

# PART I

## Effective Science Education

*Science is a way of knowing about ourselves and the world of which we are a part. It is a sense of wonder and a childlike way of knowing paradoxically characterized by integrity, discipline and responsibility. The goal of the enterprise is to provide awareness, understanding, and wisdom for a greater harmony between ourselves and our world.*

—Bob Samples, Bill Hammond,  
and Bernice McCarthy (1985)



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# Creating a Climate for Differentiated Instruction

## A CLIMATE FOR LEARNING

Classrooms vary. Some are dull and lifeless, while others are alive with activity, emotion, discussion, displays of student work, and an abundance of resources. Armed with an innate curiosity about the natural world, children look forward to and embrace science instruction when they are actively involved in uncovering and discovering the mysteries of the natural world. What teachers know and believe about their subject area and the nature of learning determine many of the decisions they make about the structure of their classrooms and what they teach and model.

Science engages students and activates the brain through emotion, excitement, motion, challenge, thought, reflection, and concept development. The classroom climate, as well as the instructional practices that are used, ultimately affect the ways students are motivated to learn, acquire knowledge, construct knowledge, and develop skills and attitudes. A student-friendly, well equipped classroom provides a rich environment for implementing a variety of creative approaches for learning.

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Juan, a fifth-grade student, is shaking as he “stands ready” for his next class—science. “I have been waiting three years for this activity,” he informs his teacher. “My older brother dissected owl pellets when he was in fifth grade, and I am so excited that I will finally get to do it myself.”

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## A SAFE AND ENRICHED ENVIRONMENT

*A safe environment:* Safety should be the first consideration in any classroom. Schools should have written safety plans that are familiar to both teachers and students. Federal and state agencies offer guidelines for safety in schools that identify such things as the following:

- Safe standard operating procedures and housekeeping practices.
- First aid and emergency equipment and use.
- Safe laboratory practices.
- Guidelines for keeping animals in the classroom.
- Chemical procurement, storage, and distribution.
- Guidelines for waste disposal.
- Biological hazards.
- Electrical safety.
- Other safety information relative to the grade span.

Appropriate signs and equipment should be readily available and safety rules should be practiced at all times. Fire and disaster drills should be conducted regularly. Students need to be aware of emergency telephone numbers and exits, evacuation routes, proper response behaviors, and safety equipment, such as first aid kits, eye wash stations, fire extinguishers, and fire blankets. In addition, students should know the procedures for the safe and efficient use of equipment and materials.

A safe and effective environment for science requires responsible conduct on the part of students, cleanliness, and lack of clutter. Students should not eat or drink or put anything into their mouths during a lab unless authorized by the teacher. Some students are allergic to certain foods, such as peanuts. Appropriate safety goggles should be used whenever there is a threat to eyes from projectiles or chemical splashes. Students should be allowed to have input into the policies and procedures that govern their classroom. Parents and students should agree to and sign a “safety contract” prior to student involvement in laboratory activities.

Safety equipment at the elementary and intermediate levels will vary with the types of activities offered. In addition to the guidelines in the safety plan, common sense and an atmosphere of mutual respect, trust, and consideration for others will help ensure success.

### Internet Resources Related to Health and Safety

- Occupational Safety and Health Administration: OSHA Laboratory Standard—29 CFR 1910.1450: <http://www.osha.gov/>  
OSHA’s mission is to assure the safety and health of America’s workers by setting and enforcing standards; providing training, outreach,

and education; establishing partnerships; and encouraging continual improvement in workplace safety and health.

- The Laboratory Safety Institute: <http://www.labsafety.org>

The Laboratory Safety Institute is a nonprofit, international educational organization for health, safety, and environmental affairs. It offers courses, workshops, and materials designed to enable teachers and students to learn to care about their health and safety, learn to identify life's hazards and how to protect themselves, and create a safer and healthier learning and working environment.

- National Science Teachers Association Position Statement: <http://www.nsta.org/positionstatement&psid-32>

The site includes the position statement and a list of resources.

***An enriched environment:*** Students need to feel safe and secure as they engage in challenging and meaningful learning experiences. An environment that embraces diversity, eliminates threat, and provides support and encouragement enables students to focus attention on learning. The human brain is affected by factors in the environment. Stressful environments can reduce the students' ability to learn while a stimulating environment promotes neural connections in the brain, which may be a contributing factor for an enhanced learning capacity (Jensen, 1998b; Sylwester, 1995).

Marion Diamond, a noted brain researcher, describes an enriched environment for learning as one that does the following:

- Is free of stress and pressure.
- Provides positive emotional support.
- Ensures a nutritious diet.
- Provides social interactions.
- Presents opportunities for sensory stimulation through active participation in appropriately challenging activities (Diamond & Hobson, 1998).

## NATURAL LEARNING SYSTEMS

***What are they and why are they important?*** A climate for learning must respond to human needs for emotional safety, social interactions, cognitive challenge, physical activity, and thoughtful reflection. These needs corresponding to the Brain's Natural Learning Systems (Given, 2002) form the basis for establishing a climate in which students can apply the skills of inquiry to learning standards-related content. The emotional, social, and physical systems are greedy for attention and will not allow the cognitive and reflective systems to function at optimal efficiency if their needs are not met.

## Emotional Learning System

It has long been known that negative emotions and social interactions can inhibit academic progress (Rozman, 1998). Students will spend an inordinate amount of attention and energy protecting themselves from ridicule and rejection rather than learning new knowledge and skills. Researchers tell us that we need emotional nourishment from birth (Kessler, 2000; Palmer, 1993), and that a lack of it affects us profusely. It is endorphins and norepinephrine that influences positive emotions and supports learning along with good health and success in life (Pert, 1998). Emotions are both innate and acquired. Surprisingly, peers and siblings have much more impact on learned emotions than do parents: 45% influence from peers versus 5% from parents (Harris, 1998).

When emotional needs such as love and acceptance are met, the brain produces serotonin (a feel-good neurotransmitter). When emotional needs are not met, young people often turn to drugs that obliterate the negative feelings of hunger, fatigue, and depression.

A natural high can result through connectedness and meaningful interactions, interesting learning materials, and attention to students' personal needs and goals. Csikszentmihalyi (1990) referred to the "state of flow," where all systems are focused and challenge and skill level is matched. In this state, all systems are "go" and work together toward optimal learning.

The emotional system flourishes in classrooms and schools where the following takes place:

- Educators and students believe students can learn and be successful.
- Students' hopes and dreams are recognized.
- Teachers make learning relevant to students' lives.
- Teachers provide multiple ways for students to express themselves.
- Teachers continue to challenge students.
- The climate nurtures rather than represses.

## Social Learning System

From birth we begin to form relationships with others and our environment to better understand ourselves. There are two social subsystems. One system in place at birth relates to dyadic relationships. The other evolves and deals with group relationships (Harris, 1998). The extent to which we feel part of a group influences our behavior in and out of school. All of us prefer to interact with those whose presence increases brain oxytocin and opioid levels resulting from feelings of comfort, trust, respect, and affection (Panksepp, 1998). Yet often in classrooms, there is no opportunity to develop social interactions that promote trust and connections. We naturally tend to participate in groups so that we feel a kinship that is fostered by group norms and values (Wright, 1994).

A skillful, insightful teacher can capitalize on this knowledge by creating a classroom climate that does the following:

- Includes all learners.
- Honors their hopes and aspirations.
- Provides an enriched environment for authentic learning (Given, 2002).

### **Physical Learning System**

The physical learning system involves active problem-solving challenges. It is often the system that is not utilized enough in classrooms although we know that gifted students (Milgram, Dunn, & Price, 1993) and underachievers (Dunn, 1990) have a preference for active, tactile, and kinesthetic involvement when learning new material.

Those of us who have experienced learners in our classrooms who need to have the physical learning system in the forefront have realized that if we ignore this system, the learners will find a way to “move” to satisfy their needs regardless of our plans. The movement might not have anything to do with the knowledge or skills that have been targeted for learning. So it begs the question: Do we build in opportunities for hands-on, active learning or do we let students find a way of their own to utilize physical systems that may be counterproductive to the learning?

### **Cognitive Learning System**

This is the system that we focus on most often in the classroom and rightly so, as we want students to succeed in learning new knowledge and skills. The cognitive system deals with consciousness, language development, focused attention, and memory. This system also relies on the senses for processing information. Thus good teachers facilitate learning by providing information in a novel way, stimulating the visual, auditory, and tactile senses as well as taste and smell if appropriate. However, as previously noted, the emotional, social, and physical systems seem more greedy for attention, and if their needs are not attended to, students will not be comfortable enough to learn. If all systems are “go,” students tend to learn with more ease and with greater retention.

### **Reflective Learning System**

“Reflection is a critical aspect of all sophisticated and higher order thinking and learning” (Caine & Caine, 1991, p. 149). This intelligence includes “thinking strategies, positive attitudes toward investing oneself in good thinking, and metacognition—awareness and management of one’s own mind” (Perkins, 1995, p. 234). Damasio (1999) noted that the reflective system involves the interdependence of memory systems, communication

systems, reason, attention, emotion, social awareness, physical experiences, and sensory modalities. The reflective system allows us to do the following:

- Analyze situations.
- Examine and react.
- Make plans.
- Guide behaviors toward goals.

This is the system that in the rush to cover the curriculum is often left out of the learning process in the classroom. However, the skills of ongoing reflection and self-examination are key to evolving the self. These metacognitive skills enable students to form a clear image of self and to develop the reflective strategies that lead to self-directed learning and success in life.

Children come to school with an innate curiosity and love of learning. They enjoy learning about themselves and the world around them. Subject matter and interesting approaches to learning that are meaningful to their lives and connected to their personal goals for learning heighten interest and increase motivation to learn.

### Learning Systems With Links to National Standards

The National Science Education Standards (NSES) identify a set of teaching standards for science education that relate closely to the five learning systems. Figure 2 shows the learning systems with links to the NSES recommendations for teaching.

**Figure 2** Learning Systems With Links to National Science Education Standards (NSES) Teaching Standards

Learning Systems	Recommendations for Teaching and Learning (National Research Council, 1996)
<b>Emotional</b>	Understand and respond to individual student's interests, strengths, experiences, and needs
<b>Social</b>	Provide opportunities for scientific discussion and debate among students; support a classroom community with cooperation, shared responsibility, and respect
<b>Physical</b>	Guide students in active and extended scientific inquiry
<b>Cognitive</b>	Select and adapt curriculum; focus on student understanding and use of scientific knowledge, ideas, and inquiry process; work with other teachers to enhance the science program
<b>Reflective</b>	Continuously assess student understanding; share responsibility for learning



## A PLANNING GUIDE FOR DIFFERENTIATED INSTRUCTION

The “quantum leap” between theory and practice begins with planning. Instruction is not a random set of behaviors or a collection of disparate activities intended to familiarize students with a topic. Rather, it is a carefully constructed plan for using a variety of methods and strategies to engage students thoughtfully and actively in meaningful learning of important concepts and skills. As such, instruction should be dynamic and flexible to respond to feedback about both the process and progress of learning and to capitalize on unexpected “teachable moments” as they arise.

Differentiated instruction requires thoughtful planning for success. Two models for instructional design were intertwined to create a multidimensional framework for planning inquiry-based instruction in science. The planning model shown in Figure 3 identifies the phases of the model in the left-hand column that require consideration for planning effective instruction. The phases of the model are consistent with models for high quality instruction (Gregory & Chapman, 2007; Hammerman, 2006a) and with the NSES (National Research Council, 1996) vision for inquiry where reasoning and critical thinking are used to develop concepts, appreciate how knowledge is acquired, understand the history and nature of science, develop skills for lifelong learning, and develop the dispositions underlying science.

The right-hand column provides a list of resources and strategies for differentiating instruction. The planning model provides opportunities for students to personally construct knowledge through active learning by integrating strategies for differentiating instruction with inquiry-based science: “Embedding teaching strategies within an inquiry-based pedagogy can be an effective way to boost student performance in academics, critical thinking, and problem solving” (Jarrett, 1997, p. 2).

### PHASES OF THE PLANNING GUIDE

The planning guide provides the framework for the chapters in this book. Each phase of the model plays an important role in the design of high quality, differentiated instruction to maximize student achievement. Phases 1 and 2 of the model emphasize the importance of considering content standards and key concepts, skills, and dispositions on which to base instruction. Phase 3 offers ideas and strategies for understanding learners and selecting a context for meaningful learning. Phases 4–8 integrate components of the 5E’s Lesson Plan with resources and strategies for differentiating instruction in science.

**Figure 3** A Planning Guide for Differentiated Instruction in Science

<b>Planning Guide for Differentiated Instruction in Science</b>	
<b>1. Content Standards:</b> What students should know and be able to do: Unifying concepts and processes in science; science as inquiry; life, Earth and space, and physical science; science and technology; science in personal and social perspectives; history and nature of science	<b>Consider:</b> National and state standards; scientific literacy
<b>2. Concepts, Skills, and Dispositions:</b> Key concepts, process and thinking skills; valued dispositions	<b>What teachers will do:</b> Review content and identify concepts that address learning goals and essential questions on which to base activities and experiences
<b>3. Knowing the Learner:</b> Preassess; use data to inform methods, quizzes; surveys; strategies, and grouping patterns; consider a variety of approaches to learning	<b>Consider:</b> Multiple Intelligences and learning profiles; interest, readiness, gender equity; multiculturalism
<b>4. Activate and Engage:</b> create wonder; motivate; generate interest; use novelty; identify inquiry questions	<b>K-W-L:</b> discrepant events; poem or story; demonstration; video clip; field trip; speaker; questions; school site; displays
<b>5. Acquire and Explore:</b> investigate through inquiry; use varied methods and strategies; offer multiple pathways for learning based on student needs, interests, and learning profiles	First-hand experiences; teacher and student-constructed inquiries; problem-based learning; projects and products; demonstrations; action research; centers; stations; choice boards; role play; debates; compacting; case studies; novel strategies
<b>6. Explain and Apply Learning; Create Meaning:</b> Link new learning to prior knowledge; make connections; apply learning and create meaning	Use questions and discussion to reflect on process and data; explain data; support conclusions with data; analyze learning; apply content to technology, society, and lives of students
<b>7. Elaborate and Extend:</b> Ask and research new questions; construct inquiries based on questions	Action research; applications to community, state, national, global problems and issues; problem solving; inventions; Internet research; community involvement; reading; videotapes; interviews; compacting
<b>8. Assess and Evaluate:</b> Capture evidence of learning to monitor progress and guide instruction; provide opportunities for relearning	Use rubrics for self-assessment; notebook entries, explanations, interviews, teacher-made tests, performance tasks, projects, products, and presentations that provide evidence of learning; portfolio entries show work and progress over time

**1. Content Standards:** The content standards are based on the qualities and characteristics of scientifically literate citizens. The standards are the “end product” of instruction, that is, they describe what students should know and be able to do to understand, relate to, contribute to, and participate successfully in the scientific and technological world in which they live. As such, standards provide the building blocks of knowledge and skills for a K–12 science program.

**2. Concepts, Skills, and Dispositions:** Standards-based concepts, skills, and dispositions provide clear targets for learning. Concepts build from simple to complex as students explore deeper meanings over time. Process skills are the thinking strategies for learning and creating meaning. Process and thinking skills develop as students engage in active learning and discourse. Dispositions are attitudes and actions that are valued by the scientific community.

**3. Knowing the Learner:** Differentiated instruction is student centered, that is, it is designed around variables such as student cultural backgrounds, learning profiles, multiple intelligences, interest, and readiness for learning. Once these factors are realized, it is possible to choose a context for learning that is relevant and meaningful.

**4. Activate and Engage:** Capturing the attention of students and motivating them to learn are two objectives of this phase of instruction. Creative contexts, discrepant events, high impact lesson starters, problems and issues, and the like provide emotional stimuli, create wonder, and motivate students. This phase generates standards-based inquiry (essential) questions.

**5. Acquire and Explore:** A wide range of instructional approaches, activities, and experiences enables students to investigate inquiry questions, explore, learn, and ask new questions. It is here that instruction focuses on what students need to know and be able to do, accommodates student interests and differences, and provides a variety of methods and strategies for learning.

**6. Explain and Apply Learning; Create Meaning:** In this very important phase, students describe and reflect on what they did, the data they collected, and what they learned. It is here that they link new learning to prior knowledge and construct meaning. Questions that promote discussion and dialogue are the cornerstone of this metacognitive phase. Questions that require students to use critical thinking and reasoning enable them to make sense of new knowledge.

**7. Elaborate and Extend:** This phase offers multiple opportunities to apply concepts to the lives of students, to technology, and to the social

world. Students often generate new questions that relate to their lives or to their community. They may express interest in conducting Internet research or engaging in action research to deepen their understanding. Opportunities to elaborate or extend learning should be available through a variety of activities, references, and resources.

**8. Assess and Evaluate:** Formative assessment is an ongoing process of seeking evidence from a number of sources to inform and to guide learning. Notebook entries, written and verbal explanations, quizzes, projects, products, and presentations are a few ways to assess learning. Self-evaluation tools provide a set of criteria against which students can measure their learning on an ongoing basis.

Valid assessments align with standards and instructional goals and provide important feedback related to learning. Summative evaluations are used to determine what students have learned and are able to do as a result of instruction.