Shell Education

Effective Teaching in Today's Classroom

Teaching Science Today

2nd Edition

Kathleen Kopp

Foreword by Alan McCormack

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Foreword

Our ability to compete as a nation depends on knowledge, ingenuity, and a growing menu of intellectual skills. Scientific literacy is now paramount in a complex, competitive world and this demands excellence in our nation's science education. We desperately need fresh approaches to science education that fuse the Next Generation Science Standards, Common Core Standards, and major efforts to develop higher-order thinking skills in all of our students. Our 21st Century society and its supporting economy need to be refocused on up-to-the-minute scientific knowledge, innovation, and creativity.

It is widely known that there is an achievement gap between U.S. students and their international counterparts. American students fare poorly on international assessments such as the Programme for International Student Assessment (PISA). These assessments measure more than just mastery of memorized information—they assess higher-order thinking and problem-solving, which has been a stumbling block for our U.S. students. There is an important point here: Countries that do well on the PISA tests tend to demonstrate greater increases in Gross Domestic Product (GDP) than counties that perform less well.

In recent decades, our industrial economy has shifted to a service economy driven by need to use information and innovative skills rather than carry out repetitive manufacturing tasks. We now have a new, globally-connected economy, and companies have changed their modes of operation. Technology displaces workers with low-level skills who perform routine tasks. On the other hand, the new technology rewards workers with higher-level skills, enabling them to be more creative and productive. Workers need be able to respond flexibly to complex problems, work amicably in cooperative teams, deal with complex data, communicate effectively, and produce new ideas.

In *Teaching Science Today*, Kathleen Kopp elaborates the current need for retooling U.S. science education, noting the societal and economic changes mentioned above. She proposes that teachers of science at all grade levels incorporate the exciting new foci now revitalizing teaching and learning of science. She builds a strong case for the need for scientific literacy, aiming for commonplace skills among citizens to understand and evaluate science information as presented by the media, and be able to apply knowledge of human use of soils, water, air, and energy in sustainable ways. A scientifically literate society requires all citizens to be able to process scientific information and use it to make sound decisions regarding everyday personal life and world-changing decisions through thoughtful voting.

The author shows the key functioning of inquiry as the lifeblood of both professional science and as a primary mode for student learning of science. She guides teachers in the use of the inquiry-oriented 5E (Engage/Explore/Explain/Extend/Evaluate) Instructional Model, which has been thoroughly tested by both classroom practitioners and researchers and established as eminently effective. This approach is melded with both the New Generation Science Standards and the Common Core Standards showing how students can be inspired to be scientific problem-solvers, budding engineering designers, and also learn to better deal with information on the printed page, communicate better through writing and speaking and understand the uses or mathematics in dealing with personally-collected experimental data.

I think you will find this book to be a wonderful overview of the best current trends in science education and as a source for inspiration for making your classroom a place for joyful learning.

—Alan McCormack, Ph.D.
Professor Emeritus of Science Education
San Diego State University
Past President NSTA

Acknowledgments

I must thank my family for awarding me the time and space to put this book together for the benefit of science teachers everywhere. My two boys, Jeffrey and Christopher, are especially helpful and understanding when I drag out equipment to conduct mini-labs, clog our refrigerator with investigative samples, and go on hikes and road trips to gather scientific evidence and materials (e.g., rocks), which I use to develop engaging and meaningful lessons. These lessons I now pass onto you, the reader, for your own classroom.

This book is made possible in part because of the many teachers who are committed to providing engaging, meaningful science activities to their students in spite of time and financial shortfalls in today's schools. I enjoy teaching and learning right along with my peers. I appreciate opportunities to collaborate in my school and in my district, and on the web. I appreciate my school's support of science through the benefit of a full-time science resource teacher and the encouragement of field trips and guest speakers to spark students' interest in science. I also have had many, many opportunities to continue my own professional development in the area of science and the teaching of science. These new skills and strategies weave easily into other areas of the curriculum. With today's emphasis on reading, writing, and math, I gratefully present ideas for science teachers to support these essential areas of the curriculum. Together, teachers of all subjects can continue to move students through the 21st century and help students regain their lost ground internationally in science.

I also appreciate my community's commitment to science and scientific learning. First, thank you, Citrus County Schools, for supporting the district's Marine Science Station and Science Fair competition. Thank you, Florida, for protecting ecologically sensitive lands and supporting our State Parks system. Thank you, Southwest Florida Water Management District for sponsoring annual science-related grants. Finally, thank you to our area businesses and resident experts who eagerly visit schools and book field

trips in the name of science learning. Your care and concern to build a future of scientists surely help teachers to help students see value and gain interest in science-related topics.

—Kathleen Kopp

Introduction

Science education in the United States today needs your help. Our students are graduating from high school without understanding much about the world, and they are lagging far behind graduates in other countries in problem-solving, mathematics, and reading skills (Layton 2013). Fewer and fewer students in the United States are choosing careers in science and engineering (Hossain and Robinson 2012). The dire lack of women and minorities in science research and applications fields is concerning (Pollack 2013).

Yet, nearly all aspects of daily living today, and in the foreseeable future, require an understanding of basic and advanced science and technology concepts and skills. *What is global warming all about*? *What are stem cells, and why do scientists want to study them*? *How do I know this medicine is safe and effective*? *Should I vaccinate my child*? *What are alternative energy sources*? *Will eating a genetically modified food change my own DNA or cause me harm*? These are everyday questions asked in today's society. Who knows what questions will become imperative tomorrow, and how will we be able to answer them?

The importance of science in daily life was highlighted when a major tsunami hit several countries surrounding the Indian Ocean on December 26, 2004, resulting in nearly 230,000 deaths. One 10-year-old girl is credited with saving the lives of her family and approximately 100 tourists staying at the same hotel. When she saw the water rush out, and large waves beginning to violently return, she warned her mother that these were signs of a tsunami and that they should get off the beach immediately. Her mother quickly notified the hotel management, who evacuated the hotel and beachfront. Two weeks earlier, the girl had completed a school project on tsunamis (The Telegraph 2005). Her teacher could not have imagined this being a result of his lessons on a relatively rare phenomenon, but it illustrates the importance of teaching students facts and concepts about the world in which they live.

You will never know if one lesson, one demonstration, or one project you conduct with students will start them on the path to becoming research scientists, engineers, doctors, astronauts, storm chasers, or members of any other science-related career. However, many professionals in science can point to a single moment in time, or a single encounter with one person, that marked the beginning of a lifelong love of science. It doesn't have to be you, but it *could* be you.

To remain globally competitive, the United States needs competent, qualified scientists and engineers. In an article posted by the Center for American Progress, Donna Cooper, Adam Hersh, and Ann O'Leary acknowledge the growing share of economic output by China and India between 1980 and 2011. They explain that the commitment of these countries to education that focuses on science, math, engineering, and technology (commonly referred to as STEM) courses is "an integral part of a national economic strategy" (Cooper, Hersh, and O'Leary 2012, under "The Competition that Really Matters"). However, students in the United States continue to lag behind their global peers in the areas of science and math. The Huffington Post (2012), using evidence from a report published by Harvard University's Program on Education Policy and Governance, states that students in other countries are making academic gains two and three times the rate of students in the United States. Students in the United States ranked 29th out of 34 countries in math and science. Tomorrow's economic leaders all begin as children in classrooms. It could be *your* enthusiasm, *your* ability to provide interesting learning activities, and *your* encouragement to develop critical-thinking and problem-solving skills that will make all the difference. Maybe someday you'll meet an adult who greets you with, "Remember me? I was in your class. I became a (e.g., doctor, veterinarian, nutritionist, meteorologist, researcher, teacher) because of what I did in your classroom." Teachers can ask for no more greater reward than this.

You may be a beginning teacher, a veteran teacher, or a teacher who wants to personally enhance his or her instructional approach to teaching science concepts, skills, and processes. Regardless of who you are or where you are along your career path, by the time you finish this book, you will surely have many meaningful and engaging ideas up your sleeve to adequately and thoroughly provide science lessons to intrigue, motivate, and, teach what our students need today to be productive citizens of tomorrow.

Chapter 1

Science Education: Past, Present, and Future

> "Men love to wonder, and that is the seed of science."
>
> —Ralph Waldo Emerson

Like all topics in education, science education has experienced a swing from one extreme to the other—from exclusively text-based instruction to exclusively hands-on activity. Is any one approach better than another? What about safety issues and concerns about students' maturity levels? How do these approaches acknowledge and accommodate students with special needs or those who are English language learners? Before seeing where we are today with regard to science education, let us take a short trip through the past.

Science Then

The first mention of United States training in hands-on experiences and physical examples for teaching students (known at the time as the "object method") dates back to 1861 (Sykut 2005). The Oswego Primary Training School (at the time, an industrial arts school) was founded in this year, and these instructional methods were led by Margaret E. M. Jones from London (LaValley). With the advent of the industrial revolution, teachers readily adjusted their instructional practices to meet the needs of high-demand skills and labor. These practices were better conducted through interactive, hands-on experiences and opportunities rather than through reading about how things work in manuals.

Since the mid- to late-nineteenth century, philosophers and science advocates have been imposing their thoughts and ideas regarding science education on the American education system. Biologist and author Thomas H. Huxley and philosopher Herbert Spencer, as well as Horace Mann and John Dewey, all have had influences on education in general, including science education.

Education has been influenced by worldwide events in addition to theorists and philosophers. Fast forward to the twentieth century. The launch of *Sputnik*, the world's first artificial satellite by the Soviet Union on October 4, 1957, challenged the standing of the United States as a global leader in science and technology. That single successful launch led to two major changes in how science and technology were emphasized at the national level. The first change in the United States was the establishment of the National Aeronautics and Space Administration (NASA) in 1958. The second change, in the same year, was the passage of the National Defense Education Act (NDEA). This federal legislation was designed to increase the academic competitiveness of students in the United States in mathematics, science, and foreign languages (Siegel 1963).

As we moved into the twenty-first century, societal topics, such as global warming and deforestation, and technological advances, such as electric cars and mobile devices, surely impacted what the science teachers chose to teach. However, it wasn't until recently that science education standards have been an area of national importance. For example, the Next Generation Science Standards (NGSS) are focused on "preparing students for college and careers (2013a, 2). These standards are "goals, that reflect what a student should know and be able to do (2013a, 2)."

Along with new theories and philosophies came changes in education: what students should know, how teachers should teach, and how students learn best. Fortunately for us today, teachers and students have been exposed to a wide variety of instructional approaches and learning models through the years. Theories and philosophies have morphed into research and best-practice models. We know what to teach, we know how best to teach it, and we know how to support student learning to maximize achievement. Of course, teachers are learning more each day, but we have a good foundation upon which to build.

Today's Reality

When measuring the science skills of fourth-grade students in the United States and their peers in other countries, the *Trends in International Mathematics and Science Study* (TIMSS) revealed that students in the United States were outperformed by students in only five other countries (Singapore, Chinese Taipei, Japan, Hong Kong, and England). By the time these students reached 8th grade, their ranking dropped significantly. By graduation, these same students ranked near the bottom of all students in math and science skills (TIMSS 2011). It appears that students show an interest and propensity for learning science at a young age, but this interest and ability precipitously decline as they move through the United States educational system.

A report titled *Rising Above the Gathering Storm* was released by a committee of experts from K–12 education, higher education, research and development companies, top-ranking scientists, and members of the National Academy of Sciences (2007). This report states, "Having reviewed trends in the United States and abroad, the committee is deeply concerned that the scientific and technological building blocks critical to our economic leadership are eroding at a time when many other nations are gathering strength. We fear the abruptness with which a lead in science and technology can be lost—and the difficulty of recovering a lead once lost, if indeed it can be regained at all" (National Academy of Sciences 2007, 3).

The Program for International Student Assessment (PISA) is an international assessment coordinated by the Organization for Economic Cooperation and Development (OECD). It measures 15-year-old students from around the world in terms of reading, math, and science literacy skills. PISA collects, organizes, analyzes, and publishes the results in all these areas. PISA also includes measures of general cross-curricular competencies, such as problem solving. In 2003, PISA surveyed student knowledge and problem-solving skills of 250,000 students in 40 countries. It assigned students achievement levels based on raw scores, with levels defined by the following descriptions:

- **Level 3:** Reflective, communicative problem solvers
- **Level 2:** Reasoning, decision-making problem solvers
- **Level 1:** Basic problem solvers
- **Below Level 1:** Weak or emergent problem solvers

In the United States, 58 percent of 15-year-olds who took the test scored at or below level 1—weak, emergent, or basic problem solvers. Based on the realities of today's global workplace, economists believe that these students are the ones who will not be able to compete in an increasingly technological, highly skilled workforce. Perhaps of even more concern is how students in the United States compare to those in other countries. Of the 40 countries assessed in the PISA study, the United States, once a leader in education, ranked 29th in the percentage of students achieving levels 2 or 3 in problem-solving abilities. This suggests that current methods of education do not allow United States students to effectively learn essential problem-solving skills. The educational system we have been using since prior to World War II is not meeting the needs of students preparing to be college and career ready for the 21st century. There are many explanations for this mismatch of education and workforce skills, but the fact remains that students in the United States must gain the skills to be more competitive in tomorrow's workforce, especially with regard to problem solving. The United States answered the call by creating the Next Generation Science Standards (NGSS 2013g). These standards will help students be better prepared for the future.

Today, the United States faces a critical need for its students to begin meeting the higher levels of achievement of their global peers in science, mathematics, and problem-solving skills. Because students in the United States are underperforming in these areas, teachers can sense there is an immediate need for significant improvement in science education. The basic skills necessary for all students entering today's workforce are at the very heart of scientific investigation. One of the most important ways students can learn about science is through collaborating to tackle real-world problems. By doing so, students can gain the skills they need to analyze and apply information across the curriculum. This type of inquiry-based learning is the foundation of current science education reform.

What's New in Science Education?

The National Research Council (NRC) developed its landmark publication, the *National Science Education Standards*, in 1996. On April 10, 2012, a 26-state consortium released the *Next Generation Science Standards* (NGSS). These latest standards are based on a report generated by the NRC: *A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and*

Core Ideas. The NGSS refer to the Practices, Crosscutting Concepts, and Core Ideas as the "three dimensions."

Practices

The Science and Engineering Practices encourage teachers to think of scientific investigations as a combination of skills (abilities to perform tasks) and knowledge (information). These include the following:

- Asking Questions and Defining Problems
- Planning and Carrying Out Investigations
- Analyzing and Interpreting Data
- Developing and Using Models
- Constructing Explanations and Designing Solutions
- Engaging in Argument from Evidence
- Using Mathematical and Computational Thinking
- Obtaining, Evaluating, and Communicating Information

Crosscutting Concepts

The Crosscutting Concepts link all the domains in the core ideas. These concepts include the following:

- Patterns
- Cause-and-Effect Relationships
- Scale, Proportion, and Quantity
- Systems and System Models
- Energy and Matter: Flows, Systems, and Conservation
- Structure and Function
- Stability and Change

Core Ideas

There is no way any one teacher or series of teachers can possibly teach students every piece of scientific information. According to the NGSS Executive Summary, the goal of science education is to "prepare students with sufficient core knowledge so that they can later acquire additional information on their own" (2013a, 2). The Disciplinary Core Ideas relate to the following:

- Physical Science
- Life Science
- Earth and Space Science
- Engineering, Technology, and the Application of Science

According to the National Science Education Standards (National Research Council 1996), regardless of grade level, background, or intellectual ability, all students are expected to emerge from their thirteen years of schooling being able to "ask, find, or determine answers to questions derived from curiosity about everyday experiences… describe, explain, and predict natural phenomena… read with understanding articles about science in the popular press and to engage in social conversation about the validity of the conclusions… identify scientific issues underlying national and local decisions and express positions that are scientifically and technologically informed… evaluate the quality of scientific information on the basis of its source and the methods used to generate it… pose and evaluate arguments based on evidence and to apply conclusions from such arguments appropriately" (22).

In addition to the newly published National Science Education Standards, many states have also adopted the Common Core State Standards for English/Language Arts and Mathematics. The Common Core English/Language Arts standards include specific standards related to reading and writing in science (and other subject areas). Likewise, since scientific equipment typically requires students to measure, and investigations require simple to complex computations with whole numbers, fractions, and decimals (and all their conversions), the mathematics standards also play a part in the overall education of today's science students.

Looking Ahead

What do these standards mean for science teachers? It means that they need to prepare today's students for a much higher level of understanding of science and technology than expected in previous generations. Numerous research studies by the North Central Regional Educational Laboratory (NCREL) demonstrate that the skills today's students will need to succeed in the twenty-first century workforce are different from the skills taught in the past. NCREL states: "As society changes, the skills needed to negotiate the complexities of life also change. In the early 1900s, a person who had acquired simple reading, writing, and calculating skills was considered literate. 'Only in recent years has the public education system expected all students to build on those basics, developing a broader range of literacies' (Educational Testing Services 2002). To achieve success in the twenty-first century, students also need to attain proficiency in science, technology, and culture, as well as gain a thorough understanding of information in all its forms" (NCREL 2003, 15).

According to Stuart W. Elliott, director of the Board on Testing and Assessment at the National Research Council, "If you're a K–12 teacher, the workforce that you're influencing is one that will exist several decades into the future, not the one that exists now. You need to shift your focus into the future" (Cech 2007, under "Job Skills of the Future in Researchers"). The best way for today's teachers to accomplish this seemingly impossible mission is to maintain focus on the Next Generation Science Standards; provide opportunities for students to engage in open-ended critical analysis scientific investigations and STEM activities; and integrate technology as much as possible.

Conclusion

Science education, like other subject areas, has undergone some major shifts. Today's science teachers face the daunting task of preparing scientifically literate students in an ever-changing, technology-driven society. No one knows exactly what the future holds for students, but today's teachers can use the best research-based, educationally sound instructional practices to prepare them for an exciting future in a global society.