Research Points

Summer 2007 | Volume 5, Issue 1

Essential Information for Education Policy

Science Education That Makes Sense

Demand for students with a solid foundation in science continues to grow. By 2010, jobs in science and engineering nationally are expected to increase by 2.2 million.[1] Equally important, science education needs to ready citizens who do not pursue careers in science to handle dilemmas they will face in their lives, such as selecting treatments for diseases, evaluating messages about climate change, or using new technologies.

However, current science education in the United States falls short of these goals. American students continue to languish in international comparisons of science achievement.[2] The situation only grows worse in later grades. In national assessments, U.S. students' performance becomes increasingly weaker at higher grade levels.[3]

Reversing this trend and significantly improving science achievement will require coordinated changes in science standards, curricula, laboratories, assessments, professional development, and uses of modern technologies. But as recent studies show, there is a long way to go.

- *Taking Science to School*, a National Academy of Sciences report, recommends revising standards to focus on core ideas, designing curriculum to build on students' knowledge of the natural world, and aligning assessments with understanding — in short, an overhaul of the entire system.[4]
- *America's Lab Report*, another National Academy of Sciences study, labels current science laboratories as poor for most students and recommends redesign of lab experiences to emphasize integrated instruction and coherent understanding.[5]
- *Teaching Science in Five Countries*, a video study of classroom instruction, reports that American students have less opportunity to experience conceptual links than their peers in countries that score higher on international tests.[6]
- The American Association for the Advancement of Science's *Project 2061*'s analysis of middle school science textbooks demonstrates that the instructional materials students encounter are not always presented in a logically connected way, making it difficult for them to understand the concepts being taught.[7]

Fortunately, more than 30 years of research on science learning offers sound recommendations for making these needed changes.

Published by the American Educational Research Association

Some Difficulties Are Good

Surprisingly, students do not always benefit when instructional materials make learning easier or faster. Requiring students to complete difficult tasks, such as generating a response rather than reading or responding to multiple-choice questions, slows learning but improves outcomes. Difficulties are *desirable* when students have to explain their ideas.[8] For example, when students carefully distinguish phenomena such as plant and animal respiration, they learn and remember more information.

Science learning requires integrating knowledge from disparate sources. By emphasizing explanations, science instruction motivates students to organize their own ideas and look for connections to new information. Extensive research shows that students naturally develop multiple conflicting, often confusing ideas that they must wrestle with in their everyday interactions with science. For example, students often report that plants eat dirt, objects in motion come to rest, and Earth is round like a pancake. Instruction is most effective when teachers use students' views as a starting point for investigating scientific phenomena, guiding learners as they articulate their ideas, adding evidence that stimulates students to reflect on the ideas they have developed, enabling students to learn how to distinguish among ideas, and encouraging students to seek coherent accounts of science.[9]

Questions that require students to integrate new knowledge and articulate their ideas help students learn science. They also inform teachers and instructional material designers about the strengths and limitations of the instruction.[10]

When Is Less More?

Students need time to explore science topics and test their ideas on practical, realistic dilemmas. Current textbooks, in an attempt to meet wide-ranging science standards, cover a daunting array of topics and offer students an extremely incoherent and, at times, almost incomprehensible array of facts.[11] They leave out the important connections among ideas. Fleeting coverage of multiple topics results in instructional materials that emphasize memorization more than coherent understanding of scientific concepts and lead to students' rapidly forgetting the material.

This situation is intensifying as scientific knowledge expands while instructional time stays constant or even declines. Typically, students study science infrequently in the early grades, for four years between 5th and 8th grades, and for two years in high school. During this time they need to learn biology, physics, chemistry, and earth science, along with topics that bridge these disciplines, such as biochemistry, geophysics, biophysics, and engineering. Rapid advances in scientific knowledge bring an increasing array of complex issues that compound the problem.

Compared to students in other countries, American students cover many more science topics in each grade.[12] Countries such as Japan where students regularly outperform U.S. students on international assessments implement a narrow curriculum that requires deep, integrated understanding so that students can build on foundational concepts as they integrate new ones. By designing science teaching tools that challenge students to develop coherent ideas about key science concepts, we can guarantee a deeper understanding of science and instill the practice of lifelong science learning.

Why Lifelong Learning?

Science courses do not have time to cover every important topic, so they need to instill a desire to learn more. Most students find uses for mathematics and reading every day but claim that nothing learned in science is relevant to their lives. One way to counteract this belief is to embed some science teaching in personally relevant situations — for example, exploring the role of thermodynamics in picnic cooler design.

Research shows that carefully designed experiences with real or simulated investigations can substantially improve understanding of complex ideas and lead to long-term understanding of science.[13] These experiences have the added advantage of attracting and supporting a diverse group of science learners to meet the need for an educated workforce.[14]

Successful science curricula ensure that students identify and use scientific methods. Such programs carefully guide students to gather evidence and connect findings to their existing ideas.[15] Simply providing "hands-on" science activities without careful guidance is not sufficient.[16]

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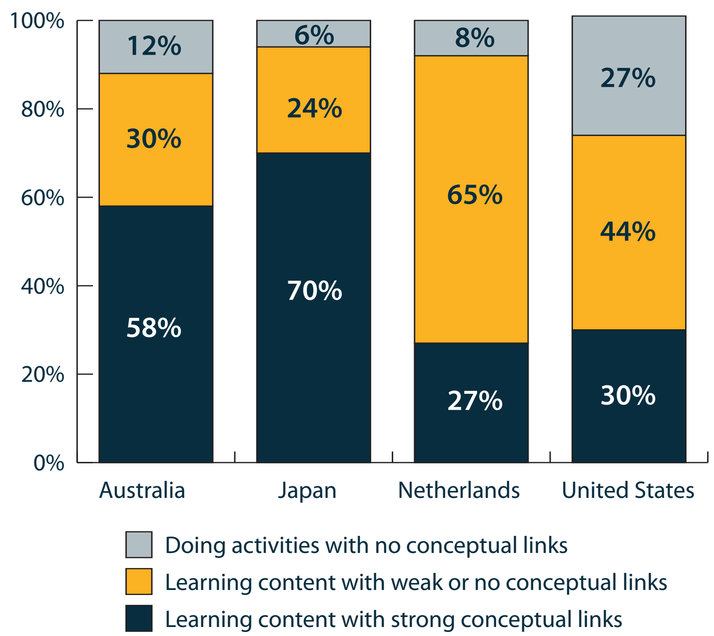
United States Focuses Less Than Other Countries on Making Connections

Students in Japan, who perform at higher levels than U.S. students on international comparisons, encounter far more activities in science class that focus on making connections among ideas, experiences, patterns, and explanations. U.S. lessons tend to focus more on acquiring information such as facts, definitions, and algorithms.

Percentage distribution of eighth-grade science lessons by focus and strength of conceptual links, by country, 1999



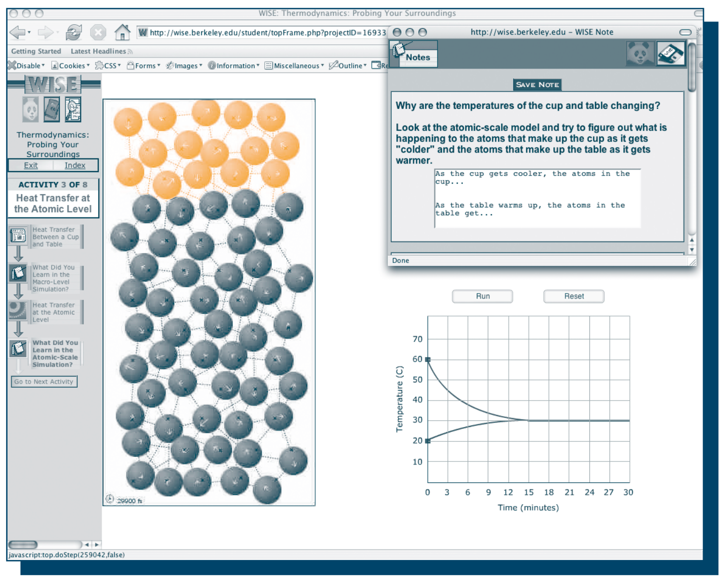
Notes: Detail may not sum to 100 because of rounding and data not reported.

Source: Adapted from Highlights from the TIMSS 1999 Video Study (NCES 2006-017). *Washington, DC: National Center for Education Statistics, p. 13. Available: http://nces.ed.gov./timss.*

Effective Visualizations Help Make Essential Connections

The Web-based Inquiry Science Environment (WISE) modules embed powerful visualizations of topics such as thermodynamics, electrostatics, and plate tectonics in mini-explorations. They guide students to explain connections among scientific ideas, conduct informative investigations, and reach scientifically valid conclusions.

Sample WISE Module



Source: Web-based Inquiry Science Environment, http://wise.berkeley.edu.

Facts at a Glance

- Questions that require students to integrate new knowledge and articulate their ideas help students learn science. They also inform teachers and instructional material designers about the strengths and limitations of the instruction.
- Requiring students to complete difficult tasks, such as generating a response rather than reading or responding to multiple-choice questions, slows learning but improves outcomes.

Visualizations Help

Using powerful technology to embed scientific visualizations in investigations can illuminate processes such as molecular interactions, mitosis, or the forces in an automobile collision. Research shows that students gain insights when they use visualizations to link situations, rather than using only text or static drawings. Such tools can help learners connect salient information to their existing ideas.[17]

Conclusion

Instruction that invites students to make sense of science by explaining complex ideas, uses the power of technology to provide a window on scientific processes, guides students to explore compelling problems, and focuses on key ideas can sustain interest in science and promote lifelong learning.

Loading students down with too many facts and insufficient connections to appreciate the power and potential of science has deterred students and frustrated teachers. This unfortunate situation results from textbooks that lack coherence, science projects that lack conclusions, and tests that emphasize recall of isolated ideas. We can do better. Science provides essential knowledge to improve on this situation right now.

- First, research indicates that slowing learning by requiring students to explain their ideas and connect scientific events can improve outcomes.
- Second, by carefully guiding scientific investigations, teachers can help students explore complex phenomena, develop confidence in their abilities to make sense of science, and extend scientific ideas beyond the classroom.
- Third, by making sophisticated use of technology, science courses can provide visualizations of complex phenomena that help students connect school science to everyday situations.

What Should Policymakers Do?

First, support policies to create curricula and develop instructional practices that focus on key topics and on teaching them in an in-depth manner. The curricula also should include enough connections showing how science affects students' everyday lives to keep students interested along the way.

Second, create an environment that provides the necessary supports to engage students in understanding, explaining, and critiquing science using effective investigative practices rather than learning isolated ideas.

Third, provide funds so that schools can use today's powerful technologies to support visualization of scientific phenomena.

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