent tendency to systematize and integrate intellectual structures into coherent systems. This tendency results in the spontaneous transition to higher orders of intellectual complexity. These processes are further described in an educational context elsewhere (Bybee and Sund, 1982; Lawson and Wollman, 1975).

Adaptation is the process of changing the intellectual structure through interaction with the environment. This modification results in development of the cognitive structure. Intellectual adaptation consists of two processes that are simultaneous and complementary. These processes are accommodation and assimilation.

I can clarify the processes of accommodation and assimilation with an educational example. Assume that cognitively a student is at equilibrium with respect to particular events in the world, say, the motion of objects in response to the gravitational pull of the earth. That is, the student has a conception of the world that satisfactorily explains how and why objects roll downhill. The teacher confronts the student with a puzzling science demonstration, a discrepant event. For example, an object released on an inclined plane rolls up the plane rather than down. This instance of an object rolling uphill is associated with prior experiences of objects rolling downhill. The student tries to explain the event in terms of prior experiences (assimilation) and cannot do so. So the student has to change some cognitive schemes in order to explain the anomalous event. Accommodation occurs in the same time frame as the assimilation. The intellectual structure is somewhat readjusted to the external reality, the phenomenon of the demonstration. The student's prior conception of how objects respond to the earth's pull is

changed, or a new explanation is developed that maintains the "gravity model" of objects rolling downhill. For instance, the student explains the event by another model (the object rolled uphill because it was powered by a rubber band).

I briefly summarized the process of equilibration for several reasons. The SCIS learning cycle, which I introduce next, is based on this model of learning. Much of the recent research on the cognitive sciences assumes a similar model. And the instructional model I propose assumes that students' construct knowledge in a similar manner.

The Atkin/Karplus Model

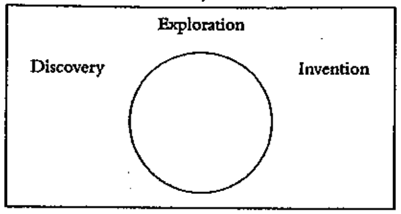
In the early 1960s, J. Myron Atkin and Robert Karplus (1962) proposed a systematic approach to instruction. Robert Karplus, Herbert Their, and their colleagues later used the instructional model, referred to as the learning cycle, in the SCIS. The learning cycle for SCIS was related to the psychological theories of Jean Piaget. The classic article "Messing About in Science" by David Hawkins (1965) described a teaching model using symbols of circle, triangle, and square. In general, the symbols represented phases of an instructional model that included unstructured exploration and multiple programmed experiences and didactic instruction.

In past decades, the SCIS learning cycle has undergone elaboration, modification, and application to different educational settings. In addition, recent analyses of elementary programs indicate that SCIS was one of the more effective programs (Shymansky, Kyle, and Alport, 1983). These positive effects on learning relate at least in part to the learning cycle. Most recently, the SCIS learning cycle has been used as central to a theory of instruction (Lawson, Abraham, and Renner, 1989) (see Figure 8.1).

Using the learning cycle creates situations in which the processes of assimilation, accommodation, and organization occur (Renner and Lawson, 1973; Lawson, Abraham, and Renner, 1989). The three phases and the normal sequence of the SCIS learning cycle are exploration, invention, and discovery. Exploration refers to the relatively unstructured experiences in which students gather new information. This phase predominantly involves the process of assimilation. Invention refers to a formal statement, often the definition, of a new concept. Following the exploration, the invention phase begins the process of accommodation that allows interpretation of newly acquired information through the restructuring of prior concepts. The discovery phase involves application of the new concept to another, novel situation. During this phase, the learner continues to move closer to a state of equilibrium and to a new level of cognitive organization (integration of the new concept with related concepts).

A number of studies have shown that the SCIS learning cycle has many advantages when compared with other approaches to instruction, specifically the transmission model of teaching. These studies are summarized in Abraham and Renner (1986). Jack Renner and his colleagues (Renner, Abraham, and Birnie, 1985; Abraham and Renner, 1986; Renner, Abraham, and Birnie, 1988) have investigated, respectively, the form of acquisition of information in the learning

FIGURE 8.1 *The Atkin/Karplus Instructional Model*



cycle, the sequencing of phases in the learning cycle, and the necessity of each phase of the learning cycle. These studies have generally supported use of the SCIS learning cycle as originally designed by Atkin and Karplus. Research on discovery, guided discovery, and statement-of-rule learning (Egan and Greeno, 1973; Gagne and Brown, 1961; Roughead and Scandura, 1968) supports the "sequencing and necessity" conclusions drawn by Renner and his colleagues.

Although the form and structure of the Atkin/Karplus learning cycle have undergone little revision, researchers have offered different interpretations of each phase of the cycle. Abraham and Renner (1986) refer to the exploration phase as "gathering data." This interpretation provides more structure for the assimilation of new material and restricts Atkin and Karplus' original notion that exploration should provide students with common experiences, regardless of whether those experiences involve gathering data in a laboratory sense.

Lawson (1988) describes the invention phase as "concept introduction," suggesting that because the new concept is not fully developed during this phase, the learner does not truly invent the concept. Lawson further suggests that the appropriate label for this phase may be "term introduction," since only the vocabulary associated with the new concept is learned at this point.

Renner renamed the discovery phase "expansion," taken from the idea that the learner actually expands on the new concept and is involved in the Piagetian process of organization. Lawson (1988) suggested a more restrictive interpretation of this phase when he used the words "concept application." One should be aware, however, that in applying the concept to new situations, the learner may still be in the process of restructuring or reconstructing the concept.

Design Requirements for an Instructional Model

Design for an instructional model must bridge the everyday and scientific thinking of students and teachers (Hawkins and Pea, 1987). The model has to have a practical quality for teachers and provide understandable features for students. The following statements describe some of the essential design requirements for an instructional model:

1. The model should incorporate the essential features of the three phases of the SCIS learning cycle in the traditional sequence. The research base for this model is substantial and should not be ignored.

2. The model must have an initial stage that engages the learner and brings about disequilibrium in the student. This stage should be designed to gain the student's attention on critical aspects of an experience and to focus thinking on concepts deemed important.

3. The model must help the learner integrate new knowledge with prior knowledge. In order to understand any new concept, the learner must, in a meaningful way, connect that concept to other concepts in science and technology as well as to new and old experiences.

4. The model must allow for student–student as well as student–teacher interaction. Social interaction among students encourages argument and opportunities to formulate new explanations for experiences.

5. The model must help the learner through the process of conceptual change in a "generic" fashion that includes, but is not tied to, specific misconceptions. That is, the instructional model must be applicable to many science concepts. Designing an instructional model unique to each science concept seems complex, inefficient, and fails to recognize the fact that science teachers must interact with twenty-five or thirty students at a time. This requirement is both crucial and challenging. The research on conceptual change necessarily focuses on specific concepts, but teachers cannot anticipate and recognize all of the student conceptions associated with a particular topic or curriculum. The model must therefore allow for explanations generated by students as well as ample time for discussion of those explanations.

6. Although allowing for conceptual change, the model must be manageable for the teacher. It is generally not feasible for a teacher, prior to any lesson, to ascertain each student's prior conceptions and then structure instruction accordingly. In the future, technology may help overcome this problem. But for now, teachers will confront classrooms with considerable variation in conceptual understanding. Thus, the model should include strategies that are designed to maximize the benefit for individual students and also that are usable for the teacher in the typical classroom environment.

7. The model must be intelligible and apparent to both teachers and students. Teachers who initially use an instructional model are themselves engaged in a process of conceptual change. Most science teachers have models of teaching and learning that probably vary with the one presented here. The model should therefore be easily recognizable. Students also should know what phase of the model they are in and what is expected of them during that phase so that they can engage in appropriate behaviors.

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. Uses previous information to ask questions, propose solutions, make decisions, design experiments. Draws reasonable conclusions from evidence. Records observations and explanations.	**Elaborate** Challenge and extend students' conceptual understanding and skills. Through new experiences, the students develop deeper and broader understanding, more information, and adequate skills.	Expects students to use vocabulary, definitions, and explanations provided previously in new context. Encourages students to apply the concepts and skills in new situations. Reminds students of alternative explanations. Refers students to alternative explanations.
Checks for understanding among peers. Answers open-ended questions by using observations, evidence, and previously accepted explanations. Demonstrates an understanding or knowledge of the concept or skill. Evaluates his or her own progress and knowledge. Asks related questions that would encourage future investigations.	**Evaluate** Encourage students to assess their understanding and abilities and provide opportunities for teachers to evaluate student progress.	Refers students to existing data and evidence and asks, What do you already know? Why do you think . . .? Observes students as they apply new concepts and skills. Assesses students' knowledge and/or skills. Looks for evidence that students have changed their thinking. 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 scientific inquiry and technological design, (3) utility of the model for designing and developing curriculum materials, and (4) practical use by science teachers.

Reforming science education and transforming purposes to practices will only occur when science teachers improve instructional practices. Implementing systematic and coherent approaches to science teaching such as the 5 Es model represents a tremendous advance in the reform of science education.

9 *Implementing a Standards-Based Systemic Reform*

The immense journey of contemporary educational reform began with declarations that our nation was at risk, proceeded to the major educational aims of *Goals 2000*, and progressed to the development of standards. Whether local, state, or national, the development of standards for science education represents an essential step; and contrary to some views, the step to develop standards was one of the easiest, not the hardest. The next steps on the journey involve improving instructional materials, changing teaching practices, and enhancing assessment strategies. Central to these steps is the professional development of science teachers, because the ultimate reform of science education must occur in classrooms and in the interactions among science teachers and students. The next steps toward achieving scientific literacy will cost more, take more time, involve more people, and require coordination and coherence within the educational system. The payoff for these increases of costs, time, personal involvement, and systemic reform, however, will be substantial in terms of moving learners to higher levels of scientific literacy.

This chapter first examines some ideas and assumptions about standards, introduces some ideas related to large-scale reform, then elaborates the idea of systemic reform in science education. Finally, I provide insights from the area of large-scale policy.

Understanding What Science Education Standards Are

Before discussing the meaning of standards, it will be helpful to review several of the *National Science Education Standards*. Following are listed two standards from content (inquiry and life science) and one each from teaching and assessment. I include these four standards because one must view all content standards and not examine only subject matter standards (physical, life, earth and space science, inquiry, technology, science in personal and social perspectives, history and nature of science); the standards must be viewed as an integrated whole, which means that