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What Science Teaching Looks Like: An International Perspective

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The TIMSS video study shows that high-achieving countries link science learning activities to strong concept development.

How does science teaching differ from country to country? What do international comparisons tell us about how to improve science teaching and learning? Answers to these questions are available in our recent report Teaching Science in Five Countries: Results from the TIMSS 1999 Video Study (Roth et al., 2006). For this report, we analyzed information collected in the Trends in International Mathematics and Science (TIMSS) video study—the first international study to provide a detailed picture of science teaching practices.[1]

International comparisons are important because they challenge us to step outside our cultural assumptions. The report on the first TIMSS video study, which examined mathematics teaching, concluded that teaching is a cultural activity: It is learned implicitly, hard to see from within the culture, and hard to change (Stigler, Gonzales, Kawanaka, Knoll, & Serrano, 1999). Viewing videos of science teaching in different countries can help educators recognize alternative ways of teaching science and rethink their ideas about effective science instruction.

The TIMSS Video Study of Science

The video study examined teaching practices in the United States and in four countries that outperformed the United States in science achievement on the 1999 TIMSS assessment: the Czech Republic, Japan, Australia, and the Netherlands. A random sample of 100 8th grade science lessons in each of the five countries was selected to be videotaped during one school year. This process captured a range of science content and painted a picture of typical science teaching practices within each country.

Although many teaching strategies were common to all five countries, the video study revealed two major differences between the United States and the other countries. First, each of the higher-achieving countries had its own distinct core pattern of science teaching; in contrast, the U.S. lessons were characterized by variety. Second, although each country had its own approach, all of the higher-achieving countries had strategies for engaging students with core science ideas—that is, their science lessons focused on content. In U.S. lessons, content played a less central role, and sometimes no role at all; instead, lessons were usually built around engaging students in a variety of activities.

The Czech Republic: Learning Challenging Content

Lessons in the Czech Republic were filled with many science ideas and placed a premium on ensuring that students had accurate science understandings. Czech teachers exposed their students to challenging, often theoretical science knowledge and ideas. They held students accountable for understanding the material through scientifically technical and challenging public discussions.

Lessons often started with a review discussion, followed by the teacher calling individual students to the front of the class to be quizzed orally (and graded) on their understanding of multiple content ideas, not just those currently being studied. Students also presented their work publicly as the lesson progressed. Teachers used hands-on, practical activities less frequently and for shorter time periods in the Czech Republic than in the other countries studied. When students did participate in these activities, the activities were closely connected to the development of science ideas.

For example, one videotaped chemistry lesson began with an 18-minute review period in which the teacher orally quizzed the students about their understanding of a variety of topics (methods of chemical separation, air as a mixture, tests for the different gases, and chemical change versus physical change). The teacher demonstrated various mixtures and challenged students to explain them specifically and accurately. After the review, the teacher announced that the new content for that day's class would focus on the typical characteristics of molecules. As he quickly demonstrated Brownian motion, diffusion, simple and macromolecules, and colloidal versus pure solutions, students were expected to explain their observations using molecular theory. The teacher called several students to the board to draw and explain molecular representations, asking them questions that probed their understanding. The lesson ended with a summary of the topics addressed.

Japan: Using Evidence to Develop Concepts

Although Japanese lessons presented students with fewer theoretical ideas than did Czech lessons, teachers in Japan developed the science content more conceptually and coherently. A typical Japanese lesson used an inductive, inquiry-oriented approach, focusing on just one or two main ideas that were developed in depth and supported with data, phenomena, and visual representations. Thus, students had opportunities to work independently on hands-on, practical science activities that were preceded and followed by discussions that helped them link these activities to science ideas.

For example, one lesson on the videotape developed a single big idea—a change of matter from one form to another is not always a change of state (for example solid to liquid or liquid to gas). The teacher began the lesson by asking students what kind of gas they thought was produced in the previous lesson, when they had heated sodium bicarbonate. Did they think it was a gaseous form of sodium bicarbonate or something else? The teacher wrote the students' ideas on the board and stated what the lesson would investigate: What kind of change occurred when the gas was produced?

The students then worked in small groups to heat the sodium bicarbonate, test for carbon dioxide, and write conclusions. After this activity, the class discussed the lesson question. Because the tests indicated that the gas was carbon dioxide, the students concluded that the reaction was not a change of state from a solid to gaseous sodium bicarbonate. The students conducted additional experiments to support their conclusion, discussing the results of each experiment in turn. The teacher then summarized the main idea, telling the class that their work provided evidence that some type of reaction other than a change of state had taken place and that tomorrow they would continue to examine examples of such reactions.

Australia: Using Evidence and Real-Life Connections

Like their counterparts in Japan, Australian teachers frequently used scientific evidence to support ideas. Exposing students to only a few ideas enabled teachers to develop those ideas in depth, primarily through inquiry activities that built connections between the ideas and evidence. Students had opportunities to deepen their understanding of science concepts by working independently on practical tasks, often collecting data or studying phenomena that were linked to the lesson's main ideas. Australian science lessons differed from

Japanese lessons, however, in two ways. They included more real-life connections to help develop science ideas, and they used more high-interest activities—such as games, puzzles, role plays, humor, and dramatic demonstrations—to capture and hold students' attention.

In a lesson on friction and force, for example, the teacher began by posing questions that he described as having intrigued "the ancients": What is the natural state of a body? Do objects naturally come to rest or do they keep moving once they're in motion? He first elicited students' ideas about these questions, sliding objects across the table to stimulate more responses. To challenge students' thinking further, he asked about real-world examples, such as a tossed ball, a fired bullet, and a rocket in space. Although most students believed that force must be kept behind the object to keep it moving, the discussion of the rocket in space led one student to mention friction.

The teacher then introduced the lesson questions: What is friction? What determines how powerful it is? He elicited the students' ideas about these questions and then asked for examples of ways that friction is important and ways that you can maximize or minimize friction (holding a pen tightly versus loosely, using oil to make things slide more easily, and so on). The teacher challenged students to test some of their predictions about friction by devising ways of measuring force under different conditions. After this hands-on activity, the class discussed the results. In the inquiry spirit, the lesson ended with only tentative conclusions and a question to think about: How would you define the force of friction?

The Netherlands: Learning Science Content Independently

The Netherlands was unique among the five countries in expecting students to assume responsibility for their own science learning. Whereas Czech students typically talked about the understanding of science publicly with their teacher and their peers, Dutch students ordinarily learned science by working independently, often on assignments requiring them to read and write more than students in the other countries. They were also expected to monitor their own work on long-term assignments and to check their work as they progressed.

In the Netherlands, the textbook and the homework assignments largely defined science lessons' content and organization. Class discussions supplemented the text as the teacher went over the sets of assigned homework questions and responded to students' difficulties and questions. Therefore, Dutch lessons did not demonstrate the planned conceptual sequence and development seen in the Australian and Japanese lessons. However, Dutch students were continually engaged with science content ideas.

One typical lesson started with the class reviewing a homework assignment for which students had read about the structures and functions of the heart, the pulmonary blood circulation, and the systemic blood circulation. Instead of telling students about the heart in a planned presentation, the teacher wove in explanations to supplement the text as the class discussed each question that they had answered in their homework. She held up a model of the heart, comparing it with the diagrams in their textbook and challenging students to identify the parts of the heart in the model.

The introduction of new content (the pathways of blood flow) consisted of a five-minute orientation to the text that students would be reading next. The teacher briefly described some diagrams in the textbook and asked a series of questions about the heart model to help students prepare for successful reading of the text. Students were then given their next assignment and worked for about 20 minutes writing sentence-length responses to questions in their textbook. The class ended with a quick review of these questions; the teacher challenged students to elaborate on their explanations and then assigned homework.

The United States: Including More Varied Activities

Science teaching in the United States can be characterized in one word: variety. In U.S. science lessons, students worked on many different activities, with almost equal emphasis on practical, hands-on activities; independent seatwork, including reading and writing; and whole-class discussions.

High-interest activities designed to be fun and engaging to students (such as games, puzzles, humor, dramatic demonstrations, and outdoor excursions) were prominent in U.S. lessons, as was exposure to real-life issues related to the science content. Unlike the teachers in Australia and Japan, however, U.S. teachers did not typically use these various activities to support the development of content ideas in ways that were coherent and challenging for students. When they did present science content, they more commonly organized it as a collection of discrete facts, definitions, and algorithms rather than as a connected set of ideas. In contrast with Australian science lessons, for example, U.S. lessons more often mentioned real-life issues as interesting, topic-related sidebars rather than using these issues as tools for developing concepts.

Figure 1 shows that almost one-third of U.S. lessons narrowly focused students' attention on performing activities, with no attempt on the teacher's part to relate those activities to science ideas. No other country among this group engaged in nearly as large a proportion of activities with no links to concepts.

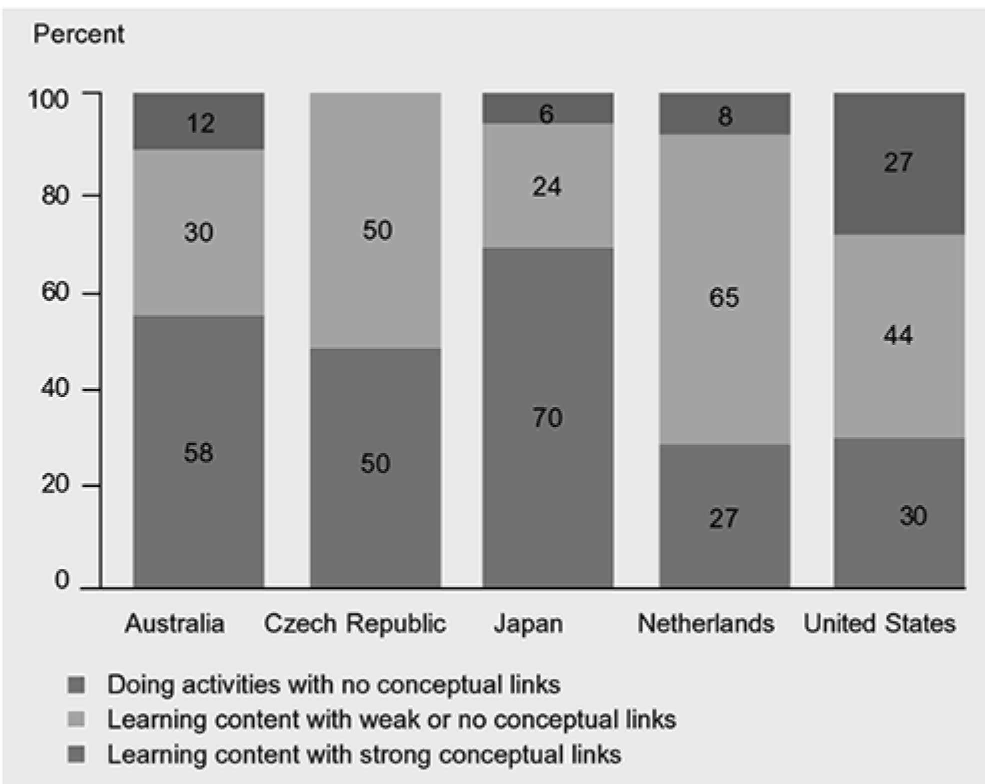

Figure 1. To What Degree Do Science Lessons Focus on Concepts?

Sometimes, the U.S. lessons contained no explicit science content at all. For example, one teacher spent the first 10 minutes of class talking about an upcoming "teamwork-building" field trip, collecting permission slips for the field trip, reading over an assignment about teamwork related to the field trip, and discussing the schedule for the launching of the students' rockets the following week. The teacher then directed students to get out their rockets and their directions for building rockets. For the next 25 minutes, the students worked individually on building the rockets, consulting with the teacher and their peers as needed for help. The lesson ended with a five-minute clean-up period. During the entire lesson, there was no mention of a single science content idea related to the rocket-building process.

Developing Content in High-Achieving Countries

These comparisons of science lessons in five countries reveal striking differences in middle school science instruction. All the higher-achieving countries in the video study shared high content standards and a content-focused instructional pattern. In Australia and Japan, for example, teachers carefully and thoughtfully developed just one or two science ideas across a lesson, presenting the ideas in a logical, coherent sequence. They expected students to understand science concepts and be able to support those concepts with specific evidence. In the Czech Republic, teachers sometimes presented content conceptually and sometimes by introducing many facts, theories, and terms related to a given topic. But in both cases, Czech teachers held their students to high standards for mastering challenging, often theoretical content through frequent oral reviews, assessments, and public student work. In the Netherlands, science content expectations were high in terms of holding students responsible for their own independent learning.

This focus on high content standards distinguished science instruction in the higher-performing countries from that in the United States, where content was often secondary to activities. Each of the other countries had a distinct instructional approach, but all of these approaches strongly focused on developing science content and connecting that content to activities, in contrast to the fragmented variety of pedagogical approaches and activities that characterized U.S. science lessons.

Improving Science Teaching in the United States

Using videotapes to place ourselves inside hundreds of 8th grade science classrooms gave us a unique opportunity to see how students in different countries experience science teaching. These observations led us to recommend potential directions for improving science teaching in the United States.

Develop a Clear, Coherent Science Content Storyline

The emphasis in the United States on hands-on inquiry activities may have overshadowed the importance of developing science content ideas as part of the inquiry process. To strengthen the science content development—the storyline—of lessons, teachers (and curriculum materials) need to focus more squarely on the science ideas in the lesson. Science teachers need to select activities to support a clearly specified learning goal and a content storyline (see "A Science Lesson Built Around a Strong Storyline," p. 23).

Through our observations of the TIMSS video study, we identified the following strategies that helped teachers create more coherent content storylines in their lessons:

- Identify one main learning goal.
- Communicate the purpose with goal statements and focus questions.
- Select content representations that are matched to the learning goal.
- Select activities that are matched to the learning goal.
- Sequence the content storyline.
- Link content ideas and activities.
- Highlight for students important ideas and links among them.
- Summarize and synthesize important ideas.

Link All Activities to Science Ideas

U.S. teachers have gotten the message that hands-on science activities are important. The next step is to help teachers learn how to select, sequence, and link those activities to content ideas so that students understand important science concepts (including ideas about the nature of scientific inquiry).

Three of the countries in this study—the United States, Japan, and Australia—often engaged students in working independently on practical activities during large portions of the lesson. The nature of the activity, however, differed across the countries. Australian and Japanese students were more likely to have a science question driving the hands-on activities, whereas U.S. students were often simply verifying knowledge or following procedures. Moreover, Australian and Japanese students typically had the opportunity to conclude a practical activity by discussing the results and drawing conclusions. This rarely occurred in U.S. science lessons. Thus, in the higher-achieving countries, teachers made the links between science ideas and activities more apparent to students.

In our current work with in-service and preservice teachers, we are using the insights gained from these international comparisons. As part of their lesson planning, these teachers explicitly think about how they will set up and follow up each activity in the lesson (hands-on or otherwise) to focus students on science ideas related to the activity, not just on procedures. In addition, teachers review each potential lesson activity and real-life issue to make sure that it matches the learning goal of the lesson and helps move the content storyline along. Teachers who use this approach comment on how much it helps them focus their science lessons. They often recognize how much they have been shortchanging this part of the planning process in the past.

Strengthen Teachers' Content Knowledge

To develop coherent, conceptual storylines for lessons and to select appropriate activities linked to those storylines, teachers need a strong understanding of the "big ideas" that they are teaching. How can teachers best develop this knowledge? The approach advanced by current federal initiatives—requiring all middle school science teachers to have a science major—has its limitations. In particular, this approach may not provide teachers with the kinds of content knowledge they need to teach science effectively (Ball, Hill, & Bass, 2005).

In our current professional development work with teachers, we are exploring a different approach. Teachers learn about science content as they analyze videos of science teaching (including their own) and examine related student work. Studies of mathematics teacher learning (Hiebert, Morris, & Glass, 2003; Mumme & Seago, 2002) suggest that learning about content in the context of analyzing teaching artifacts will make this knowledge more accessible and meaningful to teachers.

Better science curriculum materials could also support teachers in understanding the content and developing strong content storylines in their lessons. Current U.S. science textbooks are strong on presenting information and vocabulary and short on putting concepts and activities together to coherently develop big ideas (Kesidou & Roseman, 2002). In most textbooks, activities and descriptive text sit side by side on the page, but the links between the two are often vague and limited to a topic-level match.

Rethinking the Role of Content in Science Teaching

The TIMSS video study results challenge us to think more deeply about the role of science content in hands-on, inquiry teaching and to question how schools can better link such hands-on, inquiry teaching to the development of science content understandings. Those directing science education policy in the United States need to look into science professional development and teacher education programs and ask, Is our emphasis on “inquiry” unintentionally obscuring the importance of understanding science ideas?

Why I Became a Scientist

Bruce Alberts

President Emeritus, National Academy of Sciences (1993–2005)

Professor of Biochemistry and Biophysics, School of Medicine, University of California, San Francisco

“As a premed student at Harvard University, I took Chemistry I, Analytical Chemistry, Organic Chemistry, Biology I, Physics I, and so on. In my third year, I took Physical Chemistry. Although I found the content fascinating, after the first semester I could no longer tolerate the required afternoon laboratory exercises. For two and one-half years, I had spent two or three afternoons each week performing tedious cookbook exercises: Measure this, measure that, get an answer and compare it with all the answers your friends got, fudge the data so that you get the right answer, and then turn in your notebook. (Amazingly, the same boring laboratory exercises continue at most of our universities today, nearly 50 years later!)

I finally found the courage to complain: “I love Physical Chemistry, but I hate this laboratory. What can I do?” My professors told me that if I joined a research laboratory for a semester, I wouldn’t have to take the Physical Chemistry laboratory. So that spring I worked in Professor Paul Doty’s laboratory. This was completely different from the afternoon course laboratories. I discovered the excitement of science, and I forgot about medical school.”

A Science Lesson Built Around a Strong Storyline

The following lesson was conducted by a teacher working with Science Teachers Learning from Lesson Analysis (STeLLA), a three-year project funded by the National Science Foundation. The lesson starts with a question and remains focused on that question throughout. Each activity in the lesson is linked to the question and builds carefully on the previous activity.

As part of a series of lessons about photosynthesis, a 5th grade teacher identifies one learning goal for her science lesson: Students will understand that food is matter that supplies plants (and all living things) with energy to live and grow; by this definition, water is not food. She begins her lesson by saying to the students,

Yesterday we came up with many ideas about food for plants. Today we are going to examine our most popular hypothesis—water. So today’s focus question is, “Is water food for plants?”

The teacher asks students to write down their ideas about this question and to support their ideas with evidence. In the ensuing discussion, students provide examples of plants dying when they are not watered.

“So we have evidence that plants need water, but does that mean water is a food for the plant?” After some students express different opinions, the teacher asks them, “How do you define food? By your definition, is water a food?” Some students say that water is food because you need it to live; others think that only things you chew are food; still others think that water is a food for plants but not a food for people. The students then read a scientific definition of food: matter that contains energy for living things to live and grow. The teacher asks her students how that definition differs from their own. "What is a key word in this definition? Did you mention that in your own definition?"

"By this definition, is this cereal food?" (The teacher holds up a cereal box.) "How do you know that it provides energy?" After listening to student responses, she shows a food label from a cereal box on the overhead and explains how calories are a measure of food energy. The students see that the cereal contains calories and therefore must provide food energy.

The teacher asks the students to examine the nutrition label on bottles of water, which she passes out. Each group is to refer to the scientific definition of food and decide whether the nutrition label gives them any new evidence for thinking about whether water is food for plants. After the students share their ideas, they reach unanimous agreement that water is not food according to the scientific definition, but they still disagree about whether water provides energy for plants. Some students assert that "plants are different from people, and they can get energy from water somehow."

The teacher ends the lesson by saying, "Look back at what you wrote at the beginning of the lesson about our question: Is water food for plants? Do you have any new ideas? Do you want to change anything about what you wrote?" After listening to students' ideas, the teacher summarizes:

So we now know that water is not food according to the scientific definition because it does not contain energy that living things can use. We agree that water is not food for us, that it does not give us energy. But some of us still think water might provide energy for plants. We'll continue to explore that tomorrow.

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Endnote

1. The full TIMSS Video Study science report and a highlights report are available at http://nces.ed.gov/timss. In addition, a public release 5-CD set with five full lesson videos from each country, along with commentaries by the teachers and researchers, is available for purchase from LessonLab at www.lessonlab.com/bkstore (click on the Videos tab and type TIMSS in the Search Videos box).

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