

enough to help others make sense of what otherwise lies beyond their reach and experience.

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EDUCATION

Inside the Schooled Mind

Elsbeth Stern

Despite the everyday use of electrical appliances and technical devices and travel by cars and airplanes, only a minority of people living today has deeper insight into the scientific foundations of modern life. As a consequence, concerted efforts have been made in many modern societies to improve the level of public education in science, technology, engineering, and mathematics (STEM) and to increase the number of university students in these fields. As part of these efforts, psychologists, educators, and researchers from STEM disciplines have collaborated in attempts to explain why the human mind so often seems impervious to conventional instruction and how these barriers can be overcome by designing learning environments that are better adapted to our cognitive functioning. *Applying Cognitive Science to Education* provides an excellent example of the contributions that scientists, provided they are willing to cross some disciplinary boundaries, can make to solving important real-life problems.

Discussing physics with laypeople, Frederick Reif (an emeritus professor of physics and education at Carnegie Mellon University and the University of California, Berkeley) found a topsy-turvy world. He was told that objects have an "internal force" of motion, conveyed to them by being pushed; that objects move because they are driven by this force; and that they finally stop moving because it gets "used up." A growing body of research literature in science education and cognitive psychology documents that such explanations (absurd as they may appear from an expert's point of view) are quite common, even among otherwise well-educated people. As Reif notes,

students may successfully complete introductory physics courses without acquiring conceptual knowledge about how the world works that is compatible with scientific physics. Many teachers are terribly disappointed when after all those lessons their students still believe in internal force as the cause of motion.

Some teachers blame their students for this failure, bemoaning a lack of intelligence, interest, or motivation. Others make desperate efforts to introduce the concepts even more systematically. They strictly keep to a logical sequence, and they present very clear and precise definitions (preferably based on mathematical formulas). When tests require students to reproduce definitions and to figure out quantitative information, performance often seems satisfactory. However, a serious lack of conceptual understanding remains, as students cannot transfer the insights they should have gained to problems that differ from those dealt with in the classroom.

What has gone wrong? Often teachers hold the "direct transmission" view of learning, according to which successful classroom practice is seen as

teachers providing information that students memorize and retell. Reif describes why such learning environments may, at best, help students accumulate facts or acquire simple skills but will not support them in building up the conceptual knowledge they need to model new and complex situations, as required in science and mathematics. He emphasizes that the main barrier that keeps students from learning science and mathematics is not so much what they lack, but what they have—namely, naïve scientific knowledge that often works well in everyday life but largely differs from and even contradicts scientific explanations.

Thus, to support students' learning, teachers must diagnose students' initial understanding of the content at hand. Knowledge not conforming to scientific views should not be dismissed as the sad result of deficiencies in previous instruction but, rather, be recognized as an inevitable step in learning. Effective teaching requires presenting students with questions and problems that stimulate processes of knowledge reorganization and thereby help them overcome their bounded or deficient beliefs. By referring to well-established cognitive theories of human information-processing, Reif

explains in detail how different kinds of knowledge can emerge through learning and under what conditions this knowledge may be recalled for problem solving. For instance, he discusses why all students have to learn the use of multiple representations for the same situations as well as the translations among these representations.

The numerous examples and the sophisticated way they are embedded in theories of cognitive science make Reif's book a veritable gold mine for all those who teach physics or mathematics at high-school or college level. They will find introductory questions for activating students' prior knowledge about standard curricular content as well as stimulating ideas for engaging students in meaningful activities, e.g., through reciprocal teaching or written self-explanations. However, the book's merits go far beyond practical advice. A broad range of academics will find *Applying Cognitive Science to Education* intellectually stimulating.

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Applying Cognitive Science to Education
Thinking and Learning in Scientific and Other Complex Domains

by Frederick Reif

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SCIENCE EDUCATION

A Handbook for Hands-On Learning

Robert A. Lue and Richard Losick

How do undergraduate students become engaged in and excited about science? For many scientists, the formative event was joining a laboratory for an inquiry-based project that had the elements of ownership and discovery. Indeed, rewarding undergraduate research experiences played a critical role in both of our career trajectories. In recent years, undergraduate research activities have grown from a cottage industry into a national movement. Programs now range from summer and term-time courses to engaging students in multiyear projects. This intense interest in undergraduate research has prompted serious thought about how young scientists should be mentored and how the effectiveness of undergraduate research programs should be assessed. Thus *Creating Effective Undergraduate Research Programs in Science*, a collection of essays edited by Roman Taraban (a psychologist at Texas Tech University) and Richard L.

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