The BSCS 5E Instructional Model: Origins, Effectiveness, and Applications

Full Report

by

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with research and preparation assistance from

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A Report Prepared for the

Office of Science Education
National Institutes of Health

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Introduction

Science teachers continuously strive to improve their instructional practices to enhance student learning. Complementing the aims of science teachers, curriculum developers systematically attempt to identify research findings they can incorporate in materials that will facilitate connections between teachers, the curriculum, and students. Recently, the use of coordinated and coherent sequencing of lessons—learning cycles and instructional models—has gained popularity in the science education community.

Recent research reports, such as *How People Learn: Brain, Mind, Experience, and School* (Bransford, Brown & Cocking, 2000) and its companion, *How Students Learn: Science in the Classroom* (Donovan & Bransford, 2005), have confirmed what educators have asserted for many years: **The sustained use of an effective, research-based instructional model can help students learn fundamental concepts in science and other domains.** If we accept that premise, then an instructional model must be effective, supported with relevant research *and* it must be implemented consistently and widely to have the desired effect on teaching and learning.

Since the late 1980s, BSCS has used one instructional model extensively in the development of new curriculum materials and professional development experiences. That model is commonly referred to as the BSCS 5E Instructional Model, or the 5Es, and 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 to the learners' formulation of a better understanding of scientific and technological knowledge, attitudes, and skills. The model frames a sequence and organization of programs, units, and lessons. Once internalized, it also can inform the many instantaneous decisions that science teachers must make in classroom situations. See Table 1 for a summary of the BSCS 5E Instructional Model.

This report summarizes recent research on the sequencing of science instruction, including laboratory experiences, in order to facilitate student learning. Specifically, the report provides a rationale and empirical support for the BSCS 5E Instructional Model.

One reason for reviewing the historical development and research base for the BSCS 5E Instructional Model is its ubiquitous use in education today. This widespread use falls into three primary categories of use: 1) documents that frame larger pieces of work such as curriculum frameworks, assessment guidelines, or course outlines; 2) curriculum materials of various lengths and sizes; and 3) adaptations for teacher professional development, informal education settings, and disciplines other than science. A simple internet search, using a popular search engine such as Google, reveals the wide and varied applications of the 5E model. In spring 2006, this type of search showed the following range of uses:

- more than 235,000 lesson plans developed and implemented using the BSCS 5E Instructional Model;
- more than 97,000 posted and discrete examples of universities using the 5E model in their course syllabi;
- more than 73,000 examples of curriculum materials developed using the 5E model;
- more than 131,000 posted and discrete examples of teacher education programs or resources that use the 5Es; and

- at least three states that strongly endorse the 5E model, including Texas, Connecticut, and Maryland.

The first section of this report provides a brief history of instructional models and discusses the Science Curriculum Improvement Study (SCIS) learning cycle (Karplus & Thier, 1967), the predecessor to the BSCS 5Es. After that discussion, the same section summarizes research supporting contemporary views of learning and the effectiveness of different instructional models, with emphasis on the SCIS learning cycle and the BSCS 5E model.

Table 1. Summary of the BSCS 5E Instructional Model

Phase	Summary
Engagement	The teacher or a curriculum task accesses the learners' prior knowledge and helps them become engaged in a new concept through the use of short activities that promote curiosity and elicit prior knowledge. The activity should make connections between past and present learning experiences, expose prior conceptions, and organize students' thinking toward the learning outcomes of current activities.
Exploration	Exploration experiences provide students with a common base of activities within which current concepts (i.e., misconceptions), processes, and skills are identified and conceptual change is facilitated. Learners may complete lab activities that help them use prior knowledge to generate new ideas, explore questions and possibilities, and design and conduct a preliminary investigation.
Explanation	The explanation phase focuses students' attention on a particular aspect of their engagement and exploration experiences and provides opportunities to demonstrate their conceptual understanding, process skills, or behaviors. This phase also provides opportunities for teachers to directly introduce a concept, process, or skill. Learners explain their understanding of the concept. An explanation from the teacher or the curriculum may guide them toward a deeper understanding, which is a critical part of this phase.
Elaboration	Teachers challenge and extend students' conceptual understanding and skills. Through new experiences, the students develop deeper and broader understanding, more information, and adequate skills. Students apply their understanding of the concept by conducting additional activities.
Evaluation	The evaluation phase encourages students to assess their understanding and abilities and provides opportunities for teachers to evaluate student progress toward achieving the educational objectives.

Origins of
Contemporary Instructional Models

Origins of Contemporary Instructional Models

Although the idea of instructional models is not new, their application and use has increased dramatically in recent years. This discussion presents a brief history of several instructional models, in particular those that influenced the development of the contemporary BSCS 5E Instructional Model. The historical models include brief discussions of several approaches including one by Johann Herbart and John Dewey. We then provide greater philosophical and psychological detail for a model presented by J. Myron Atkin and Robert Karplus because this model was the foundation for the BSCS 5E Instructional Model.

Johann Friedrich Herbart

Johann Friedrich Herbart, a German philosopher, influenced American educational thought around the turn of the 20th century. For Herbart, the primary purpose of education is the development of character, and the process of developing character begins with the students' interest. Herbart considers concepts to be the fundamental building blocks of the mind, and the function of a concept is justification for including a concept in a course of study. In a contemporary sense, Herbart is interested in the creation and development of conceptual structures that would contribute to an individual's development of character.

Herbart proposes two ideas as foundations for teaching: interest and conceptual understanding. The first principle of effective instruction consists of the students' interest in the subject. Herbart suggests two types of interest, one based on direct experiences with the natural world and the second based on social interactions. Science 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 suggests the observation and collection of living organisms and the introduction of tools and machines (Herbart, 1901).

Herbart's model also incorporates the social interests of children and their interactions with other individuals. A thorough education takes into account the contribution of social interactions 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 is the formation of concepts. For Herbart, sense perceptions of objects, organisms, and events are essential, but in and of themselves they are 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.

In summarizing Herbart's ideas into an instructional model, we begin with the current knowledge and experiences of the students and the new ideas related to concepts the students already have. Introducing new ideas that connect with extant ideas would slowly form concepts. According to Herbart (1901), the best pedagogy allows students to discover the relationships among experiences. Teachers would guide, question, and suggest through indirect methods. The next step involves direct instruction, where the teacher systematically explains ideas that the student could not be expected to discover independently. In the final step, teachers ask students to demonstrate their understanding by applying the concepts to new situations. Herbart's model is one of the first systematic approaches to teaching and has been used in various forms by educators for more than 100 years. Table 2 summarizes Herbart's instructional model.

Table 2. Herbart's Instructional Model

Phase	Summary
Preparation	The teacher brings prior experiences to the 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.

John Dewey

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* (1910, 1933), Dewey outlines what he terms a complete act of thought and describes what he maintains are indispensable traits of reflective thinking. Those traits include (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 provide the best solution for the problem.

In *Democracy and Education* (1916), Dewey further describes the relationship between experience and thinking. He summarizes 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; (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 implies an instructional approach that is based on experience and requires reflective thinking. In contemporary terms, doing hands-on activities in science is not enough. Those experiences also must be minds on.

The 1938 report *Science in General Education* (Commission on Secondary School Curriculum, 1937) expresses Dewey's model of reflective thinking, and a section on "How the Science Teacher May Encourage Reflective Thinking" describes elements of an instructional model.

Table 3 synthesizes an instructional model from Dewey's statements and from *Science in General Education*.

Table 3. Dewey's Instructional Model

Phase	Summary
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 the 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.

By 1950, a variation of John Dewey's instructional model emerged in science methods textbooks (Heiss, Obourn, & Hoffman, 1950). The authors based their "learning cycle" (their term) on Dewey's complete act of thought. Table 4 presents that learning cycle.

Table 4. Heiss, Obourn, and Hoffman Learning Cycle

Phase	Summary
Exploring the Unit	Students observe demonstrations to raise questions, propose a hypothesis to answer questions, and plan for testing.
Experience Getting	Students test the hypothesis, collect and interpret data, and form a conclusion.
Organization of Learning	Students prepare outlines, results, and summaries; they take tests.
Application of Learning	Students apply information, concepts, and skills to new situations.

The Atkin-Karplus Learning Cycle

In the late 1950s and early 1960s, an era of curriculum reform, instructional models were popularized by leaders of the reform movement. In a popular and now-classic article, "Messing About in Science," David Hawkins (1965) describes a teaching model that uses the symbols of the circle, the triangle, and the square. In general, the symbols represent phases of an instructional model that includes unstructured exploration, multiple programmed experiences, and didactic instruction.

The model described by Hawkins provides the basic strategies for the units developed by the Elementary Science Study (ESS). The systematic approach to instruction did not, however, gain the widespread acceptance of other curriculum development studies, in particular the Science Curriculum Improvement Study (SCIS).

Robert Karplus, a theoretical physicist at the University of California–Berkeley, became interested in science education in the late 1950s. His interest led to an exploration of children's thinking and their explanations of natural phenomena. By 1961, Karplus began connecting the developmental psychology of Jean Piaget to the design of instructional materials and science teaching.

In 1961, J. Myron Atkin, then at the University of Illinois, shared Karplus's ideas about teaching science to young children. Eventually, they collaborated on a model of *guided discovery* in instructional materials (Atkin & Karplus, 1962). Karplus continued refining his ideas and the instructional model as he tested different instructional materials and observed the responses of elementary children.

By 1967, Robert Karplus and his colleague Herbert Thier used the original terms and provided greater clarity and a curricular context as they described the three phases of their model for science teaching. "The plan of a unit may be seen, therefore, to consist of this sequence: preliminary exploration, invention, and discovery" (Karplus & Thier, 1967, p. 40).

The three phases and the sequence of the SCIS learning cycle are exploration, invention, and discovery. Exploration refers to relatively unstructured experiences in which students gather new information. Invention refers to a formal statement, often the definition and terms for a new concept. Following the exploration, the invention phase 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 develop a new level of cognitive organization and attempts to transfer what he or she has learned to new situations. (See Table 5.)

A number of studies have shown that the SCIS learning cycle has many advantages when compared with other approaches to instruction. These studies are summarized in Abraham and Renner (1986). Jack Renner and his colleagues (Renner, Abraham, & Birnie, 1985; Abraham & Renner, 1986; Renner, Abraham, & Birnie, 1988) have investigated, respectively, the form of acquisition of information in the learning 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 & Greeno, 1973; Gagne & Brown, 1961; Roughead & Scandura, 1968) supports the "sequencing and necessity" conclusions drawn by Renner and his colleagues. Lawson (1995) provides an excellent detailed history of the development and modifications of the SCIS learning cycle.

Initially, the SCIS learning cycle used the terms exploration, invention, and discovery to identify the phases and sequence of the model. In the 1980s, Lawson (1988) and others slightly modified the terms used for the learning cycle. The modified terms are exploration, term introduction, and concept application. Although there were changes in terminology, the conceptual foundation of the learning cycle remained essentially the same.

Table 5. Atkin-Karplus Learning Cycle

Phase	Summary
Exploration	Students have an initial experience with phenomena.
Invention	Students are introduced to new terms associated with concepts that are the object of study.
Discovery	Students apply concepts and use terms in related but new situations.

Analyses of elementary programs indicate that SCIS was one of the effective programs (Shymansky, Kyle, & Alport, 1983). These positive effects on learning relate at least in part to the learning cycle. The SCIS learning cycle was used as central to a theory of instruction prescribed by Lawson, Abraham, & Renner (1989). In addition, the SCIS learning cycle has been applied successfully in different educational settings.

The BSCS 5E Instructional Model

In the mid-1980s, BSCS received a grant from IBM to conduct a design study that would produce specifications for a new science and health curriculum for elementary schools. Among the innovations that resulted from this design study was the BSCS 5E Instructional Model. As mentioned earlier and elaborated later in this section, the BSCS model has five phases: engagement, exploration, explanation, elaboration, and evaluation. When formulating the BSCS 5E Instructional Model, we consciously began with the SCIS learning cycle. The middle three elements of the BSCS model are fundamentally equivalent to the three phases of the SCIS learning cycle.

Table 6. Comparison of the Phases of the SCIS and BSCS 5E Models

SCIS Model	BSCS 5E Instructional Model
	Engagement (New Phase)
Exploration	Exploration (Adapted from SCIS)
Invention (Term Introduction)	Explanation (Adapted from SCIS)
Discovery (Concept Application)	Elaboration (Adapted from SCIS)
	Evaluation (New Phase)

The following paragraphs describe the phases of the BSCS 5E Instructional Model. Phases of the BSCS model can be applied at several levels in the design of curriculum materials and instructional sequences. They may be applied to the organizational pattern of a yearlong program, to units within the curriculum, and to sequences within lessons. These paragraphs are slightly modified from the original descriptions in *New Designs for Elementary School Science and Health* (BSCS, 1989).

Engagement: The first phase engages students in the learning task. The students mentally focus on an object, problem, situation, or event. The activities of this phase make connections to past experiences and expose students' misconceptions; they should serve to mitigate cognitive disequilibrium.

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 task. The role of the teacher is to present the situation and identify the instructional task. The teacher also sets the rules and procedures for establishing the task.

Successful engagement results in students being puzzled by, and actively motivated in, the learning activity. Here, the word “activity” refers to both mental and physical activity.

Exploration: Once the activities have engaged the students, the students have a psychological need for time to explore the ideas. Exploration activities are designed so that the students in the class have common, concrete experiences upon which they continue formulating concepts, processes, and skills. Engagement brings about disequilibrium; exploration initiates the process of equilibration. This phase should be concrete and hands on. Educational software can be used in the phase, but it should be carefully designed to assist the initial process of formulating adequate and scientifically accurate concepts.

The aim of exploration activities is to establish experiences that teachers and students can use later to formally introduce and discuss 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 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 reconstructing their explanations. Use of tangible materials and concrete experiences is essential.

Explanation: The word “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 the teacher with a common use of terms relative to the learning task. In this phase, the teacher directs students’ 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, explicit, and formal manner. Explanations are ways of ordering 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 to move on to the next phase.

Teachers have a variety of techniques and strategies at their disposal to elicit and develop student explanations. Educators commonly use verbal explanations; but, there are numerous other strategies, such as videos, films, and educational courseware. This phase continues the process of mental ordering and provides terms for explanations. In the end, students should be able to explain exploratory experiences and experiences that have engaged them by using common terms. Students will not immediately express and apply the explanations—learning takes time.

Elaboration: Once the students have an explanation and terms for their learning tasks, it is important to involve the students in further experiences that extend, or elaborate, the concepts, processes, or skills. This phase facilitates the transfer of concepts to closely related but new situations. In some cases, 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) provides a clear description of this phase:

> During 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 cycle is not closed to information from the outside. Students get information from each other, the teacher, printed materials, experts, electronic databases, and experiments that they conduct. This is called the information base. 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.

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

Evaluation: This is the important opportunity for students to use the skills they have acquired and evaluate their understanding. In addition, the students should receive feedback on the adequacy of their explanations. Informal evaluation can occur at the beginning and throughout the 5E sequence. The teacher can complete a formal evaluation after the elaboration phase. As a practical educational matter, teachers must assess educational outcomes. This is the phase in which teachers administer assessments to determine each student's level of understanding.

What are the commonalities and differences between the SCIS learning cycle and the BSCS 5E Instructional Model? The principle commonality underlying both models is the psychological theory that informed the sequence and emphasis for the phases. Both models use the work of Jean Piaget (Piaget & Inhelder, 1969; Piaget, 1975) and subsequent research consistent with the Piagetian theory, specifically the focus of cognitive sciences and the work on misconceptions, the difference between novice and expert explanations of phenomena, and naive versus canonical theories. The view of learning is summarized here and discussed in greater detail in the next section.

Briefly, the theory underlying both SCIS and the BSCS 5Es views learning as dynamic and interactive. Individuals redefine, reorganize, elaborate, and change their initial concepts through interaction with their environment, other individuals, or both. The learner "interprets" objects and phenomena and internalizes the interpretation in terms of the current experience encountered. To change and improve conceptions often requires challenging the students' current conceptions and showing those conceptions to be incomplete or inadequate. If a current conception is challenged, there must be opportunity, in the form of time and experiences, to develop a more accurate conception. In sum, the students' construction of knowledge can be assisted by using sequences of lessons designed to challenge current conceptions and provide time and opportunities for reconstruction to occur.

The changes introduced to the BSCS model reflect research on learning published since the original SCIS learning cycle. BSCS recognized the need for the explicit *engagement* of the learner with his or her prior knowledge (Champagne, 1988). BSCS maintained the term *exploration* and the original intent of the phase; however, we incorporated cooperative learning into this phase based on the research of Johnson, Johnson, and Holubec (1986). We maintained the invention or concept introduction phase, but changed the term to *explanation* to emphasize the development of scientific explanations. For the discovery phase, we again incorporated cooperative learning. We also changed this phase to *elaboration* to emphasize the application and transfer of ideas to further develop current understanding. Finally, we added a phase of *evaluation*. In this phase, students demonstrate their understandings and abilities through a new activity. This change was made to address the need for formal assessment opportunities that were integral to the instructional plan (Kulm & Malcolm, 1991). This phase also provides opportunities for self-reflection, an essential component of learning revealed by studies on metacognition (Brown & Campione, 1987). See Figure 1 for a summary of the origins and evolution of the instructional models reviewed in this section.

Since the late 1980s, the 5E instructional model has been a central feature in the majority of BSCS programs, especially our core programs. The core programs are summarized in Tables 7 and 8. Field-test results for several of these programs are described in a later section of the report.

Table 7. Core Programs That Incorporate the BSCS 5E Instructional Model

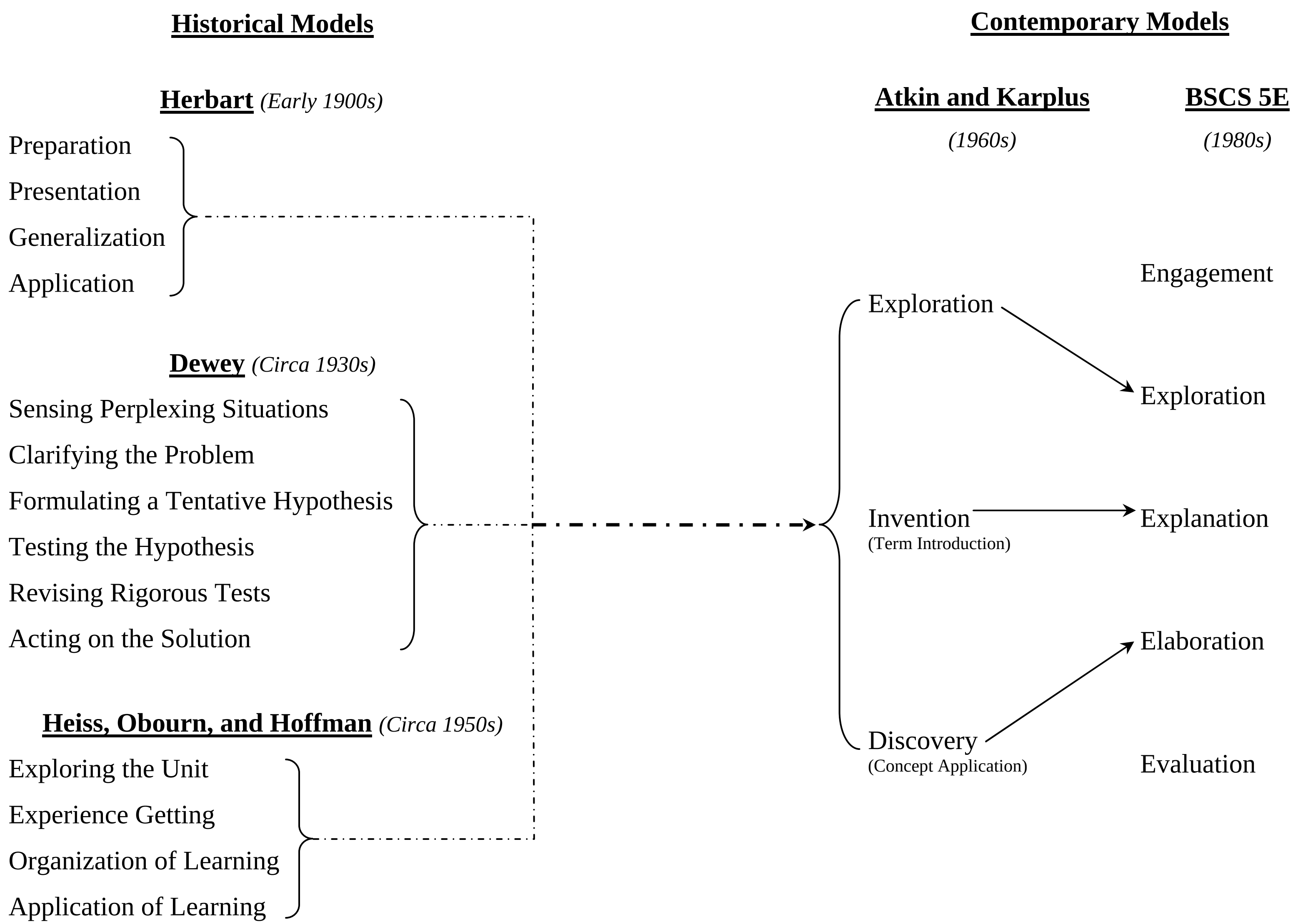
Original Program	Contemporary Program
Science for Life and Living © 1992 1st Edition (Grades K–6)	*BSCS Science Tracks* © 2006 2nd Edition (Grades K–5)
Middle School Science & Technology © 1994 1st Edition (Grades 6–8)	*BSCS Science & Technology* © 2005 3rd Edition (Grades 6–8)
BSCS Biology: A Human Approach © 1997 1st Edition (Grades 9–12)	*BSCS Biology: A Human Approach* © 2006 3rd Edition (Grades 9–12)
BSCS Science: An Inquiry Approach © 2006 1st Edition (Grades 9–11)	*BSCS Science: An Inquiry Approach* © 2006 1st Edition (Grades 9–11)

Table 8. Modules in the NIH Curriculum Supplement Series That Incorporate the BSCS 5E Instructional Model

Elementary Level
Open Wide and Trek Inside (Grades 1–2)
Middle School Level
The Brain: Our Sense of Self (Grades 7–8)
Chemicals, the Environment, and You: Explorations in Science and Human Health (Grades 6–8)
Doing Science: The Process of Scientific Inquiry (Grades 7–8)
How Your Brain Understands What Your Ear Hears (Grades 7–8)
Looking Good, Feeling Good: From the Inside Out (Grades 7–8)
The Science of Energy Balance: Calorie Intake and Physical Activity (Grades 7–8)
The Science of Healthy Behaviors (Grades 7–8)
The Science of Mental Illness (Grades 6–8)
Understanding Alcohol: Investigations into Biology and Behavior (Grades 7–8)
High School Level
The Brain: Understanding Neurobiology Through the Study of Addiction (Grades 9–12)
Cell Biology and Cancer (Grades 9–12)
Emerging and Re-emerging Infectious Diseases (Grades 9–12)
Human Genetic Variation (Grades 9–12)
Sleep, Sleep Disorders, and Biological Rhythms (Grades 9–12)
Using Technology to Study Cellular and Molecular Biology (Grades 9–12)

In summary, the BSCS 5E Instructional Model is grounded in sound educational theory, has a growing base of research to support its effectiveness, and has had a significant impact on science education. While encouraging, these conclusions indicate that it is important to conduct research on the effectiveness of the model, including when and how it is used, and continue to refine the model based on direct research and related research on learning.

Figure 1. Origins and Development of Instructional Models



Effectiveness of
Contemporary Instructional Models

Effectiveness of Contemporary Instructional Models

The BSCS 5E Instructional Model builds on the work of other instructional models and is supported by current research on learning. BSCS has a long history of developing curriculum materials that reflect the most recent research about learning and teaching. Our current understanding has been informed by research conducted by cognitive scientists from around the world (Brooks & Brooks, 1993; Driver, et al., 1994; Lambert, et al., 1995; Matthews, 1992; National Research Council, 2000; Piaget, 1976; Posner, et al., 1982; Vygotsky, 1962). Cognitive research shows that learning is an active process occurring within and influenced by the learner. Hence, learning results from an interaction between what information is encountered and how the student processes that information based on perceived notions and extant personal knowledge. The BSCS 5E Instructional Model applies this research to curriculum materials.

How People Learn

Several reports from the National Research Council and the National Academy of Sciences (NRC and NAS) present significant syntheses of contemporary research on learning. The first NRC review, *How People Learn: Brain, Mind, Experience, and School* (Bransford, Brown & Cocking, 1999), has been followed by other reports that go beyond the synthesis and discuss strategies for applying the findings to practice, including *How People Learn: Bridging Research and Practice* (Donovan, Bransford, & Pellegrino, 1999) and *How Students Learn: Science in the Classroom* (Donovan & Bransford, 2005).

How People Learn (Bransford, Brown & Cocking, 1999) offers insights about learners and learning that are especially important for this review. Three major findings are highlighted because they have a strong research base and clear implications for the use of systematic and carefully designed instruction:

1. Students come to the classroom with preconceptions about how the world works. If their initial understanding is not engaged, they may fail to grasp new concepts and information that are taught, or they may learn for the purpose of a test but revert to their preconceptions outside the classroom.

2. To develop competence in an area of inquiry, students must: (a) have a deep foundation of factual knowledge, (b) understand facts and ideas in the context of a conceptual framework, and (c) organize knowledge in ways that facilitate retrieval and application.

3. A "metacognitive" approach to instruction can help students learn to take control of their own learning by defining learning goals and monitoring their progress in achieving them. (pp. 10–13)

These findings have parallel implications for classroom instruction and translating those implications into curriculum materials. The findings imply that teachers must be able to do the following:

- Recognize and draw out preconceptions from their students and base instructional decisions on the information they get from their students.

- Teach their subject matter in depth so that facts are conveyed in a context with examples and a conceptual framework.

- Integrate metacognitive skills into the curriculum and teach those skills explicitly.

Relative to this review and the BSCS 5E Instructional Model, a quote from *How People Learn* (Bransford, Brown, & Cocking, 1999) seems especially germane:

> An alternative to simply progressing through a series of exercises that derive from a scope and sequence chart is to expose students to the major patterns of a subject domain as they arise naturally in problem situations. Activities can be structured so that students are able to explore, explain, extend, and evaluate their progress. Ideas are best introduced when students see a need or a reason for their use—this helps them see relevant uses of the knowledge to make sense of what they are learning. (p. 127)

This quotation directs attention to a research-based recommendation for a structure and sequence of instruction that exposes students to problem situations (i.e., engage their thinking) and then provides opportunities to explore, explain, extend, and evaluate their learning. This research summary from the National Research Council supports the design and sequence of the BSCS 5E Instructional Model.

Integrated Instructional Units

Following the work of Bransford, Brown, and Cocking, the National Research Council published *America's Lab Report: Investigations in High School Sciences* (2006). This report examined the status of science laboratories and developed a vision for their future role in high school science education. The NRC committee (NRC, 2006) used the following definition for laboratory experiences:

> Laboratory experiences provide opportunities for students to interact directly with the material world (or with data drawn from the material world), using tools, data collection techniques, models, and theories of science. (p. 31)

Note that this definition includes physical manipulation of substances, organisms, and systems; interactions with simulations; interactions with actual (not artificially created) data; analysis of large databases; and remote access to instruments and observations, for example, via World Wide Web links.

The committee was very clear that science education includes both learning about the methods and processes of scientific research and the knowledge derived from those processes. The learning goals that should be attained as a result of laboratory experiences include the following:

- Enhancing mastery of subject matter
- Developing scientific reasoning
- Understanding the complexity and ambiguity of empirical work
- Developing practical skills
- Understanding the nature of science
- Cultivating interest in science and interest in learning science
- Developing teamwork abilities (NRC, 2006, p. 76–77)

In the analysis of laboratory experiences, the committee applied results from the large and growing body of cognitive research. Some researchers have investigated the sequence of science instruction, including the role of laboratory experiences, as these sequences enhance student achievement of the aforementioned learning goals. The NRC committee (NRC, 2006) proposed the phrase “integrated instructional units”:

> Integrated instructional units interweave laboratory experiences with other types of science learning activities, including lectures, reading, and discussion. Students are engaged in forming research questions, designing and executing experiments, gathering and analyzing data, and constructing arguments and conclusions as they carry out investigations. Diagnostic, formative assessments are embedded into the instructional sequence and can be used to gauge the students’ developing understanding and to promote their self-reflection on their thinking. (p. 82)

Integrated instructional units have two key features; first, laboratory and other experiences are carefully designed or selected on the basis of what students should learn from them. And second, the experience is explicitly linked to and integrated with other learning activities in the unit.

The features of integrated instructional units map directly to the BSCS instructional model. Stated another way, the BSCS model is a specific example of integrated instructional units. According to the NRC committee’s report, integrated instructional units connect laboratory experience with other types of science learning activities including reading, discussions, and lectures.

Typical (or traditional) laboratory experiences differ from the integrated instructional units in their effectiveness in attaining the goals of science education. Research shows that typical laboratories suffer from fragmentation of goals and approaches. Although the studies are still preliminary, research indicates that integrated instructional units are more effective than typical laboratory research for improving mastery of subject matter, developing scientific reasoning, and cultivating interest in science. In addition, integrated instructional units appear to be effective for helping diverse groups of students progress toward these three goals. Table 9 compares typical laboratory experiences and integrated instructional units.

Table 9. Attainment of Goals: Typical Laboratory Experience versus Integrated Instructional Units

Goal	Typical Laboratory Experience	Integrated Instructional Unit
Mastery of Subject Matter	Is no better or worse than other modes of instruction	Increases mastery compared with other modes of instruction
Scientific Reasoning	Aids the development of some aspects	Aids the development of more-sophisticated aspects
Understanding of the Nature of Science	Shows little improvement	Shows some improvement when explicitly targeted as the goal
Interest in Science	Shows some evidence of increased interest	Shows greater evidence of increased interest
Understanding of the Complexity and Ambiguity of Empirical Work	Has inadequate evidence	Has inadequate evidence
Development of Practical Skills	Has inadequate evidence	Has inadequate evidence
Development of Teamwork Skills	Has inadequate evidence	Has inadequate evidence

Source: NRC. (2006). *America's lab report: Investigations in high school science*. Washington, DC: The National Academies Press.

Direct Instruction and Discovery Learning

Over the years, different groups have advocated different strategies for teaching science. On one end of the continuum is direct instruction. At its extreme, direct instruction relies on lecturing and rote memorization. At the other end of the continuum is discovery learning or full inquiry. The extreme position in this view is that students must discover all the knowledge themselves without direct guidance from the teacher. In reality, most teaching strategies are somewhere in the middle of the continuum. One difficulty, however, is that the terms "direct instruction" and "discovery learning" are interpreted differently by different people. Not only are they interpreted differently, they have had additional values ascribed to them, such as "one is good, the other is bad." As we shall see, a case can be made for the general idea of integrated instructional units and, specifically, the BSCS 5E Instructional Model. That case emerges from research that often is cited as supporting "direct instruction."

Research headed by David Klahr and colleagues has stimulated review and discussion of the relative importance of direct instruction and discovery learning as instructional approaches to science teaching (Chen & Klahr, 1999; Klahr & Nigam, 2004). In the 1999 study, Chen and Klahr investigated the efficacy of different instructional approaches for an important aspect of scientific reasoning. Specifically, they intended to compare the efficacy of direct instruction vs. discovery learning. They asked the question: "What is the effectiveness of different instructional strategies in children's acquisition of the domain-general strategy, Control of Variables Strategy, or CVS." They had children aged seven to 10 years old design and evaluate experiments after direct instruction in CVS and without direct instruction (i.e., discovery learning). They reported that with explicit training (i.e., direct instruction), children were able to learn and transfer the basic strategy for designing unconfounded experiments, that is, they could apply CVS (Chen & Klahr, 1999).

One interesting aspect of the research conducted by Klahr and his colleagues is that their approach actually paralleled a key characteristic of an instructional model or integrated instructional unit. While this is evident in the articles, it is not expressed in their conclusion that direct intervention is the most effective strategy for teaching the Control of Variables Strategy. The following quotations are from the methodological sections of the key articles cited in the direct instruction versus discovery learning debate. In Table 10, we point out the phases that parallel the BSCS 5E Instructional Model. The entire approach used by Klahr and colleagues could well be described as an integrated instructional unit that centers on students learning the key concepts of CVS.

> The present study consisted of two parts. Part I included hands-on design of experiments. Children were asked to set up experimental apparatus so as to test the possible effects of different variables. The hands-on study was further divided into four phases. In Phase 1, children were presented with materials in a source domain in which they performed an initial exploration followed by (for some groups) training. Then they were assessed in the same domain in Phase 2. In Phases 3 and 4, children were presented with problems in two additional domains (Transfer-1 and Transfer-2). Part II was a paper-and-pencil posttest given two months after Part I. The posttest examined children's ability to transfer the strategy to remote situations. (Chen & Klahr, 1999, p. 4)

In a further summary of the design, the researchers note the following:

> … children were given explicit instructions regarding CVS. Training occurred between the Exploration and Assessment phases. It included an explanation of the rationale behind controlling variables as well as examples of how to make unconfounded comparisons. (Chen & Klahr, 1999, p. 4)

Chen and Klahr's 1999 research article presents a very well-designed study that, in our view, most likely used an integrated instructional approach closely resembling the BSCS 5E Instructional Model. As indicated in their summary of the methodology for the intervention, Chen and Klahr used an instructional sequence that included four of the five phases in the 5E model. With an engagement phase omitted, the researchers had the students begin with an exploration, proceeded to an explanation of CVS that included a demonstration, and then had the students apply or elaborate CVS to these new situations for which they used the terms assessment and Transfer-1 and Transfer-2.

Table 10. Alignment between Chen and Klahr's Work and the BSCS 5E Instructional Model

Quotes from Chen and Klahr (1999)	Alignment with the BSCS Model	Rationale
"Children were presented materials in a source domain in which they performed an initial exploration."	Engagement	Engagement initiates the learning process and exposes students' current conceptions.
"Children were asked to set up experimental apparatus so as to test the possible effects of different variables."	Exploration	In the exploration phase, students gain experience with phenomena or events.
"… included an explanation of the rationale behind controlling variables as well as examples of how to make unconfounded comparisons."	Explanation	In the explanation phase, the teacher may give an explanation to guide students toward a deeper understanding.
"… children were presented with problems in two additional domains"	Elaboration	In the elaboration phase, students apply their understanding in a new situation or context.
"Part II was a pencil-and-paper post-test given two months after Part I."	Evaluation	In the evaluation phase, student understanding is assessed.

In this section, we have pointed out the similarity of the methodology used by Klahr and colleagues to the BSCS model. Our discussion describes the research method Klahr's team uses and points out the parallel of the method to the 5E instructional model. However, Klahr and colleagues isolate one strategy of that model, the training, explanation, or direct instruction, as the key factor in student learning. Others have generalized these results to claim that direct instruction is the best way to teach the process skills of science (Adelson, 2004; Begley, 2004a, 2004b). The entire context and teaching approach used in Klahr's research presents a situation that suggests such a conclusion is far beyond the evidence.

In a second article, the authors (Klahr & Nigram, 2004) clarify the characteristics of direct instruction:

> … we use an extreme type of direct instruction in which the goals, the materials, the examples, the explanations, and the pace of instruction are all teacher-controlled. (p. 2)

The researchers (Klahr & Nigram, 2004) also describe discovery learning:

> In our discovery learning condition, there is no teacher intervention beyond the suggestion of a learning objective: no guiding questions and no feedback about the quality of the child's selection of materials, explorations, or self-assessments. (p. 2)

Here are the outstanding differences between direct instruction and discovery learning:

> The main definition is that, in direct instruction, the instructor provided good and bad examples of CVS, explained what the differences were between them, and told the students how and why CVS worked, whereas in the discovery condition there were no examples and no explanations, even though there was an equivalent amount of design and manipulation of materials. (Klahr & Nigam, 2004, p. 4)

In this study by Klahr and Nigam, the researchers used a methodology generally similar to that described earlier. As a result of a very detailed and thorough study, the authors (Klahr & Nigam, 2004) concluded:

> These results suggest a re-examination of the long-standing claim that the limitations of direct instruction, as well as the advantages of discovery methods, will manifest themselves in broad transfer to authentic contexts. (p. 7)

We note that integrated instructional models such as the SCIS learning cycle (Karplus & Thier, 1967) and the BSCS 5E Instructional Model are not limited by the constraints that Klahr and Nigam impose on direct instruction. On the contrary, both SCIS cycle and the BSCS 5E Instructional Model incorporate direct instruction in one phase in an integrated instructional model.

Klahr and his colleagues have not explicitly acknowledged that the teaching strategies used in their research could be interpreted as much more than direct instruction. The implications of their research, however, have been stated in the extreme by the popular press, with titles such as "Instruction Versus Exploration in Science" (Adelson, 2004) and "Carnegie Mellon Researchers Say 'Direct Instruction,' Rather Than 'Discovery Learning,' is Best Way to Teach Process Skills in Science." Unfortunately, characterization of these instructional approaches as separate, as opposed to possibly being integrated, has done a disservice to both approaches.

A Review of the Support for Contemporary Instructional Models

Teaching strategies and instructional models may have their foundations on solid research and they may expand on previous models, but we need to evaluate them to determine if they are actually effective in improving students' mastery of subject matter, scientific reasoning, interest in science, and understanding of the nature of science. In this section, we review the studies of the effectiveness of instructional models based on the learning cycle. However, before beginning this review, it is important to acknowledge the difficulties in conducting this type of educational research. Unlike other types of research, it is often not feasible, appropriate, or, at times, even ethical to use methods that include randomized samples. Other challenges related to conducting effectiveness studies include assessing the different degrees of fidelity of implementation by different teachers and differences in the experience and qualifications of the teachers.

Methodology

The information synthesized in this section was gathered by searching established databases; using Web search engines; and reviewing the table of contents and citations in articles, handbooks, journals, and summary chapters. The searches were conducted by five different research teams. This process provided a wide sweep of the available information with enough redundancies to catch details one researcher might have missed. Table 11 summarizes the specific databases, search engines, and search phrases used to find the literature, dissertations, and reports cited here.

Table 11. Sources of Information

Type of Source	Details
Databases	Academic Search Premier Academic Universe, LexisNexis Dissertation Abstracts EBSCOhost, Library Education: A SAGE Full-Text Collection ERIC ERIC, First Search ERIC, EBSCOhost ERIC, U.S. Department of Education, Professional Development Collection Information Science & Technology Abstracts JSTOR Online ProQuest WilsonWeb OmniFile Full Text Mega
Search Engines	Google Google Scholar Info Yahoo
Search Phrases	5E 5 E 5-E 5E Curriculum

	5E Cycle 5E Education 5-E effectiveness 5E instruction 5E Instructional Model 5E Model Effectiveness 5-E learning 5E Learning 5E lessons 5E model 5E model lessons 5E Science 5E Teacher 5-E teacher Learning Cycle
Books Reviewed	*Handbook of Research on Curriculum* (1992) *Handbook of Research on Teacher Education* (1996) *Handbook of Research on Science Teaching and Learning* (1994) *Handbook on Science Teaching and Learning* (1997) *Science Teaching and the Development of Thinking* (1995)
Journals Reviewed	*The American Biology Teacher* *Journal of Research on Science Teaching* *Science Education* *School Science and Mathematics* *The Science Teacher*

Historical Research on the SCIS Learning Cycle

Lawson (1995) completed a comprehensive review of more than 50 research studies on the learning cycle that were conducted through the 1980s. The earliest studies investigated the effectiveness of the Science Curriculum Improvement Study (SCIS) program developed in the 1960s for teaching elementary science. Because the SCIS program used a learning cycle instructional model, the results of studies about SCIS provide evidence about the effectiveness of this type of instruction. Later studies focused specifically on the learning cycle model. Several studies focused on the impact of omitting one or more phases of the learning cycle, changing the sequence of the phases, or using different instructional formats within the phases.

In addition, Guzzetti, Snyder, Glass, & Gamas (1993) conducted a rigorous meta-analysis that included 47 research studies conducted from 1981 through the spring of 1991. The focus of these studies was the effectiveness of different instructional interventions, including the learning cycle, for addressing student misconceptions in science. This section summarizes what these studies reveal about the learning cycle’s effectiveness for improving students’ mastery of subject matter, scientific reasoning, and interest and attitudes about science. In addition, we further the connection to the goals of integrated instructional units described in *America’s Lab Report* (NRC, 2006, p. 100) by aligning the key findings of the studies to those goals.

Mastery of subject matter: Ten studies cited by Lawson investigated the impact of the learning cycle approach on subject matter knowledge of elementary through undergraduate students. Typically, these studies compared learning gains for students taught using a learning cycle approach with those taught using a "traditional" approach. The traditional approaches are generally described as a lecture followed by a verification lab or activity. Six of the studies (Bishop, 1980; Bowyer, 1976; Nussbaum, 1979; Renner & Paske, 1977; Saunders & Shepardson, 1987; Schneider & Renner, 1980) found that students who were taught using the learning cycle had greater gains in subject matter knowledge than students taught using more traditional approaches. These studies examined science subject matter learning from the elementary (Nussbaum, 1979), middle school (Bishop, 1980; Bowyer, 1976; Saunders & Shepardson, 1987), high school (Schneider & Renner, 1980), and college (Renner & Paske, 1977) levels. Furthermore, two of the studies (Bishop, 1980; Schneider & Renner, 1980) found that the achievement gains among students who experienced learning cycle instruction persisted in delayed post-tests of students' understanding of science concepts.

Four of the studies that Lawson reviewed found no differences in achievement between students who experienced learning cycles and those who received traditional instructional formats. Horn (1980) reported that SCIS curriculum materials were no more effective than traditional text materials for helping first graders learn new vocabulary and understand text. Vermont (1985) found no differences in learning the mole concept and changing misconceptions between college chemistry students who experienced either learning cycle or traditional lecture-laboratory instructional approaches. In the other two studies, researchers reported some differences in favor of the learning cycle approach, but not in the area of content achievement. For example, Campbell (1977) found that college physics students in learning cycle–based classes used formal reasoning patterns and had more positive attitudes toward science than students in traditional classes, although he found no significant differences in content achievement. Similarly, Davis (1978) found more positive attitudes and better understanding of the nature of science among fifth and sixth graders in learning cycle classes than in classes using a traditional approach, but there were no differences in content achievement between students who experienced the two approaches.

Several additional studies that had inconclusive results may help identify variables that limit the effectiveness of this model. In a study of college chemistry students, Ward and Herron (1980) developed learning cycle versions of three experiments. Students in the learning cycle sections clearly had greater achievement on one of the three experiments, but there was no difference between scores in the learning cycle and traditional sections for the other two experiments. The researchers speculated that limited time spent on activities in the experiments, flaws in the achievement test, and teaching assistants' lack of fidelity in implementing the learning cycle might explain the results. Another possible explanation is the developmental level of students. Purser and Renner (1983) compared subject matter learning for high school students enrolled in an eight-month biology course that used either a learning cycle or a traditional approach. Most of the students were at a concrete or transitional level of reasoning, based on Piagetian tasks. The researchers found no achievement differences between students for concepts that required formal thought. However, students in the learning cycle section had greater learning gains for concepts that required concrete thought.

Guzzetti, Snyder, Glass, & Gamas (1993) used cluster analysis to identify instructional approaches that had the largest effects on conceptual change. They concluded that "Meta-analysis of research testing the success of the Learning Cycle and its modifications in eradicating misconceptions provides support for the approach." Specifically, they found that the average effect of the learning cycle on conceptual change was about one-quarter of a standard deviation unit, with larger effects when additional strategies (such as prediction laboratories) were included as part of the learning cycle. They further noted that when a learning cycle that included laboratory work was compared with a one that did not include a laboratory, the differential effect was about one and one-half standard deviations. When a laboratory was combined with other forms of traditional instruction (i.e., lecture, demonstration, and nonrefutational text not in a learning cycle format), however, it was much less effective. Comparison of a prediction laboratory–learning cycle combination with traditional instruction showed positive results in favor of the former, by one-third of a standard deviation.

Scientific reasoning: Many of the studies reviewed by Lawson investigated the impact of learning cycle instruction on students' scientific reasoning abilities. This instructional model consistently showed superior results over more traditional instructional approaches for cultivating the development of these abilities: 17 of 18 studies had positive results. For the purpose of our discussion, we have divided the studies into two categories. The first category contains studies that address scientific inquiry abilities (e.g., asking questions, designing experiments, developing and communicating scientific explanations), which are the cornerstones of how scientific reasoning is defined in *America's Lab Report*. The second category contains studies that address more general reasoning skills, such as conservation of number or weight, proportional reasoning, or development from concrete to formal operational thinking.

Scientific inquiry abilities

Thier (1965) and Allen (1971) reported that elementary students who had experienced the SCIS curriculum had a superior ability to describe objects by their properties, compared with students who experienced traditional instruction. Allen (1967), however, found no difference in classifying skills for elementary school students who were taught using either SCIS or non-SCIS materials. Other studies noted gains in identifying and controlling variables by students who experienced the learning cycle approach, as opposed to those who experienced more traditional instruction (Allen, 1973b; Lawson, Blake, & Nordland, 1975; Lawson & Wollman, 1976). Several studies identified the superiority of the learning cycle approach for developing science process skills such as classifying, measuring, experimenting, and predicting (Renner, et al. 1973; Brown, Weber, & Renner, 1975; Bowyer, 1976; TaFoya, 1976).

General reasoning skills

Many studies of the SCIS program and the learning cycle investigated the impact of these approaches on students' general reasoning skills. The studies reviewed by Lawson assessing these types of skills all showed that instruction based on the learning cycle was more effective than traditional instruction. For example, Renner, et al. (1973) concluded that first graders who used the SCIS materials had greater gains in reasoning skills, as measured by Piagetian conservation tasks, than first graders who used a textbook. Linn & Thier (1975) found that fifth graders who were taught using the SCIS materials performed better than those who did not on tasks that required identification and compensation of variables. Several studies noted general gains in reasoning skills and in proportional reasoning for students who experienced instruction using the learning cycle model (McKinnon & Renner, 1971; Renner & Lawson, 1975; Wollman & Lawson, 1978). Finally, a number of studies assessed the development of formal thinking skills among students who experienced either learning cycle or traditional instruction. These studies also found greater gains for students who were taught science using a learning cycle format (Carlson, 1975; Schneider & Renner, 1980; Saunders & Shepardson, 1987).

Renner and Paske (1977) obtained ambiguous results in a study of college students enrolled in a physics course for nonscience majors. Students enrolled in the course sections that used a learning cycle format had greater gains on formal tasks from the low to the high concrete levels, and from the high concrete to the low formal levels. Students enrolled in the course sections that used the traditional lecture-demonstration approach had greater gains from the low to the high formal levels. The researchers concluded that a learning cycle approach is more effective for producing reasoning gains for students at a concrete level, but the traditional method may be better for further progress in reasoning among students at a formal level of reasoning.

Interest and attitudes about science: Instruction that uses a learning cycle approach consistently results in more positive attitudes about science. Lawson reviewed 12 publications that reported the impact of learning cycle instruction on students' attitudes. Eight of the studies found more positive attitudes for students who experienced learning cycle instruction than for those who did not. Four studies that did not do this comparison also reported positive attitudes about science among students in learning cycle classes. Lawson commented that finding a positive relationship between the use of learning cycle programs and student attitudes is typical; he noted only one study that found no relationship between attitudes and the SCIS program (presented at a meeting of the National Science Teachers Association in 1977).

With regard to the SCIS program, Malcolm (1976) found that students who experienced the SCIS program had higher levels of self-concept that those who experienced a textbook-based program. Hendricks (1978) found general affective domain gains for students in a SCIS program, and Allen (1973a) reported slightly better motivation for students in a SCIS program. Others who reported positive attitudes about science following exposure to the SCIS program include Brown (1973); Brown, Weber, and Renner (1975); Krockover and Malcolm (1976); Haan (1978); and Lowery, Bowyer, and Padilla (1980).

Lawson reviewed four studies that focused specifically on the impact of the learning cycle approach (as opposed to the entire SCIS program) on student attitudes toward science. All reported a positive relationship. Campbell (1977) found not only more positive attitudes toward laboratory work in a physics course, but also a decreased likelihood of withdrawing from the course among college students in the learning cycle sections of the course as compared with those in the traditional sections. Another study found that college students enrolled in learning cycle sections of a nonmajor physics course enjoyed their instruction more than those enrolled in the traditional sections (Renner & Paske, 1977). Middle school students taught science using a learning cycle approach also had more positive attitudes about science than those taught using a traditional approach (Davis, 1978; Bishop, 1980).

Critical features of the learning cycle approach: Some researchers have critiqued conclusions of the studies because the learning cycle programs include multiple teaching strategies within the phases of the learning cycle. This multifactorial nature of instruction and analysis makes it difficult to determine whether the success of the model is due to the entire package, to specific phases within the model, or to one or more of the strategies used within the phases. A series of studies conducted in high school physics and chemistry classes by Renner and his colleagues addressed this criticism (Renner, Abraham, & Birnie, 1984; Abraham & Renner, 1984; Abraham & Renner, 1986; Renner, Abraham, & Birnie, 1985, 1988). These studies investigated the effects of changing the sequence of the learning cycle phases, omitting one or more of the phases, and using different instructional formats within the phases.

Regarding gains in science subject matter knowledge, the researchers found that

- optimum learning of concepts requires all three phases of the learning cycle;
- students learn new concepts better when the term introduction phase is second;
- the combination of the exploration and the term introduction phases is more effective for conceptual learning than using the term introduction phase alone;
- the laboratory format is effective only when it is used in conjunction with discussions; and
- the effectiveness of the laboratory format depends on the clarity of the data that leads to the concept.

The studies also reported differences for the Piagetian categories of learners—formal operational and concrete operational. For formal operational learners, optimum learning occurred when all phases of the learning cycle are present, but the sequence and instructional format of the learning cycle phases did not matter. For concrete operational learners, highest achievement occurred when the term introduction phase was last and the laboratory format was used.

These studies also provided information about the impact of the learning cycle approach on student attitudes about science instruction. Students believed the sequence of the instructional phases was important and preferred to gather their own data from an experiment before they discussed the concept. They regarded the laboratory format most positively and the reading format the most negatively.

In summary, the line of research by Renner and his colleagues reinforced the notion that the learning cycle is most effective when used as originally designed:

- All three phases of the model must be included in instruction, and the exploration phase must precede the term introduction phase.
- The specific instructional format may be less important than including all phases of the model, but laboratory work (typical in the exploration phase) is more effective for many students, provided it is followed by discussion (term introduction).
- Finally, student attitudes toward science instruction are more positive when they are allowed to explore concepts through experimentation or other activities before discussing them.

Impact of the learning cycle approach on teaching behaviors: Several of the studies reviewed by Lawson investigated the impact of using SCIS curriculum materials on teacher behaviors. Studies that compared teachers who were trained in the SCIS learning cycle and used SCIS materials with those who were not found that SCIS teachers asked higher-order questions that emphasized skills such as interpretation, analysis, prediction, and synthesis more often than non-SCIS teachers, who asked recognition and recall questions (Moon, 1969; Porterfield, 1969; Wilson, 1969; Eaton, 1974). Simmons (1974) found that SCIS teachers were more student-oriented than non-SCIS teachers, and Kyle (1985) reported that SCIS teachers allotted more time for teaching science than non-SCIS teachers.

Findings from Recent Research on the Learning Cycle

The effectiveness of the learning cycle is also well documented in more contemporary research. Like the earlier studies, recent research studies link the use of the learning cycle to positive changes in students' mastery of subject matter, scientific reasoning, and interest and attitudes toward science. In the following sections, we discuss studies that describe the learning cycle's effectiveness toward furthering student outcomes in each of these three categories.

Mastery of subject matter: A significant line of research shows that learning cycle–based teaching approaches help students develop deep understanding of science concepts. For example, several comparative studies examined student learning gains across traditional and learning cycle–based teaching approaches. Across multiple disciplines and grade levels, teaching approaches based upon the learning cycle were found to result in greater gains of subject matter learning. Examples include studies of undergraduate physics (Ates, 2005) and biology students (Lord, 1997) as well as studies of high school physics (Billings, 2001) and elementary school science students (Ebrahim, 2004).

Interestingly, there also is evidence that merely reading instructional materials that are structured with a learning cycle can be educative. In a randomized-control trial study of 123 high school students, Musheno and Lawson (1999) found that students who were randomly assigned to read learning cycle–based instructional materials scored higher on a subject matter assessment than their counterparts who were randomly assigned to read materials that were structured in a more traditional, encyclopedic fashion.

A subset of this comparative research on learning cycle–based teaching explores the effect of augmenting the learning cycle with other teaching strategies. For example, Odom and Kelly (2001) found that integrating concept mapping into learning cycle–based instruction enhanced its impact on the subject matter learning gains of high school biology students. Similarly, Lavoie (1999) compared student learning gains resulting from the standard learning cycle of exploration, term introduction, and concept application with those resulting from this standard learning cycle preceded by a predict-discuss activity. Although both approaches resulted in considerable learning gains for high school biology students, the augmented learning cycle produced gains that were significantly larger.

Scientific reasoning: Learning cycle–based teaching is also useful in helping students develop the ability to reason scientifically. For example, Johnson and Lawson (1998) found that learning cycle–based teaching had a statistically significant positive effect on the scientific reasoning (i.e., proportional reasoning and control of variables) of undergraduate biology students while a more didactic teaching approach did not. Similar research by Curtis (1997) demonstrated that learning cycle–based instruction can have a positive impact on the scientific reasoning of high school chemistry students. Findings from these studies are corroborated elsewhere in recent research literature (e.g., Lavoie, 1999).

Interest and attitudes toward science: The impact of learning cycle–based curricula and teaching on attitudes toward science is described thoroughly in the literature. Evidence that learning cycle–based teaching can have a positive effect on attitudes exists in studies of elementary school students (Ebrahim, 2004), middle school physical science students (McDonald, 2003), and high school chemistry (Curtis, 1997), physics (Billings, 2001), and biology students (Lavoie, 1999). In addition, similar findings exist in studies of undergraduate biology students (e.g., Lord, 1997).

Findings from Recent Research on the BSCS 5E Instructional Model

Due to the relative youth of the BSCS 5E Instructional Model compared with the learning cycle, there are fewer published studies that compare the BSCS 5E Instructional Model with other modes of instruction. However, the findings of these studies suggest that, like its predecessor the learning cycle, the BSCS 5E Instructional Model is effective, or in some cases, comparatively more effective, than alternative teaching methods in helping students reach important learning outcomes in science. For example, several comparative studies suggest that the BSCS 5E Instructional Model is more effective than alternative approaches at helping students master science subject matter (e.g., Akar, 2005; Coulson, 2002). Coulson (2002) also explored how varying levels of fidelity to the BSCS 5E model affected student learning. Coulson found that students whose teachers taught with medium or high levels of fidelity to the BSCS 5E Instructional Model experienced learning gains that were nearly double that of students whose teachers did not use the model or used it with low levels of fidelity. The impact of varying levels of fidelity identified here may help explain the ambiguous results of Ward and Herron (1980) described earlier.

We did not find any comparative studies for the learning outcomes of scientific reasoning, interest and attitudes toward science, and understanding of the nature of science. However, we found studies whose findings indicated that the BSCS 5E Instructional Model had a positive effect on scientific reasoning (Boddy, 2003) and on interest and attitudes toward science (Akar, 2005; Boddy, 2003; Tinnin, 2001). One study reported a decrease in understanding of the nature of science among middle school students who used field-test curriculum materials based on the BSCS 5E Instructional Model (Meichtry, 1991). Given the novel and unfinished nature of the field-test curriculum materials, these results should probably be considered in the light of Coulson's (2002) findings about the impact of fidelity of use on learning gains, described previously.

Summary and Implications for Further Research

Table 12 summarizes the relationship between the evidence from lines of research about the learning cycle and the BSCS 5E Instructional Model and the goals for integrated instructional units from *America's Lab Report*. Clearly, many areas need further research, as indicated by the number of cells stating “has inadequate evidence.” Appendix A summarizes the findings from the studies that exist and the citations.

There is compelling research on the learning cycle suggesting that it can have a positive impact on mastery of subject matter, scientific reasoning, and interest and attitudes toward science. Similar evidence exists in a smaller number of studies for the BSCS 5E Instructional Model. The most noticeable void in the literature is research exploring the utility of both the learning cycle and BSCS 5E approach in helping students develop an understanding of the nature of science and the complexity and ambiguity of empirical work, as well as practical and teamwork skills. In addition, the research base around the BSCS 5E Instructional Model should be elaborated on through additional studies that compare its effect on mastery of subject matter, scientific reasoning, and interest and attitudes with other modes of instruction. The widespread use of the BSCS 5E Instructional Model warrants a commitment to a line of research that rivals that of the learning cycle.

Table 12. Comparison of the Effectiveness of the Learning Cycle and BSCS 5E Instructional Models with Integrated Instructional Units and Typical Laboratory Experiences

Goal of *America's Lab Report*	Typical Laboratory Experience	Integrated Instructional Units	Learning Cycle (SCIS)*	Learning Cycle (Other)*	BSCS 5E Instructional Model*
Mastery of Subject Matter	Is no better or worse than other modes of instruction	Increases mastery compared with other modes of instruction	Has inadequate evidence	Has strong evidence of increased mastery compared with other modes of instruction	Shows some evidence of increased mastery compared with other modes of instruction
Scientific Reasoning	Aids the development of some aspects	Aids the development of more-sophisticated aspects	Has strong evidence of the development of more-sophisticated aspects	Has adequate evidence of the development of more-sophisticated aspects	Shows some evidence of the development of more-sophisticated aspects
Understanding of the Nature of Science	Shows little improvement	Shows some improvement when explicitly targeted at this goal	Has inadequate evidence	Has inadequate evidence	Has inadequate evidence
Interest in Science	Shows some evidence of increased interest	Has greater evidence of increased interest	Has greater evidence of increased interest	Has greater evidence of increased interest	Has greater evidence of increased interest
Understanding of the Complexity and Ambiguity of Empirical work	Has inadequate evidence	Has inadequate evidence	Has inadequate evidence	Has inadequate evidence	Has inadequate evidence
Development of Practical Skills	Has inadequate evidence	Has inadequate evidence	Has inadequate evidence	Has inadequate evidence	Has inadequate evidence
Development of Teamwork Skills	Has inadequate evidence	Has inadequate evidence	Has inadequate evidence	Has inadequate evidence	Has inadequate evidence

*See the appendix for specific references.

Evaluations of the 5E Instructional Model in BSCS Programs

By the 1980s, evidence for the effectiveness of the learning cycle was clear. Consequently, as BSCS began developing a new generation of comprehensive materials, we used the learning cycle research as the basis for an updated variation of the SCIS model—the BSCS 5E model. The first of these materials, *Science for Life and Living* (BSCS, 1988), was a comprehensive K–6 program that spanned the science disciplines and incorporated health and technology. During the design of this program, BSCS conceived the BSCS 5E Instructional Model. The use and refinement of the BSCS 5E model continued as we developed three more comprehensive programs: *Middle School Science & Technology* (BSCS, 1994, 1999, 2005); *BSCS Biology: A Human Approach* (BSCS, 1997, 2003, 2006); and *BSCS Science: An Inquiry Approach* (BSCS, 2006).

In each program, the BSCS 5E Instructional Model is the explicit pedagogical principle. The 5Es are expressed on several levels, with the most concrete at the unit level in the elementary program and at the chapter level in the middle and high school programs. As the students explore each unit or chapter, they experience a 5E cycle that carefully structures their learning. To differing degrees, the 5Es are also expressed at the lesson level and at the program level, but the most explicit use occurs at the unit or chapter level. Appendix B contains an example of the how the BSCS 5E Instructional Model is used in each comprehensive program as well as in selected National Institutes of Health (NIH) modules.

In addition to comprehensive programs, BSCS also uses the 5Es in content areas other than science and in supplementary materials, such as our middle school health series *Making Healthy Decisions* (BSCS, 1997; 2004) and the 16 modules that BSCS developed for the Office of Science Education at the National Institutes of Health. The NIH modules, each comprising a 5E cycle, span the grade levels, and each is designed to take five to 10 days of classroom time. (See Table 8.)

In the development process, every BSCS program is field-tested nationwide to ensure that the activities work well in the classroom and improve students' understanding of the concepts. The results of the field tests inform a careful revision of the program before it is published. For a more detailed description and discussion of these results, see the evaluation section that follows.

BSCS curriculum developers carefully design each activity to exemplify the given stage of the instructional model. In addition, the materials for teachers help them apply the most current research on learning. To ensure that the materials have the greatest chance of being implemented in the way they were intended and to honor the integrity of the 5Es, BSCS developed two charts that explicitly show the salient characteristics of each stage of the 5Es (see Tables 13 and 14). These tables describe in detail what each phase of the instructional model should look like and what it should not look like, from the students' and the teacher's perspective.

Table 13. The BSCS 5E Instructional Model: What the Student Does

Stage of the Instructional Model	The BSCS 5E Instructional Model: What the Student Does	
	That Is Consistent with This Model	**That Is Inconsistent with This Model**
Engagement	▪ Asks questions such as, "Why did this happen?" "What do I already know about this?" "What can I find out about this?" ▪ Shows interest in the topic	▪ Asks for the "right" answer ▪ Offers the "right" answer ▪ Seeks one solution
Exploration	▪ Thinks freely, within the limits of the activity ▪ Tests predictions and hypotheses ▪ Forms new predictions and hypotheses ▪ Tries alternatives and discusses them with others ▪ Records observations and ideas ▪ Asks related questions ▪ Suspends judgment	▪ Lets others do the thinking and exploring (passive involvement) ▪ "Plays around" indiscriminately with no goal in mind ▪ Stops with one solution
Explanation	▪ Explains possible solutions or answers to others ▪ Listens critically to others' explanations ▪ Questions others' explanations ▪ Listens to and tries to comprehend explanations that the teacher offers ▪ Refers to previous activities ▪ Uses recorded observations in explanations ▪ Assesses own understanding	▪ Proposes explanations from "thin air" with no relationship to previous experiences ▪ Brings up irrelevant experiences and examples ▪ Accepts explanations without justification ▪ Does not attend to other plausible explanations
Elaboration	▪ Applies new labels, definitions, explanations, and skills in new but similar situations ▪ Uses previous information to ask questions, propose solutions, make decisions, and design experiments ▪ Draws reasonable conclusions from evidence ▪ Records observations and explanations ▪ Checks for understanding among peers	▪ Plays around with no goal in mind ▪ Ignores previous information or evidence ▪ Draws conclusions from thin air ▪ In discussion, uses only those labels that the teacher provided
Evaluation	▪ 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	▪ Draws conclusions, not using evidence or previously accepted explanations ▪ Offers only yes-or-no answers and memorized definitions or explanations as answers ▪ Fails to express satisfactory explanations in his or her own words

Table 14. The BSCS 5E Instructional Model: What the Teacher Does

Stage of the Instructional Model	**The BSCS 5E Instructional Model: What the Teacher Does**	
	That Is Consistent with This Model	**That Is Inconsistent with This Model**
Engagement	▪ Creates interest ▪ Generates curiosity ▪ Raises questions ▪ Elicits responses that uncover what the students know or think about the concept or topic	▪ Explains concepts ▪ Provides definitions and answers ▪ States conclusions ▪ Provides closure ▪ Lectures
Exploration	▪ Encourages the students to work together without direct instruction from the teacher ▪ Observes and listens to the students as they interact ▪ Asks probing questions to redirect the students' investigations when necessary ▪ Provides time for the students to puzzle through problems ▪ Acts as a consultant for students ▪ Creates a "need to know" setting	▪ Provides answers ▪ Tells or explains how to work through the problem ▪ Provides closure ▪ Directly tells the students that they are wrong ▪ Gives information or facts that solve the problem ▪ Leads the students step by step to a solution
Explanation	▪ Encourages the students to explain concepts and definitions in their own words ▪ Asks for justification (evidence) and clarification from students ▪ Formally clarifies definitions, explanations, and new labels when needed ▪ Uses students' previous experiences as the basis for explaining concepts ▪ Assesses students' growing understanding	▪ Accepts explanations that have no justification ▪ Neglects to solicit the students' explanations ▪ Introduces unrelated concepts or skills
Elaboration	▪ Expects the students to use formal labels, definitions, and explanations provided previously ▪ Encourages the students to apply or extend the concepts and skills in new situations ▪ Reminds the students of alternate explanations ▪ Refers the students to existing data and evidence and asks, "What do you already know?" "Why do you think …?" (Strategies from exploration also apply here.)	▪ Provides definitive answers ▪ Directly tells the students that they are wrong ▪ Lectures ▪ Leads students step by step to a solution ▪ Explains how to work through the problem
Evaluation	▪ Observes the students as they apply new concepts and skills ▪ Assesses students' knowledge and skills ▪ Looks for evidence that the students have changed their thinking or behaviors ▪ Allows students to assess their own 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 *x*?" "How would you explain *x*?"	▪ Tests vocabulary words, terms, and isolated facts ▪ Introduces new ideas or concepts ▪ Creates ambiguity ▪ Promotes open-ended discussion unrelated to the concept or skill

Summary of Evaluation Results for BSCS Programs That Use the 5E Instructional Model
***Science for Life and Living*:** Student cognitive outcomes were measured in four areas. Science content outcomes in grades five and six included general energy concepts and general ecology concepts. Health content was measured at grades three through five, and scientific inquiry understandings were assessed at all grade levels. Students in grade two were given an oral scale that combined scientific processes and content. Of the eight significant differences found in the cognitive scales, seven were in favor of the treatment group (students using *Science for Life and Living*). (See Harms, 1991, for more detail.)

Table 15. Measurements of Student Cognitive Outcomes

Grade Level	Cognitive Area Tested	Standard Deviation
2	Change and Measurement	–0.19*
3	Health Patterns and Predictions	No significant difference No significant difference
4	Health: Substance Avoidance Skills Systems	0.20** 0.30***
5	Energy Health: Fitness, Safety, Interpretation of Ads Process Skills: Observation, Measurement, Experimental Design, Interpretation	0.57*** 0.24** 0.21**
6	Ecology Subscale for Ecosystems Decision-Making Skills	0.46** 0.64** No significant difference

*Statistically significant difference is in favor of the control group.
**Statistically significant difference < 0.05.
***Statistically significant difference < 0.001.

An additional study conducted in North Carolina compared the student outcomes in fifth grade on the end-of-grade test for students who used *Science for Life and Living* (*SFLL*) and students who used an activity-centered, but traditional, science program (ACTS) for a full academic year (Maidon & Wheatley, 2001). Students taking *SFLL* outscored the students in ACTS on the overall measure and all subscales. The results are summarized in Table 16.

Table 16. Comparison of Test Results for Students in *SFLL* and ACTS

Fifth-Grade End-of-Grade Test	*SFLL* Number	*SFLL* Mean	ACTS Number	ACTS Mean	p Value
Overall	191	31.21	215	26.10	0.0000
Process Skills Subscale	191	14.63	215	12.20	0.0001
Conceptual Knowledge Subscale	191	12.80	215	10.83	0.0000
Nature of Science Subscale	191	2.63	215	2.22	0.0001
Manipulative Skills Subscale	191	1.15	215	0.84	0.0004
Lower-Order Thinking Skills	191	16.45	215	13.91	0.0000
Higher-Order Thinking Skills	191	18.10	204	15.51	0.0001

These results are significant. Both programs were activity centered, but *Science for Life and Living* used the BSCS 5E Instructional Model, while ACTS used a more traditional approach to instruction in which students received content information first and then did an activity to reinforce the information the teacher had provided. These results indicate that the use of an instructional model has a positive effect on the learning and doing of science as well as on thinking skills.

Middle School Science & Technology**:** The formative evaluation conducted during the development and field-testing of *Middle School Science & Technology* (*MSST*) provided valuable data about student learning and attitudes. BSCS administered pre- and post-tests to students that covered concepts from the grade level of the program the students were experiencing. There were always positive gains in these scores. In one district in Ohio, project staff administered a content test to a group of students using the program that was twice as large as a group that was not using the program. The results showed statistically significant differences ($p < 0.01$) for the treatment group. The students using *MSST* had higher raw scores and answered more questions. On open-ended questions, the treatment group used more scientific vocabulary words correctly and had higher-quality responses (BSCS, 1994).

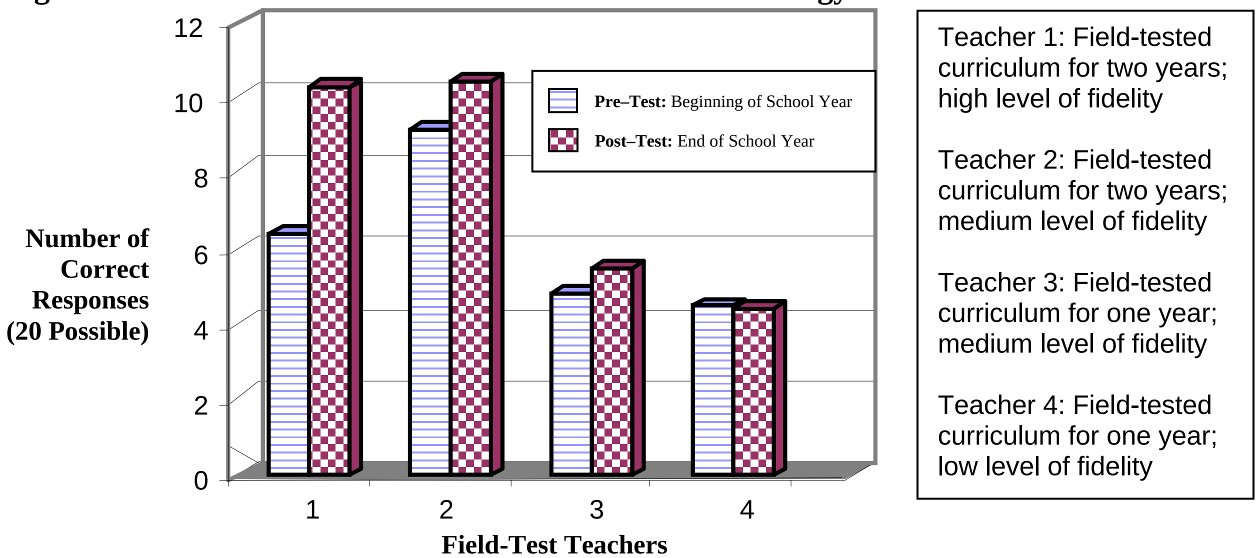
Three field-test sites in three different states compared the scores of students in the treatment group with other students on the state assessments and found that students using *MSST* scored equal to or above other students. A site in North Carolina reported gains of one-half to one full grade level on the California Achievement Test. Tests of thinking skills showed gains of two to eight percentile points after one year of use of the program.

BSCS Biology: A Human Approach**:** In a comparison study that looked at the results of 76 students using *BSCS Biology: A Human Approach* (*BB: AHA*, the treatment condition) and 49 students using another biology program (the comparison condition), there was an overall improvement in mean post-test scores. When a more detailed study was conducted to examine the relationship between the teachers' fidelity of use of the program and student learning, more interesting results emerged. One preliminary study found distinct differences in the learning gains of students whose teachers implemented the program as designed as opposed to the gains of students whose teachers implemented the program with considerably less fidelity. Student learning was measured using a 20-item subset of questions from the NABT/NSTA biology exam. This test was used because, at the time of the study, it was considered a difficult test that was independent of a particular curriculum. Fidelity was measured through classroom observations. These findings are illustrated in Table 17 and Figure 2.

Table 17. Student Learning Gains by Teacher

Teacher	Pre-Test Average	Post-Test Average	Average Gain
1	6.4	10.3	3.9
2	9.2	10.4	1.2
3	4.8	5.5	0.7
4	4.5	4.4	0

Figure 2. Pre- and Post-Test Results for NABT/NSTA Biology Exam



BSCS Science: An Inquiry Approach**:** The field test of the instructional materials developed during Phase 1 of *BSCS Science: An Inquiry Approach* comprised urban, suburban, and rural classrooms across 10 states, 31 teachers, 64 classes, and nearly 2,000 students. Assessment instruments included student surveys, teacher surveys, pre- and post-tests, an end-of-field-test survey, and classroom observations by an external evaluator and BSCS project staff. Among the findings, several stand out with respect to the quality and effectiveness of instructional materials and student achievement. The key findings are illustrated in Figures 3 and 4.

Figure 3. Student Test Gains by Grade Level

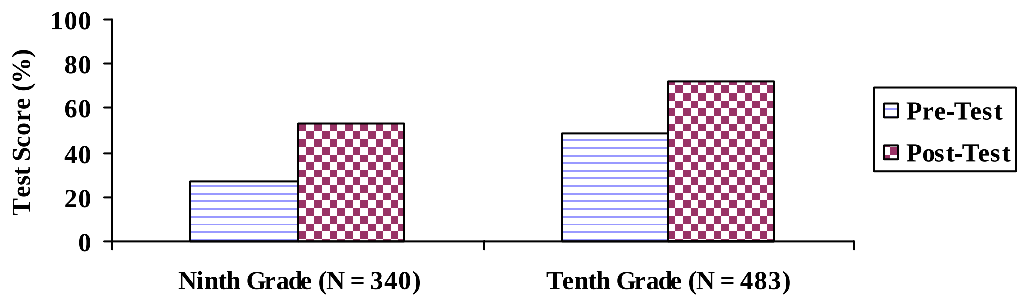
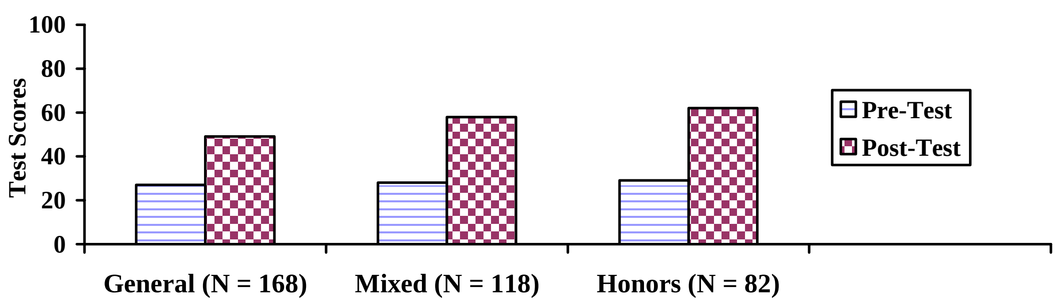


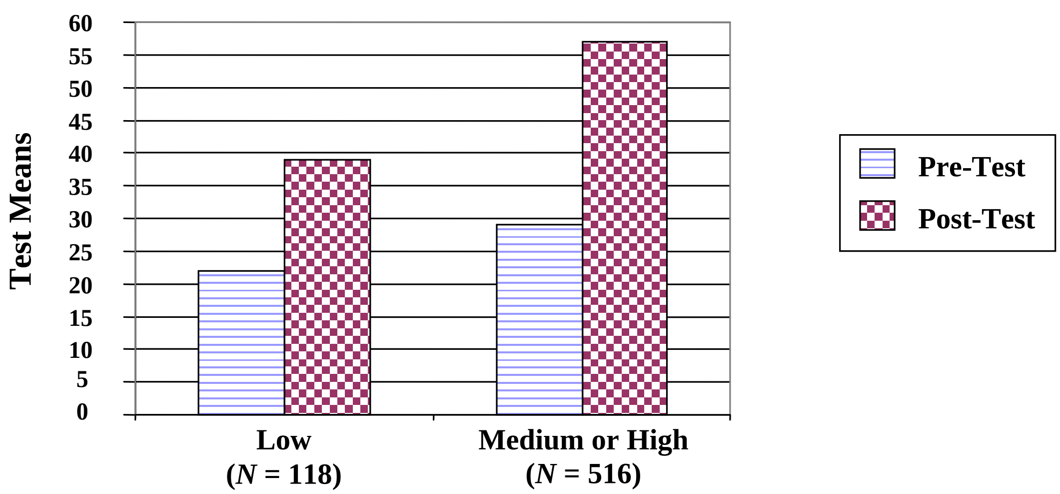
Figure 4. Ninth-Grade Test Gains by Ability Level



As mentioned above, Coulson (2002) also conducted a study examining the relationship between fidelity of use and student learning for *BSCS Science: An Inquiry Approach*. In this study, the learning gains of 634 ninth-grade students were determined by administering an identical chapter test before and after instruction. Implementation fidelity was measured by external evaluation staff and the curriculum development staff using an observation protocol adapted from the *Horizon, Inc. Classroom Observational Protocol* (HRI, 2001). This protocol allowed researchers to classify each teacher's fidelity of use as either "low," "medium," or "high." For each classroom study, three observers were in the classroom: two curriculum developers and the external evaluator. Each observer rated the teacher separately. Post-observation analysis indicated high inter-rater reliability. It is important to note that researchers operationally defined "fidelity" as teachers implementing the program as designed or in the spirit of the program's instructional model (i.e., the 5Es), not necessarily as rigid adherence to specific steps of the procedure.

The major finding of this study is the establishment of a strong relationship between student learning gains and implementation fidelity. Specifically, the data in this study suggest that when teachers implemented the program with a medium or high level of fidelity, the learning gains experienced by their students were significantly greater than the learning gains of teachers who did not adhere closely to the program (see Figure 5).

Figure 5. Ninth-Grade Test Gains by Levels of Implementation



The average student learning gain on the chapter assessment for teachers who implemented the curriculum materials with a medium or high level of fidelity is approximately 28 percent, whereas the average gain in classrooms with significantly less adherence to the program was 17 percent. This result becomes more dramatic when the scores are adjusted for differences in the pre-test. If these gain scores are normalized to express learning gains as a percentage of the *possible* gain, the raw average gain scores of 17 percent and 28 percent suggest that student learning gains in high or medium fidelity classrooms are, on average, nearly twice that of low fidelity classrooms (see Table 18).

Table 18. Normalized Gains According to Level of Fidelity

Level of Implementation Fidelity	Average Raw Gain	Average Normalized Gain
Low	17%	0.21
Medium or High	28%	0.40

NIH Modules: BSCS has developed a number of NIH-funded curriculum modules. Each module closely follows the 5E structure and is intended to immerse students in a special topic for one to two weeks. During the development phase of the modules, a field test takes place in which teachers and students provide feedback to BSCS about how the module works in the real-world classroom environment.

In 2000, Von Secker conducted an evaluation study to estimate the extent to which the first three NIH modules promoted student achievement, reduced inequity, stimulated student interest, and encouraged students to take responsibility for their own health. Von Secker sampled 17 pairs of biology teachers in New York City and randomly assigned them modules to use. She found overall positive results among those using the modules, but also found that the closer the teacher followed the 5E instructional model, the better the results were. In this study, only 60 percent of the teachers used more than two of the five activities in the module. Von Secker's findings are summarized in Table 19.

Table 19. Summary of Results for Students Using NIH Modules

Category	Overall Result	Breakout by 5E Phase
Overall Achievement	15% higher	9% higher if engagement emphasized 6% higher if exploration emphasized 6% higher if explanation emphasized 1% higher if elaboration emphasized 17% higher if evaluation emphasized
Minority Achievement (Equity)	16% higher	18% higher if engagement emphasized 13% higher if exploration emphasized 12% higher if explanation emphasized 14% higher if elaboration emphasized 12% higher if evaluation emphasized
Student Interest	96% higher	No data

For the most recent modules under development, we used a pre-test–post-test design to obtain data on student learning. Before the materials were covered in the classroom, a pre-test was administered to the students. At the conclusion of the materials, the students completed the same test, as a post-test. Table 20 illustrates the changes in the mean student score, as well as the results of a t-test for each module during the field test. Each of the BSCS modules listed in table 20 shows significant gains in student knowledge from pre-test to post-test. The observed gain in student knowledge stems from the use of a BSCS 5E Instructional Model.

Table 20. Effectiveness of NIH Modules Using the BSCS 5E Instructional Model

Module	Mean Pre-Test Score	Mean Post-Test Score	t-Test, Degrees of Freedom, and p Value
The Brain: Our Sense of Self (29 Possible Points)	15.74	18.85	t = 13.83, df = 426, p < 0.001
The Science of Energy Balance: Calorie Intake and Physical Activity (21 Possible Points)	9.73	13.51	t = 20.01, df = 400, p < 0.001
Using Technology to Study Cellular and Molecular Biology (15 Possible Points)	6.51	9.57	t = 27.77, df = 517, p < 0.001
The Science of Mental Illness (13 Possible Points)	6.88	9.84	t = 44.58, df = 1,249, p < 0.001
Looking Good, Feeling Good: From the Inside Out (22 Possible Points)	12.12	16.39	t = 22.60, df = 309, p < 0.001
Doing Science: The Process of Scientific Inquiry (19 Possible Points)	11.23	13.52	t = 18.03, df = 597, p < 0.001
The Science of Health Behaviors (21 Possible Points)	12.07	14.29	t = 19.71, df = 929, p < 0.001

Summary and Conclusion

The BSCS 5E Instructional Model is grounded in sound educational theory, has a growing base of research to support its effectiveness, and has had a significant impact on science education. Although encouraging, these conclusions indicate the need to conduct research on the effectiveness of the model, including when and how it is used, and continue to refine the model based on direct research and related research on learning.

The uniqueness of the BSCS 5E Instructional model is related to its alliterative nature. Every stage of the model begins with the same letter—in this case, an *E*. When we compare this model of 5Es with Herbart's (1901) models of preparation, presentation, generalization, and application or Atkin & Karplus' (1962) model of exploration, invention, and discovery, it becomes apparent why those models did not "catch on." A danger, of course, is that something that is catchy and easy to remember might be misused as often as it is used effectively; however, something that cannot be remembered or understood is less likely to have widespread sustainable effects.

The five phases of the BSCS 5E Instructional Model are designed to facilitate the process of conceptual change. The use of this model brings coherence to different teaching strategies, provides connections among educational activities, and helps science teachers make decisions about interactions with students. The 5E model had its origins with the work of others especially the SCIS learning cycle. The research reinforced the effectiveness of the learning cycle:

- All three phases of the model must be included in instruction, and the exploration phase must precede the term introduction phase.
- The specific instructional format may be less important than including all phases of the model, but laboratory work (typical in the exploration phase) is more effective for many students, provided it is followed by discussion (term introduction).
- Finally, student attitudes toward science instruction are more positive when they are allowed to explore concepts through experimentation or other activities before discussing them.

Using a learning-cycle approach to teaching and learning continues to be supported in significant reports, such as *How People Learn* (Bransford, Brown & Cocking, 1999). Bridging theory and practice can be accomplished by implementing the three major findings from this report through curriculum materials and professional development sessions designed on the instructional sequence to 5Es.

Findings from *How People Learn* can be implemented by curriculum developers and professional development providers by following these principles:

1. Learners preconceptions about how the world works will be engaged so that they may grasp new concepts and information in a meaningful manner.

2. Learners will develop a deep foundation of factual knowledge that is understood in the context of a conceptual framework and they will know how to organize that information in ways that facilitate retrieval and application.

3. Learners will be in control of their own learning by defining goals and monitoring their progress in achieving them.

Following the original work of Bransford, Brown, and Cocking, the National Research Council published *America's Lab Report: Investigations in High School Sciences* (2006). In their examination of the status of science laboratories the committee was very clear that science education should include both learning about the methods and processes of scientific research and the knowledge derived from those processes. They developed a vision for the future of high school science education that includes laboratory experiences that emphasize the following:

- Enhanced mastery of subject matter
- Development of scientific reasoning
- Understanding of the complexity and ambiguity of empirical work
- Development of practical skills
- Understanding of the nature of science
- Interest in science and interest in learning science
- Development of teamwork abilities

As mentioned earlier in this paper, the authors of America's Lab Report also support the concept of "integrated instructional units." These units are carefully designed to integrate laboratory activities and other experiences into units focused on student learning.

Table 13 emphasizes the relationship between the evidence from lines of research about the BSCS 5E Instructional Model and the goals for integrated instructional units from *America's Lab Report*.

Table 13. Comparison of the Effectiveness of the BSCS 5E Instructional Models with Integrated Instructional Units

Goal of *America's Lab Report*	**Integrated Instructional Units**	**BSCS 5E Instructional Model**
Mastery of Subject Matter	Increases mastery compared with other modes of instruction	Shows some evidence of increased mastery compared with other modes of instruction
Scientific Reasoning	Aids the development of more-sophisticated aspects	Shows some evidence of the development of more-sophisticated aspects
Understanding of the Nature of Science	Shows some improvement when explicitly targeted at this goal	Has inadequate evidence
Interest in Science	Has greater evidence of increased interest	Has greater evidence of increased interest

Goal of *America's Lab Report*	Integrated Instructional Units	BSCS 5E Instructional Model
Understanding of the Complexity and Ambiguity of Empirical work	Has inadequate evidence	Has inadequate evidence
Development of Practical Skills	Has inadequate evidence	Has inadequate evidence
Development of Teamwork Skills	Has inadequate evidence	Has inadequate evidence

Studies of the 5E model conducted by the internal and external evaluators conducted showed positive trends for student mastery of subject matter and interest in science. The most significant finding, however, is that there is a relationship between fidelity of use and student achievement. In other words, the BSCS 5E Instructional Model is more effective for improving student achievement when the teacher uses the curriculum materials the way they were developed. Without fidelity of use, the potential results of the program are greatly diminished. This is a line of research that should be pursued. In addition, the research base around the BSCS 5E Instructional Model should be elaborated on through additional studies that compare its effect on mastery of subject matter, scientific reasoning, and interest and attitudes with other modes of instruction. The widespread use of the BSCS 5E Instructional Model warrants a commitment to a line of research that rivals that of the learning cycle.

While earlier sections of this paper indicated that there is compelling research on the learning cycle suggesting that it can have a positive impact on mastery of subject matter, scientific reasoning, and interest and attitudes toward science there are still many areas need further research to fully understand how to most effectively use learning cycles and instructional models to maximize student learning. The most noticeable void in the literature is research exploring the utility of both the learning cycle and BSCS 5E approach in helping students develop an understanding of the nature of science and the complexity and ambiguity of empirical work, as well as practical and teamwork skills.

The range of applications of the BSCS 5E Instructional Model is one way to gauge the impact of the model. (See Appendix D for details on areas of impact.) In addition, it serves as an indicator of its success as an instructional model in science education. The BSCS 5E Instructional Model has become the foundation for a vast number of curriculum materials used in science education and, consequently, has had a large impact on the teaching and learning of science throughout the United States and internationally.

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