# THE BSCS 5E INSTRUCTIONAL MODEL AND 21$^{ST}$ CENTURY SKILLS

A COMMISSIONED PAPER PREPARED FOR A WORKSHOP ON EXPLORING THE INTERSECTION OF SCIENCE EDUCATION AND THE DEVELOPMENT OF 21$^{ST}$ CENTURY SKILLS

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In late 2008, the economy experienced the greatest series of crises and downturn since the Great Depression. This economic downturn has continued into 2009 and is projected to continue indefinitely. The public's attention has centered on jobs and basic needs. In the midst of discussions about bail-outs and stimulus packages, there is little or no discussion of workforce skills required in the 21st century. Although the nation's economic problems are larger and more complex than workforce skills, recovery and retraining of the retired, underemployed, and unemployed will require a new generation with knowledge, attitudes, and abilities generally needed for the 21st century.

The discussion of 21st century skills is not new. For example, in 1983 the Task Force on Education for Economic Growth of Education Commission of the States prepared *Action for Excellence.* In 1984, the National Academies published the report *High Schools and the Changing Workplace*, and in 1991 the U.S. Department of Labor released *What Work Requires of Schools: A Scans Report for America 2000.*

The recent emphasis on skills includes *Teaching the New Basic Skills* (Murnane and Levy, 1996) and more than 20 reports expressing the need to address concerns about an unprepared workforce. Among the most notable of these reports is *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future* (NRC, 2005 and 2007).

Now educators have the challenge of clarifying the skills and moving from broad statements of purpose to more specific discussions of educational practice. This paper addresses potential connections between development of 21st century skills and an instructional model used by the Biological Sciences Curriculum Study (BSCS). That model is referred to as the BSCS 5E instructional model. This paper draws upon a report for the National Institutes of Health, Office of Science Education, prepared by BSCS (Bybee et al., 2006).

Because the discussion centers on 21st century skills, I begin with a brief summary of those skills as summarized by the National Academies (NRC, 2008). The paper then introduces the BSCS 5E instructional model and continues with sections summarizing research supporting the model. I conclude with the implications for use of an instructional model for the development of 21st century skills in science education curriculum programs and instructional practices.

## 21st Century Skills

A recent discussion with a colleague made me aware of the need for a clear and specific description of the 21st century skills. I was describing the importance of these skills and he countered with—What are these skills? How do they apply to science teaching? When would science teachers introduce and develop the skills? One answer to the first question has been summarized by the National Academies and serves as the context for discussions about the BSCS 5E instructional model.

Research indicates that individuals learn and apply broad 21st century skills within the context of specific bodies of knowledge (National Research Council, 2008, 2000; Levy and Murnane, 2004). In science education, students may develop cognitive skills while engaged in study of specific science topics and concepts. Following are examples of 21st century skills.

Adaptability. The ability and willingness to cope with uncertain, new, and rapidly-changing conditions on the job, including responding effectively to emergencies or crisis situations and learning new tasks, technologies, and procedures. Adaptability also includes handling work stress; adapting to different personalities, communication styles, and cultures (Houston, 2007; Pulakos, Arad, Donovan, and Plamondon, 2000).

Complex communication/social skills. Skills in processing and interpreting both verbal and non-verbal information from others in order to respond appropriately. A skilled communicator selects key pieces of a complex idea to express in words, sounds, and images, in order to build shared understanding (Levy and Murnane, 2004). Skilled communicators negotiate positive outcomes with others through social perceptiveness, persuasion, negotiation and instructing (Peterson et al., 1999).

Non-routine problem solving. A skilled problem-solver uses expert thinking to examine a broad span of information, recognize patterns, and narrows the information to reach a diagnosis of the problem. Moving beyond diagnosis to a solution requires knowledge of how the information is linked conceptually and involves metacognition—the ability to reflect on whether a problem-solving strategy is working and to switch to another strategy if the current strategy isn't working (Levy and Murnane, 2004). It includes creativity to generate new and innovative solutions, integrating seemingly unrelated information; and entertaining possibilities others may miss (Houston, 2007).

Self management/self development. Self-management skills include the ability to work remotely, in virtual teams; to work autonomously; and to be self motivating and self monitoring. One aspect of self-management is the willingness and ability to acquire new information and skills related to work (Houston, 2007).

Systems thinking. The ability to understand how an entire system works, how an action, change, or malfunction in one part of the system affects the rest of the system; adopting a "big picture" perspective on work (Houston, 2007). It includes judgment and decision-making; systems analysis; and systems evaluation as well as abstract reasoning about how the different elements of a work process interact (Peterson, 1999).

## The BSCS 5E Instructional Model

Beginning in the late 1980s, BSCS began using an instructional model in most of its programs. That model is commonly referred to as the BSCS 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 the students' formulating a better understanding of scientific and technological knowledge, attitudes, and skills. The model has been used to help frame the sequence and organization of programs, units, and lessons. Once internalized, it also can inform the many instantaneous decisions science teachers must make in classroom situations. See Table 1 for summary of the BSCS 5E instructional model.

**Table 1. Summary of the BSCS 5E Instructional Model**

| Phase | Summary |
|---|---|
| Engagement | The teacher or a curriculum task assesses 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. |

The following sections provide more detail about the different phases of the instructional model. I have used examples from the NRC list of 21$^{st}$ century skills in discussions of the five phases.

Engagement. The first phase engages students in the learning task. The student mentally focuses on an object, situation, or event. The engagement activity introduces a new problem that students have to solve. The activities of this phase should make connections to past and future activities. The connections depend on the learning task and may be conceptual, procedural, or behavioral.

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

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

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

The aim of exploration activities is to establish experiences that teachers and students can use later to formally introduce and discuss scientific skills. During the activity, the students have time in which they can explore their knowledge and skills. This phase may require students to recognize new situations, learn new tasks, technologies, and procedures. As a result of their mental and physical involvement in the activity, the students establish relationships, observe patterns, identify variables, and of necessity, must adapt.

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 or problem. If called upon, the teacher may coach or guide students as they begin proposing explanations or solutions. Use of tangible materials and concrete experiences are essential in the exploration phase.

A portion of the exploration phase may center on cooperative learning (Johnson and Johnson, 1987; Johnson, Johnson, and Holubec, 1986; Johnson, Johnson, and Maruyama, 1983). The opportunity for students to interact, discuss, and even argue in a supportive environment about goal-centered activities enhances their skills in adapting, for example, to different communication styles and personalities. In addition, they will have to communicate their ideas in order to build a shared understanding of the problem and proposed solutions.

Explanation. Explanation means the act or process in which concepts, processes, or skills become plain, comprehensible, and clear. The process of explanation provides the students and teacher with a common use of terms relative to the learning experience. In this phase, the teacher directs student attention to specific aspects of the engagement and exploration experiences. Explanations are ways of ordering and giving a common language for the exploratory experiences and, for example, specific skills the teacher wishes to emphasize. 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 and skills briefly, simply, clearly, and directly, and then continue on to the next phase.

The explanation phase is teacher-directed and in today's parlance would be referred to as "direct instruction." Teachers have a variety of techniques and strategies at their disposal. Educators commonly use verbal explanations, but there are numerous other strategies, such as video, films, and educational courseware.

Elaboration. Once the students have an explanation, it is important to involve them in further experiences that apply, extend, or elaborate the concepts or skills. Elaboration activities provide further time and experiences that contribute to learning.

Audrey Champagne (1987) discusses an example of the elaboration phase that is appropriate for this discussion of 21st century skills.

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

> students are able to elaborate upon the conception of the tasks, information bases, and possible strategies for its [the task's] completion. (p. 82)

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

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

Evaluation. In this phase students receive feedback on the adequacy of their explanations and abilities. Informal evaluation can occur from the beginning of the instructional sequence. The teacher can complete a formal evaluation after the elaboration phase. As a practical educational matter, science teachers must assess educational outcomes. This is the phase in which teachers administer tests to determine each student's level of understanding and, in the context of this paper, their skills and abilities. This also is the important opportunity for students to use the skills they have acquired and evaluate their understanding and communicate their solutions.

## Research on Learning and Instruction

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 and 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 Academies present significant syntheses of contemporary research on learning. The first NRC review, *How People Learn: Brain, Mind, Experience, and School* (Bransford, Brown and 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, and Pellegrino, 1999), *How Students Learn: Science in the Classroom* (Donovan and Bransford, 2005), *Taking Science to School: Learning and Teaching Science in Grades K-8* (Duschl, Schweingruber, and Shouse, 2007), and *Ready, Set, Science: Putting Research to Work in K-8 Science Classrooms* (Michaels, Shouse, and Schweingruber, 2008).

The findings from these reports have implications for curriculum materials and classroom instruction designed to develop 21st century skills. The findings imply that curriculum and instruction must do the following:

- Build on current conceptions, skills, and abilities.
- Use meaningful contexts to develop concepts, skills, and abilities.
- Make the concepts, skills, and abilities explicit learning outcomes.

Relative to this review and the BSCS 5E instructional model, a quote from *How People Learn* (Bransford, Brown, and 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 structure, function, 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.

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 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 of 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. And second, the experiences are 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 the general concept 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 students' interest in science. In addition, integrated instructional units appear to be effective for helping diverse groups of students' progress toward these three goals.

Summary. After a brief description of 21st century skills, the first section introduced the BSCS 5E instructional model. The five different phases (i.e. engagement, exploration, explanation, elaboration, evaluation) were discussed in the context of the 21st century skills. This was a first examination of the possible connections between the learning outcomes expressed as 21st century skills and the instructional model. The section continued with a discussion of contemporary research on learning. Here too, close connections between the research foundations and the BSCS 5E instructional model were identified. I included a brief discussion of integrated instructional units, an insightful finding from *America's Lab Report: Investigations in High School Science* (NRC, 2006), because I believe it holds promise as a general model for effective teaching to develop 21st century skills. The BSCS 5E instructional model is a specific example of integrated instructional units.

The next section reviews research on the BSCS 5E instructional model and clarifies the degree to which it holds promise for teaching 21st century skills in school science education.

## Research on the BSCS 5E Instructional Model

This section is based on the report, *The BSCS 5E Instructional Model: Origins, Effectiveness, and Applications* (Bybee et al., 2006) and more recent research on the BSCS model. Due to the relative youth of the BSCS 5E instructional model compared with the older SCIS learning cycle, there are fewer published studies that specifically compare the BSCS 5E instructional model with other modes of instruction. However, the findings suggest that, like its predecessor the SCIS 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. 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). This observation relates to later discussion, particularly of the 21st century skill—systems thinking.

Fidelity to the instructional model. Coulson (2002) explored how varying levels of fidelity to the BSCS 5E model affected student learning. The outcome measure was selected-response tests administered pre- and post-instruction. 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 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 student 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).

Recent studies on implementation fidelity A 2007 publication by Taylor, Van Scotter, and Coulson reported two research studies that extended and strengthened the relationship between fidelity of curriculum implementation, specifically of the BSCS 5E instructional model and gains in student learning. The first research was case studies of four teachers field-testing a new high school science program using the BSCS 5E instructional model. The research identified distinctly different student learning gains for teachers implementing the program as designed as compared to teachers implementing the program with considerably less fidelity. The learning gains were assessed using a 20 item subset of questions from the standardized National Science Teachers Association (NSTA)/National Association of Biology Teachers (NABT) biology exam administered at the beginning and end of the year. Fidelity was measured by classroom observation by developers of the curriculum being field tested. Relative to this essay on 21st century workforce skills, the outcome was mastery of biological facts and concepts.

The second study centered on the same general question of learning gains of students whose teachers implemented a program with fidelity versus students whose teachers implemented the program with less fidelity. The study included 326 ninth-grade students and 15 teachers. Fidelity was measured using an observation protocol adapted from Horizon Research Inc., *Classroom Observation Protocol* (HRI, 2000).

Very important for this paper, the rating scales quantified the extent to which teachers encouraged students to engage in metacognitive activity, communicate their understanding of concepts, and apply their understanding to new situations. Teachers using strategies and learning sequences consistent with the 5Es at medium (basic) or high (extensive) levels had students with significantly higher gain scores.

The findings support the effectiveness of the BSCS 5E instructional model and complement studies conducted at other grade levels and science disciplines (see, e.g. Ates, 2005; Ebrahim, 2004; Lord, 1997). One aside to this discussion is the essential role played by professional development so teachers can develop an understanding of curriculum materials and the instructional model that is integral to this design.

## Linking the BSCS 5E Instructional Model to 21st Century Skills

In this section, I turn to the specific issue of 21st century skills and the potential of the BSCS 5E instructional model to contribute to the development of those skills. Before addressing the skills, several points must be clarified.

As prior sections have noted, fidelity to the structure and sequence of the 5E model results in greater student learning. This is not to say that teachers cannot adapt or modify teaching strategies with nuances that may enhance learning. But, the modifications should be made with knowledge and understanding of the design of curriculum material and instructional model. The decisions must be informed by an understanding of the learning theory underlying the instructional model (e.g. Bransford, Brown, and Cocking, 2000).

My review of the 5E instructional model did not find any cases where the model was used explicitly for development of the 21st century skills. Here, I would note the importance of establishing the 21st century skills as explicit learning outcomes. In this case, it seems educational policies may be leading curriculum programs and instructional practices designed for teachers to implement 21st century skills (Gewertz, 2008).

Adaptability. In general, this skill centers on the ability and willingness of individuals to cope with uncertain, new, and changing conditions. Learning new tasks, technologies, and procedures seem particularly applicable to opportunities for learning in science classrooms. Also, adapting to different personalities, communication styles, and work environments should be noted.

In the science classroom, the opportunities to develop the skills of adaptability require student activities, investigations, and laboratory work as part of an integrated instructional sequence, i.e. BSCS 5E instructional model.

Complex communication/social skills These skills require processing and interpreting information and selection of appropriate words and images, to build a shared understanding. Terms such as social perceptiveness, persuasion, negotiation, and instructing convey the essence of these skills.

The opportunities to develop these skills also center on activity-based science programs, ones with a clear inquiry orientation. Student should have opportunities to collect data and present their findings using graphs, charts, or other means. Scientific arguments based on evidence would be the essence of these skills in science classrooms. Findings by Boddy, Watson, and Aubusson (2003) reported increased higher-order thinking by students after a unit of work based on the 5E instructional model. The unit was taught to a year 3 class in Australia.

A recent study by BSCS staff is entitled, “The Relative Effects of Inquiry-Based and Commonplace Science Teaching on Students’ Knowledge, Reasoning and Argumentation: A Randomized Control Trial (Wilson et al., in press). This study used a randomized control trial that examined the effectiveness of inquiry-based curriculum materials and teaching (i.e., the BSCS 5E instructional model). Fifty-eight students aged 14-16 were randomly assigned to one of two groups. Both groups were taught toward the same goals by the same teacher with one group being taught from materials organized on the BSCS 5E instructional model and the other from commonplace teaching strategies as defined by national teacher survey data. Students in the group where the teacher used the BSCS 5E instructional model reached significantly higher levels of achievement compared to the other group. The effect was consistent for the range of learning goals—knowledge, scientific reasoning, and argumentation. The finding held for testing immediately following instruction and four weeks later. This study lends possible support to the 21st century goals of non-routine problem solving (i.e., scientific reasoning), complex communication (i.e., argumentation), and systems thinking (i.e., knowledge).

Non-routine problem solving Solving problems requires examination of a broad range of information, recognition of patterns, and selection of information to diagnose a problem and propose a solution. Proposing a solution also requires metacognition, that is, reflection on the possible consequences of applying a particular strategy. Certainly, creativity and innovation are part of problem solving.

As students engage in scientific inquiry, they have the aforementioned opportunities. The studies by Taylor et al. (2007), Boddy et al. (2003), and Wilson et al. (in press) suggest positive support for the BSCS 5E instructional model and contribute to a linkage between scientific reasoning and problem solving.

Self management/self development. The skills of self management and self development suggest the ability to work alone, acquire new information, and persist at given tasks.

Underlying these skills, one assumes interest in, motivation to study, and positive attitudes toward a domain of study or work. Research supporting the role of the BSCS 5E instructional model in developing interest can be found in studies by Von Secker (2002), Akar (2005), and Tinnin (2000).

Systems thinking. This is the ability to understand how a system works and how changes in components may affect the entire system. The skills of analyzing a system, understanding sub systems, and various elements of the structure and function of systems are part of systems thinking.

This ability requires mastery of knowledge about systems and the application of that knowledge to practical laboratory work and life situations. The majority of studies based on the BSCS 5E instructional model support the efficacy of the model to enhance students' mastery of subject matter (see e.g., Bybee et al., 2006; Coulson, 2002; Taylor et al., 2007; Akar 2005; and Wilson et al., in press).

Evaluation of field test materials. BSCS also has conducted numerous evaluations of programs, usually in a field-testing phase of development. Programs upon which the BSCS 5E instructional model is the explicit pedagogical strategy include:

- *Science for Life and Living* (BSCS, 1988)
- *Middle School Science and Technology* (BSCS, 1994, 1999, 2005)
- *BSCS Biology: A Human Approach* (BSCS, 1997, 2003, 2006)
- *BSCS Science: An Inquiry Approach* (BSCS, 2006)

In addition to these core programs, BSCS incorporated the 5E model in a number of supplemental units, most significantly a series of 16 modules that BSCS developed for the Office of Science Education at the National Institutes of Health. Specific results from these studies are described in the aforementioned BSCS publication (Bybee et al., 2006). In general, these studies supported and provided greater detail to the external evaluations cited earlier. The results indicate consistently positive results for mastery of subject matter and interest in science. There also is support for the development of scientific reasoning. Noteworthy for this discussion of $21^{st}$ century skills are results from a fifth grade study of science for Life and Living in which we found significant effects for process skills, manipulative skills, and higher order thinking skills.

Making a clear and compelling statement about the efficacy of the BSCS 5E instructional model directly to develop $21^{st}$ century skills would not be prudent based on the available evaluations. However, it is possible to provide some inferences based on the research, especially if one recognizes the parallels between $21^{st}$ century skills such as problem solving, self motivation, communication, and systems thinking and learning outcomes in science such as scientific reasoning, interest, argumentation, and mastery of science subject matter.

The majority of research on the BSCS 5E instructional model has been directed at mastery of science knowledge. Some research has been directed toward outcomes associated with scientific inquiry such as described in the *National Science Education Standards* (NRC, 1996). Here too, there is some support for positive achievement. Table 2 presents inferences about the effectiveness of research on the BSCS 5E instructional model and $21^{st}$ century skills.

**Table 2. Linkages and the Effectiveness of the BSCS 5E Instructional Model with 21st Century Skills**

| GOAL OF 21ST CENTURY SKILL | BSCS 5E INSTRUCTIONAL MODEL |
|---|---|
| ADAPTABILITY | Inadequate Evidence |
| COMPLEX-COMMUNICATION | Some Evidence Based on Argumentation |
| NON-ROUTINE PROBLEM SOLVING | Strong Evidence Based on Scientific Reasoning |
| SELF MANAGEMENT/SELF DEVELOPMENT | Strong Evidence Based on Attitudes Toward and Interest in Science |
| SYSTEMS THINKING | Strong Evidence Based on Mastery of Scientific Knowledge |

## The BSCS 5E Instructional Model and Development of 21st Century Skills: A Concluding Discussion

This section presents the potential of the BSCS 5E instructional model, but perhaps more importantly, some of the implications for science education programs and practices.

Curriculum goals. To what extent are 21st century skills targeted for instruction? The clearest and most direct answer to this question is—not very much. That said, arguments that 21st century skills should be emphasized in school science programs is relatively new. As noted in the prior section, there may be some linkages between the BSCS 5E instructional model and development of 21st century skills if one accepts a modification of, for example, non-routine problem solving to scientific reasoning and complex communication to argumentation.

Review of the contemporary program, *BSCS Science: An Inquiry Approach*, reveals that the 5E instructional model is used to introduce a unit on "The Process of

Scientific Inquiry." The context for this unit is the investigation of sports drinks. In the different phases of the instructional model, students discuss the difference between evidence and inference (engage); follow protocols to complete an investigation and gather evidence about sports drinks (explore); read about scientific inquiry (explain); review a study on the benefits of sports drinks compared to water and write a paragraph about the benefits of sports drinks (elaborate), and design a homemade sports drink, test the drink, and present it to the class as an advertisement (evaluate). In this example, the 5E model is used to develop an understanding of scientific inquiry and develop the abilities of identifying questions that guide an inquiry and use evidence and inference to develop an explanation.

This example shows that the BSCS 5E instructional model has been used to develop students' abilities and skills associated with scientific inquiry. So, making the connection to curriculum goals such as those identified as 21st century skills is certainly possible.

Alignment with learning research. To what extent does the instructional model treat 21st century skills and conceptual science knowledge as separate or intertwined? The example described in the prior section shows that conceptual knowledge, e.g., understanding scientific inquiry and skills, e.g., abilities of scientific inquiry can be intertwined.

To what extent does the BSCS 5E instructional model reflect the research on children's and adolescents' learning and development in science? Although the instructional model was developed in the late 1980s, it was based on earlier research associated with the Science Curriculum Improvement Study (SCIS) and other research on conceptual change (see, Bybee et al., 2006). Subsequent reviews by the NRC (see, e.g. Bransford et al., 2000) suggested that the BSCS model had a clear alignment with recommendations from the NRC reviews. In curriculum projects developed after 2000, the NRC studies have been used as a basis for the programs.

Assessment and evidence. Where has the model been implemented, and what are the characteristics of teachers and students exposed to the model? The model has been widely implemented in education. 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 BSCS 5E model. A recent 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.

So, one can assume an extraordinary range of teachers and students have been exposed to the model.

Does the model, or research on its effectiveness, incorporate assessment of 21st century skills? The model and research on its effectiveness have not directly incorporated an assessment of 21st century skills. Exceptions to this statement have been described. The available evidence suggests support for problem solving, self management, communication, and systems thinking, but the support is based on associated goals such as scientific reasoning, interest in science, argumentation, and mastery of science knowledge.

Effectiveness and implications. What does the evidence indicate about the impact or efficacy of the model in supporting one or more of the 21st century skills among diverse groups of students? Based on the available evidence, I would infer that the model would be effective in developing one or more 21st century skills among diverse groups of students. Evidence supporting the model's efficacy to develop conceptual understanding is very strong, especially if one also considers the evidence for the original SCIS model and variations on that model. Both of these models should be considered as the foundation for the BSCS 5E model.

One has to consider the fact that the longstanding and major goal of school science education has been learning scientific knowledge. This has been the explicit goal of most curriculum programs. If one or more of the 21st century skills were explicitly emphasized in student activities and investigations based on the 5E model, it is highly probable that students would develop the skills and abilities.

Does the evidence suggest that certain instructional design principles help to account for the impact or efficacy of the instructional model? I believe there are design principles that account for the efficacy of the BSCS model and that those principles are applicable to curriculum goals such as the 21st century skills. Table 4 lists design principles for an instructional model that could be used to develop 21st century skills. These principles are adapted from an earlier publication (Bybee, 1997). These design principles are applicable to the development of one or more of the five categories of skills. The general and primary point is that one or more of the 21st century skills must be the explicit learning outcome for the instructional model.

**Table 3. Design Principles for an Instructional Model**

1. The model should have 3 to 5 phases that represent an integrated instructional sequence.
2. The model should be based on contemporary research on student learning and development.
3. The model must help the learner integrate new skills and abilities with prior skills and abilities.
4. The model must allow for social interactions (student-student as well as student-teacher interactions).
5. The model must be generic and applicable to a wide range of classroom contexts and activities.
6. The model must be manageable for teachers with classrooms of 25-30 or more students.
7. The model must be understandable to teachers and students.
8. The model must accommodate and incorporate a variety of teaching strategies including laboratories, educational technologies, reading, writing, and individual student work.

## Conclusion

The BSCS 5E instructional model and other such models do hold promise for teaching 21st century skills. This said, it also must be noted that although the development of skills and abilities has been noted as educational goals for science programs, very little emphasis has been placed on these goals.

Activity-based school science programs that incorporate instructional models have the potential to develop 21st century skills. Among the major challenges associated with this assertion are: providing model curriculum materials that exemplify the goals, changing teachers' perceptions about explicitly teaching to develop skills and abilities, and encouraging fidelity to instructional models designed to help students attain 21st century skills.

I will conclude with a personal note. The BSCS 5E instructional model has been more successful than I ever could have imagined when we originally developed the model in the late 1980s. BSCS has included the model in most programs developed since that time. However, the dissemination and successful use of the model far exceeds the adoption of BSCS programs or implementation and professional development institutes. The BSCS 5E instructional model is recognized internationally, included in several state frameworks, applied in disciplines beyond science, adapted by curriculum developers other than BSCS, and used by science teachers at all levels—elementary school through college and university.

The wide-spread acceptance of the BSCS 5E instructional model suggests that its use in the design of curriculum materials for 21st century skills would greatly enhance the adoption and acceptance of those materials by science educators and science teachers.

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