THE TEACHING OF SCIENCE: 21st CENTURY PERSPECTIVES

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Prologue
Connecting the Past and Future

In the preface, I mentioned the fact that I knew the individuals for whom the NSTA lectures were named—Paul F-Brandwein, Robert Carleton, and Robert Karplus—and who had a great influence on my career. As work on this book continued, I thought it important to provide readers with a brief introduction to these individuals. The following discussion and this book connect these 20th-century leaders to future generations of science teachers as they themselves become the 21st-century leaders.

Paul F-Brandwein: Scientist, Environmentalist, and Curriculum Designer

The Brandwein Lectures both acknowledge Paul F-Brandwein's long and distinguished career, including serving on the Steering Committee of the Biological Sciences Curriculum Study (BSCS) from the late 1950s into the 1960s. Paul F-Brandwein directed the Gifted Student Committee at BSCS and was responsible for initiating a program on student research problems. He felt deeply about giving students the opportunity to engage in scientific inquiry as a means to encourage their future careers as scientists.

Paul F-Brandwein played a key role in BSCS's early publications for gifted students. He was a member of the BSCS Steering Committee and the Gifted Committee from 1959 to 1962 and a member of the Special Student Committee from 1962 to 1963. I also would note that Harcourt Brace, the company for which Paul was a senior editor and an education consultant, published BSCS's *Biological Sciences: An Inquiry Into Life*, known as the BSCS "Yellow Version."

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The Teaching of Science: Contemporary Challenges

In the early decades of the 21st century, science teachers face some problems unique to our times and some common to all eras. Among the challenges that require attention and leadership by science teachers are

- achieving scientific literacy,
- reforming science programs,
- teaching science as inquiry,
- improving science teachers' knowledge and skills, and
- attaining higher levels of achievement for all students.

These challenges present a variety of issues that require leadership at all levels within the science education community, but especially by science teachers. Some of the issues will be with us for the relatively brief time of political administrations, and some challenges have a longer and deeper educational standing. Although the challenges extend to all components of science education, my emphasis in this book will be on the core of instructional practice. This, it seems to me, is essential and centers on the science teacher.

The challenges center on longstanding themes in science education—scientific literacy, science programs, science as inquiry, professional development, and student achievement. These themes unite diverse topics and discussions in the chapters that follow. This chapter continues with an introduction to the core of education practice.

What is important for individuals to be able to *do* that is science related? People often have to base decisions on evidence and information, evaluate claims made by others on the basis of the evidence, and distinguish personal opinion from scientific (i.e., evidence-based) statements.

In general, citizens do not judge the worth of theories or advances in science. But they do make decisions based on the facts in advertisements, evidence in legal matters, information about their health, and issues concerning local environments and natural resources. An educated person should be able to distinguish questions that can be answered by scientists from problems that can be solved by science-based technologies.

Science Programs: Incorporating Research-Based Approaches Into Curriculum and Instruction

Enhancing student achievement will rely on designing curricula based on research that has advanced our understanding of how students learn science. The following discussion reviews contemporary research that has implications for science teaching and learning. Several examples of curriculum and instruction are provided.

Research on Learning

The National Research Council (NRC) reports *How People Learn: Brain, Mind, Experience, and School* (Bransford, Brown, and Cocking 2000), *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) present a major synthesis of research on human learning. I will also note *Learning Science and the Science of Learning* (Bybee 2002), a volume I edited for the National Science Teachers Association (NSTA) that presented many of these findings for science teachers. Three findings from the NRC reports, in particular, have both a solid research base and clear implications for science curricula and instruction.

Students Come to Class With Preconceptions

The following findings are from *How People Learn: Bridging Research and Practice* (Donovan, Bransford, and Pellegrino 1999):

> *Students come to the classroom with preconceptions about how the world works. If their initial understanding is not engaged, they may fail to grasp the new concepts and information that are taught, or they may learn them for purposes of a test but revert to their preconceptions outside the classroom.* (p. 20)

Table 1.4

Attainment of Educational Goals in Typical Laboratory Experiences and Integrated Instructional Units

Goal	Typical Laboratory Experiences	Integrated Instruction Units
Mastery of subject matter	No better or worse than other modes of instruction	Increased mastery compared with other modes of instruction
Scientific reasoning	Aids development of some aspects	Aids development of sophisticated aspects
Understanding of the nature of science	Some evidence of increased interest	Some improvement when explicitly targeted at the goal
Understanding the complexity and ambiguity of empirical work	Inadequate evidence	Inadequate evidence
Development of practical skills	Inadequate evidence	Inadequate evidence
Development of teamwork skills	Inadequate evidence	Inadequate evidence

Teaching Science as Inquiry: Teaching Both Content and Procedures

Leaders in science education have the obligation to clarify a basic confusion that persists regarding scientific inquiry as it applies to education programs and to confront the controversial view that an inquiry orientation lacks intellectual rigor. Critics often reduce teaching science as inquiry to its simplest and most inappropriate form and summarily dismiss both the content and process. Unfortunately, inquiry has become associated with an ambiguous instructional approach and often is not recognized as a viable and appropriate set of educational outcomes, namely, the cognitive abilities and conceptual and factual understandings aligned with this central feature of the scientific enterprise. One hears arguments that inquiry approaches (note that use of terms such as *approaches* and *strategies* assumes that inquiry refers to teaching methods) are not effective for learning all science content because the process takes too long. The term is misinterpreted, extended to its most unreasonable position, and dismissed as not viable. Science teachers need to participate in efforts to clarify what the education community means by scientific inquiry: It is a content goal—that is, students should understand scientific inquiry and develop cognitive abilities. Inquiry also can be instructional approaches to achieve these goals.

in fact the blank slate model) and likely did not review the assessment prior to formulating the test questions. Science teachers can do better than this.

Understanding by Design describes a process that will bring science teachers closer to determining what students have learned. The process is called *backward design* (Figure 3.1, p. 62). Conceptually, the process is simple. Begin by identifying your desired learning outcomes, for example, concepts, knowledge, or abilities. Then determine what would count as acceptable evidence of student learning and design an assessment that will provide the acceptable evidence. Then, and only then, begin developing the activities that will provide students with opportunities to learn.

The BSCS 5E Instructional Model and the *National Science Education Standards* clarify the process. Let us say you identified the desired learning as "Life Cycles of Organisms." One would review concepts and determine the acceptable evidence of learning. For instance students would need to be able to identify life cycles of plants and animals and describe aspects of the cycle (e.g., being born, growing to adulthood, reproducing, and dying). You might expect students to recognize that offspring closely resemble their parents and that some characteristics are inherited from parents while others result from interactions with the environment. One could design an *evaluate* activity, such as growing Fast Plants under different environmental conditions, then design a rubric with the aforementioned criteria. Then one would proceed to design the *engage*, *explore*, *explain*, and *elaborate* experiences. If necessary, the process would be iterative between the evaluate and other activities as the development process progresses.

Figure 3.1

Backward Design Combined With the BSCS 5E Instructional Model

Source: Wiggins, G., and J. McTighe. 2005. *Understanding by design*. Expanded 2nd ed. Alexandria, VA: Association for Supervision and Curriculum Development (ASCD).

sustainable development. These areas were selected because they will provide an international portrait of students' general appreciation of science, their specific scientific attitudes and values, and their responsibility toward select science-related issues that have national and international ramifications. Note that this is not an assessment of students' attitudes toward school science programs or teachers. The results will provide information about the emerging problem of declining interest for science studies among young people.

Table 5.2 provides a summary of key components of the PISA 2006 science assessment.

Table 5.2

Summary of the Assessment Areas for PISA 2006—Science

Assessment Area	Description
Scientific literacy and its distinctive features	Scientific literacy refers to an individual's • Scientific knowledge and use of that knowledge to identify scientific issues, to explain scientific phenomena, and to use scientific evidence; • Understanding the characteristic features of science as a form of human knowledge and inquiry; • Awareness of how science and technology shape our material, intellectual, and cultural environments; and • Willingness to engage in science-related issues, and with the ideas of science, as a reflective citizen.
Science content	Areas of scientific knowledge and concepts include: • Physical systems • Living systems • Earth and space systems • Technological systems And knowledge about science, which includes: • Scientific inquiry • Scientific explanations
Scientific competencies	• Identify scientific questions • Explain phenomena scientifically • Use scientific evidence
Personal, social, and global contexts	Areas of application within the contexts include: • Health • Resources • Environments • Hazards • Frontiers of science and technology
Attitudes	The response to scientific situations include: • Interest in science • Support for scientific inquiry • Responsibility for sustainable development

Source: Organisation for Economic Cooperation and Development (OECD). 2007. *PISA 2006: Science competencies for tomorrow's world*. Danvers, MA: OECD.

Question 2: ACID RAIN

Difficulty: 506

Normal rain is slightly acidic because it has absorbed some carbon dioxide from the air. Acid rain is more acidic than normal rain because it has absorbed gases like sulfur oxides and nitrogen oxides as well.

Where do these sulfur oxides and nitrogen oxides in the air come from?

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The effect of acid rain on marble can be modelled by placing chips of marble in vinegar overnight. Vinegar and acid rain have about the same acidity level. When a marble chip is placed in vinegar, bubbles of gas form. The mass of the dry marble chip can be found before and after the experiment.

Question 3: ACID RAIN

Difficulty: 460

A marble chip has a mass of 2.0 grams before being immersed in vinegar overnight. The chip is removed and dried the next day. What will the mass of the dried marble chip be?

A. Less than 2.0 grams
B. Exactly 2.0 grams
C. Between 2.0 and 2.4 grams
D. More than 2.4 grams

Question 5: ACID RAIN

Difficulty: Partial Credit—513, Full Credit—717

Students who did this experiment also placed marble chips in pure (distilled) water overnight.

Explain why the students included this step in their experiment.

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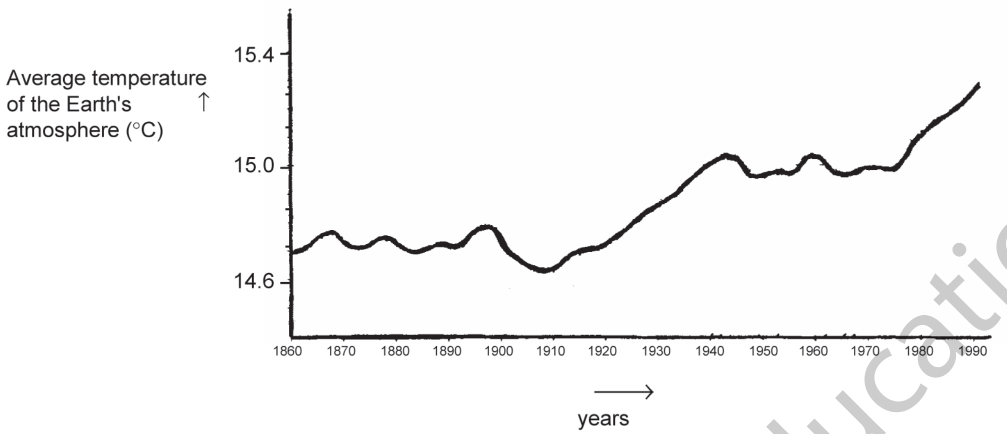

What is it about the graphs that supports André's conclusion?

Question 4: GREENHOUSE

Difficulty: Partial Credit—568, Full Credit—659

Another student, Jeanne, disagrees with André's conclusion. She compares the two graphs and says that some parts of the graphs do not support his conclusion.

Give an example of a part of the graphs that does not support André's conclusion. Explain your answer.

Question 5: GREENHOUSE

Difficulty: 709

André persists in his conclusion that the average temperature rise of the Earth's atmosphere is caused by the increase in the carbon dioxide emission. But Jeanne thinks that his conclusion is premature. She says: "Before accepting this conclusion, you must be sure that other factors that could influence the greenhouse effect are constant."