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Chapter 5 Developing Science Content

Science education research and reform documents as well as standards and curriculum documents from the five countries present different views about developing content. Such views include how many content ideas are reasonable to include in a science lesson, about how best to organize content so that it is coherent and understandable to students, and about which content ideas are appropriate for eighth-grade students to understand (DeBoer 1991; Fratt 2002; Kolavova 1998; NRC 1996; Nelesovska and Spalcilova 1998). Decisions about the science content in science lessons can be influenced by a variety of sources, including educational research knowledge about how science is learned, knowledge from the science community about what content is important for all students to learn, science knowledge as represented in textbooks and curriculum guidelines, and the goals and purposes of science education as defined at the country, state/province, or local level.

Research Background

A common theme in the science education and reform literature is the tension between including a large amount of content in the curriculum or covering fewer ideas but in more depth (AAAS 1990, 1993; DeBoer 1991; Fratt 2002; NRC 1996; Schmidt et al. 1997). In this chapter, the issue of depth versus breadth of content coverage is addressed not only by looking at how many ideas are addressed in a lesson but also through an examination of the organization and coherence of that content and the level of challenge of the content, in particular in terms of its abstractness and theoretical emphasis.

Providing opportunities for students to develop connected, evidence-based scientific understandings that students can apply to make sense of a variety of phenomena is a key idea coming out of international research on science teaching and learning (AAAS 1993; Gunstone and White 1992; Minstrell 1989; Mintzes, Wandersee, and Novak 2000; Monk and Osborne 2000; Resnick 1987b; Roth 1990; West and Pines 1985; Wiggins and McTighe 1998; Wiske 1997). Some studies document that even when students are able to memorize science information successfully, they often fail to develop the kinds of connected, conceptual understandings that enable them to use this knowledge to solve new problems or to explain phenomena in their everyday experience (Anderson and Roth 1989; Anderson, Sheldon, and DuBay 1990; Anderson and Smith 1987a, 1987b; Driver, Guesne, and Tiberghien 1985; Osborne and Freyberg 1985; West and Pines 1985). In addition, research on human learning suggests that unrelated ideas hold less meaning than those that are richly interrelated

(Chi, Glaser, and Rees 1982; Larkin et al. 1980; NRC 2000; Resnick 1987b). One result of this research has been the widespread call for “less is more” in the science curriculum—covering less content in more depth and with more coherence so that students receive the support they need to develop meaningful understandings of the science content (AAAS 1990, 1993; NRC 1996, 2000).

However, critics challenge that, in practice, “less is less”—covering less content leads to a watered-down version of the science curriculum in which students learn less science (Olson 1998). Some scientists and science educators in the United States, for example, argue that the *National Science Education Standards*’ (NRC 1996) emphasis on student-driven inquiry and minimal use of specialized vocabulary guarantee “misconceptions, fragmentation, and fog rather than clarity and comprehension” (Shea 1998, p 118). They argue that depth of understanding requires knowledge about basic science concepts and specialized terminology, and that inquiry activities void of such knowledge are promoting misconceptions about the nature of science (Cromer 1998; Metzenberg 1998a, 1998b; Schultz 1998).

Country Perspectives

Standards or curriculum documents as well as reform documents from the countries in this study differ in the degree to which they emphasize content coverage versus in-depth study of selected key concepts (Australian Education Council 1994; Czech Ministry of Education 1996; Dutch Ministry of Education 1998; Martin, Gregory, and Stemler 2000; Schmidt et al. 1997). Curriculum guides in the Czech Republic, for example, emphasize canonical knowledge and contain more content specifications than standards or curriculum guides in the other nations (Czech Ministry of Education 1996). Standards and reform documents in the United States, in contrast, emphasize covering less content in greater depth (AAAS 1990, 1993; NRC 1996). This focus is consistent with critics’ description of the science curriculum in the United States as “a mile wide and an inch deep”—trying to teach too much information and lacking in depth (Schmidt et al. 1997; Schmidt et al. 2001) as well as filled with activities having little or no meaningful connections to rich scientific content (Kesidou and Roseman 2002; Moscovici and Nelson 1998). National curriculum guides in Australia also emphasize focusing science teaching on a few key scientific ideas. For example, one of the key principles for science curriculum developers in *A Statement on Science for Australian Schools* is that “[s]tudents should explore a selection of ideas in science in depth rather than cover superficially a wide range of content” (Australian Education Council 1994, p. 10).

The countries also differ in the role of national standardization. In the Czech Republic, Japan, and the Netherlands, there is a national curriculum. By contrast, curriculum guides or standards statements distributed at the national level in Australia and the United States serve only as guidelines or suggestions, and state/provincial level guidelines have more authority. The TIMSS study of curricular visions and aims showed variations in the science content in both the curriculum guides and textbooks in the participating countries (Schmidt et al. 1997). These variations are likely to be associated with the types and amount of science content observed in the videotaped lessons, as well as the organization of that content.

Chapter 5 focuses on four main questions about development of science content in eighth-grade science lessons:

- What is the source of the science content and its organization?
- How much science content is in the lesson?
- How coherent is the science content?
- How challenging is the science content?

The results presented in this chapter relate to segments of the science lesson in which teachers developed new content, went over homework, and went over assessments (as defined in chapter 3). Segments focused on reviewing previously learned knowledge are excluded because, in our observations, these activities typically cover a large amount of content quickly and without any particular organization that would make the content coherent. Thus, lessons with longer periods of review would be assessed as less coherent because they include review activities. For the same reason, the relatively few science lessons in which the entire lesson was devoted only to review, with no time allocated to developing new content, going over homework, or going over assessments, are not included in the analyses presented in this chapter (see chapter 3, figure 3.4).

What is the Source of the Science Content and its Organization?

Several factors can influence the content in a science lesson. The amount of content, the coherence and organization of the content, and the level of challenge of the science content may be largely influenced by the organization of the textbooks or other curriculum materials being used and by national or state-level guidelines. Alternatively, the teacher may play a central role in designing the content organization of the lesson.

To identify the main source of the content organization during the eighth-grade science lessons, the videotaped lessons were analyzed to assess extent to which lesson content followed the outline of content in textbooks and worksheet pages used in the lessons. Although the content of a lesson could be organized by more than one factor, the intent of these measures was to identify the predominant source of the organization. The main sources were defined as follows:

- **Teacher:** The source of the content organization is largely determined by the teacher during the lesson. For example, the class listens to the teacher, observes the teacher, follows the teacher's directions, has discussions with the teacher, or reads teacher materials that are different from the textbook, workbook, or worksheet. The organization of the content observed in the lesson is different from that presented in the textbook, workbook, or worksheet, or there is no textbook, workbook, or worksheet used.
- **Textbook or workbook:** The teacher closely follows the content organization in the textbook or workbook by having students read from the textbook, by clarifying explanations that are in the textbook, by asking questions that are printed in the textbook/workbook, or by having students independently work through the textbook/workbook, etc.
- **Worksheet:** The class closely follows the information in a worksheet (e.g., a handout or lab protocol). A typical worksheet contains directions for how to carry out a practical activity or a

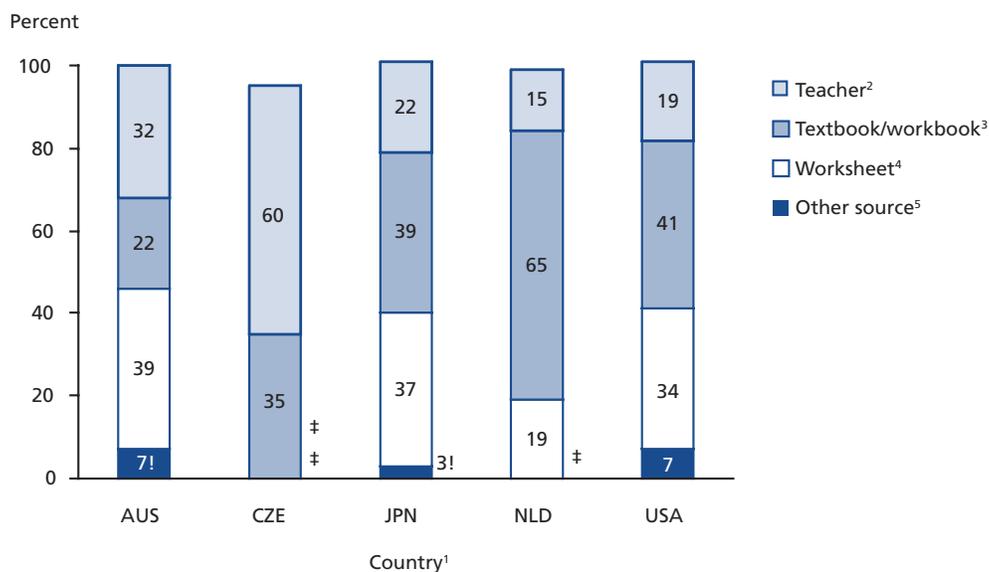
set of questions or problems for students to answer. This category was created to capture and distinguish the use of print materials that primarily guided the lesson from the use of textbooks or workbooks.

- **Other source:** The content organization comes from some other source such as the students (e.g., student presentations, students design their own experiments, or students conduct independent library research) or a video.

The percentage of eighth-grade science lessons in which the content of the lesson was influenced by the teacher, the textbook or workbook, a worksheet, and another source are presented in figure 5.1.

- The teacher influenced the content of more Czech eighth-grade science lessons (60 percent) than lessons in all the other countries, which ranged from 15 percent in the Netherlands to 32 percent in Australia (figure 5.1).
- The content of more Dutch lessons was influenced by the textbook or workbook (65 percent) than lessons in Australia, the Czech Republic, and Japan (22, 35, and 39 percent, respectively) (figure 5.1).

FIGURE 5.1. Percentage distribution of eighth-grade science lessons, by source of content and country: 1999



!Interpret data with caution.

‡Reporting standards not met. Too few cases to be reported.

¹ AUS=Australia; CZE=Czech Republic; JPN=Japan; NLD=Netherlands; and USA=United States.

² Teacher: CZE>AUS, JPN, NLD, USA.

³ Textbook or workbook: NLD>AUS, CZE, JPN.

⁴ Worksheet: No measurable differences detected.

⁵ Other source: No measurable differences detected.

NOTE: Totals may not sum to 100 because of rounding and data not reported. Lessons devoted entirely to review are not included in the analysis. See figure 3.4 for the percentages of lessons that reviewed previous content only.

SOURCE: U.S. Department of Education, National Center for Education Statistics, Third International Mathematics and Science Study (TIMSS), Video Study, 1999

How Much Science Content is in the Lesson?

Science lessons vary in terms of how much content is addressed. Lessons with fewer ideas may provide the opportunity for students to study a few ideas in depth and to develop conceptual understandings. On the other hand, lessons with more ideas may provide a strong base of vocabulary and factual knowledge that can be used to develop conceptual understanding. Lessons containing no science ideas are not likely to help students develop important science understandings at all. The science terminology spoken in a science lesson also provides opportunities for students to learn science content. Three indicators provide information about the amount of science content in the lesson: a) whether students had the opportunity to learn science content in the lesson, b) the number of publicly presented canonical ideas in the lesson, and c) the number of science terms in the lesson.

Opportunity to Learn Science Content

A first question to consider regarding the amount of content in the lesson is whether the teacher directed students' attention to learning science content knowledge at all (see chapter 4 for definitions of knowledge types). Some lessons were largely devoid of science content and focused students instead on carrying out activities or procedures. Students' opportunity to learn science content in the eighth-grade science lessons was determined using the following definitions:

- **Learning science content:** With or without the use of independent student activities, the teacher provides students with the opportunity to learn science content knowledge. The lesson may focus mainly on whole-class presentation and discussion of content knowledge or it may devote a substantial amount of time to independent activities such as student work on experiments. In either case, the teacher or the text explicitly directs students to develop and/or use science knowledge. Thus, the teacher, the textbook, or another source explicitly draws students' attention to content knowledge related to the lesson activities. If students were provided with at least some opportunity to learn science content, the lesson was categorized as providing the opportunity to learn science content. Examples of lessons focused on learning content include the following:
 - The teacher leads students through a series of simulation activities to demonstrate the relationship between population density and food supply (canonical knowledge).
 - Students work independently on a set of questions and problems about force throughout the entire lesson (canonical knowledge).
 - Students examine the pros and cons of becoming an organ donor (societal issues knowledge).
 - Students learn about fair tests and control groups, and use this knowledge to design and carry out investigations (nature of science knowledge).
- **Doing activities without the opportunity to learn science content:** The teacher provides opportunities for students to carry out science activities or procedures but does not direct or focus students' attention to learning content ideas. The activities engage students in following directions or practicing procedures without explicitly linking the activities to science content. Content may be briefly mentioned in the lesson at the topic level or as an isolated bit of information, or one or more students may develop some science content understanding in the process of carrying out an activity, but the teacher or instructional materials do not explicitly guide students to this understanding (🎥 Video clip example 5.1). Examples of lessons focused on doing activities include the following:

- Students spend the class period building rockets, following procedures supplied by the teacher.
- Students take their pulse before and after running, record their data, and graph the class results, but they are not directed to use this information to develop or support knowledge about blood circulation, about the effect of exercise, about graphical representations, or about the nature of scientific inquiry.
- Students take weather measurements, without any discussion about science content knowledge.
- The teacher directs students in organizing their science papers into a portfolio; the process does not involve discussion of science content beyond the topic level (“Put your weather maps in the next section”).

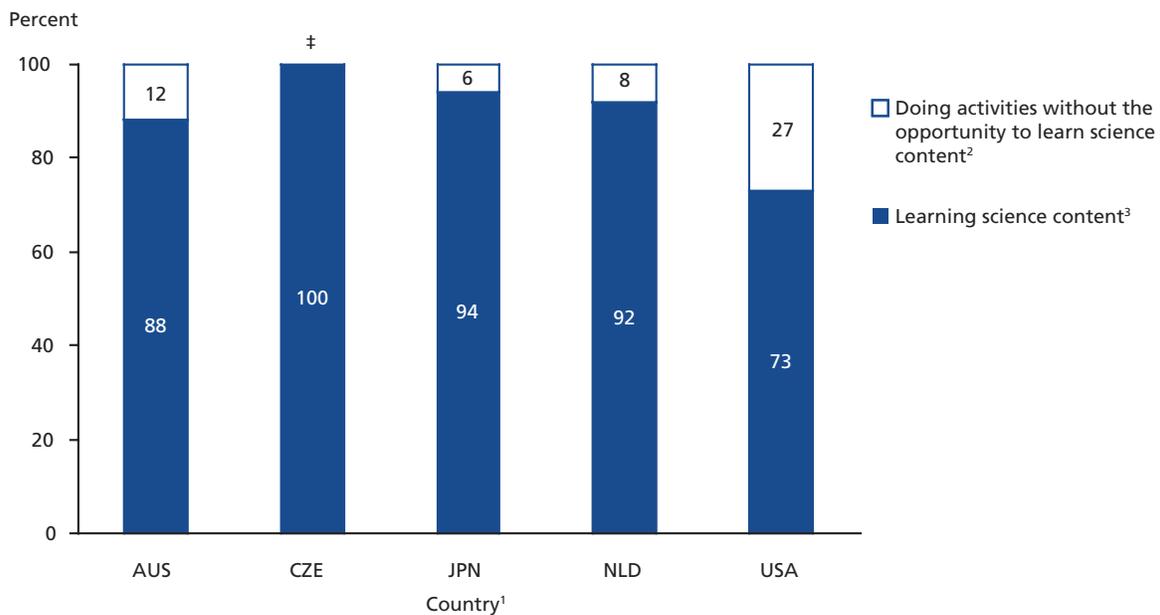
Figure 5.2 displays the percentage of eighth-grade science lessons in each country that provided different opportunities to learn science content.

- At least 73 percent of science lessons in each of the five countries provided opportunities to learn science content (figure 5.2).
- Lessons that focused on doing activities accounted for no more than 12 percent of lessons in all the countries except the United States, where 27 percent of lessons focused primarily on activities with little to no explicit linkage to content (figure 5.2).
- More U.S. science lessons focused primarily on doing activities than lessons in both Japan and the Netherlands (6 and 8 percent, respectively) (figure 5.2).

Density of Publicly Presented Canonical Ideas

The quantity of ideas presented in a lesson provides one indication of the potential coherence, challenge, and depth of science content coverage. Lessons with many ideas may provide content that is challenging for students in its complexity and level of detail, whereas lessons with fewer ideas may provide time for in-depth, challenging treatment of each idea. A lesson that moves quickly from one fact or idea to another may have less coherence and be more difficult for students to understand than a lesson that focuses on few ideas, although it is also possible that a lesson with few ideas could lack coherence and focus only on superficial coverage of the science content.

For this analysis, a public canonical idea is defined as a publicly presented statement that describes a scientific fact, concept, pattern in data, natural process, scientific model or law, or theoretical explanation (📺 Video clip example 5.2). This knowledge is canonical in the sense that it is an understanding that is generally shared by members of the scientific community. For example, a teacher draws a series circuit on the board and describes it. This public statement represents a canonical idea about the path of electron flow traveling through a series circuit. A public canonical idea can come from the teacher, the text, a video, from data collected in an experiment, from the students, etc.

FIGURE 5.2. Percentage distribution of eighth-grade science lessons that provided different opportunities to learn science, by country: 1999

‡Reporting standards not met. Too few cases to be reported.

¹AUS=Australia; CZE=Czech Republic; JPN=Japan; NLD=Netherlands; and USA=United States.

²Doing activities without the opportunity to learn science content: USA>JPN, NLD.

³Learning science content: CZE>AUS, USA; JPN>USA.

SOURCE: U.S. Department of Education, National Center for Education Statistics, Third International Mathematics and Science Study (TIMSS), Video Study, 1999.

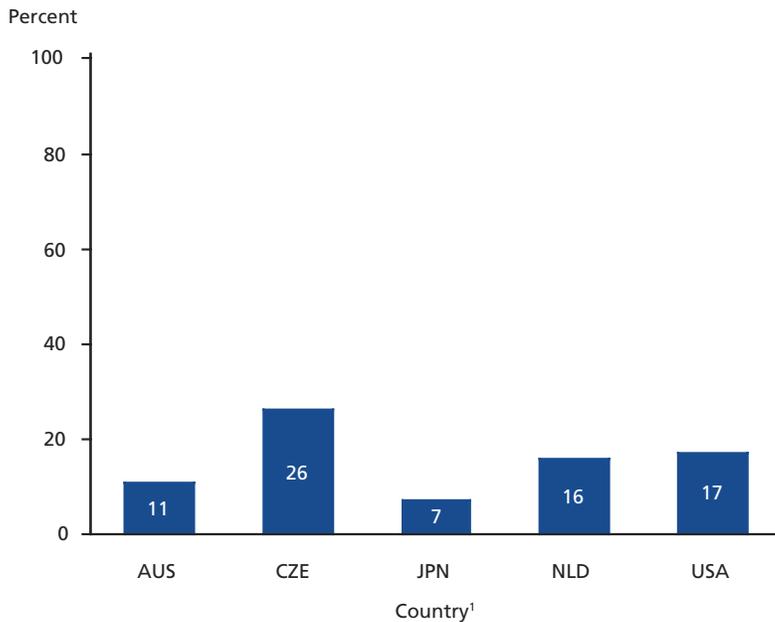
The number of public canonical ideas that are presented in a lesson provides an indication of the degree to which the lesson developed content by focusing on a few key ideas or on many ideas. A lesson with 18 ideas, for example, is more dense than a lesson with one idea.

- More eighth-grade science lessons in the Czech Republic contained a high number (at least 15) of publicly presented canonical ideas (26 percent, figure 5.3) compared to 7 percent of Japanese lessons. Japanese lessons tended to be less dense with canonical ideas.

Science Terms

- **Science terms:** A science term is defined as a one- to three-word expression (e.g., energy, photosynthesis, aneroid barometer, and relative molecular mass) with a specific scientific meaning. A count of unrepeated science terms in a lesson describes how many different terms are used in the lesson. Each term is counted only once regardless of how many times the term is repeated.
- **Highly technical science terms:** A one- to three-word expression with a specific scientific meaning that is likely to be used to support science learning in the classroom, and is not likely to be encountered by students in everyday talk (e.g., photosynthesis, magma, and ions). A count of unrepeated highly technical science terms in a lesson describes how many different highly technical terms are used in the lesson, without repetitions of the same term. Unrepeated highly technical terms are a subset of unrepeated science terms.

FIGURE 5.3. Percentage of eighth-grade science lessons that contained a high number (at least 15) of public canonical ideas, by country: 1999



¹AUS=Australia; CZE=Czech Republic; JPN=Japan; NLD=Netherlands; and USA=United States.

NOTE: CZE>JPN. A public canonical idea is defined as a publicly presented statement that describes a scientific fact, concept, pattern in data, natural process, scientific model or law, or theoretical explanation. A lesson that contains a high number of distinct publicly presented canonical ideas includes 15 or more publicly presented canonical ideas. For example, in addressing the big idea of how the digestive, respiratory, and circulatory systems work together to help all cells in the body get the energy they need, the lesson might include the names and functions of many different parts of the body as well as a description of the processes of digestion, circulation, and cellular respiration.

SOURCE: U.S. Department of Education, National Center for Education Statistics, Third International Mathematics and Science Study (TIMSS), Video Study, 1999.

Figure 5.4 presents the average number of science terms and the number of highly technical science terms that were spoken during eighth-grade science lessons. See appendix D for more information on science terms identified in the lessons.

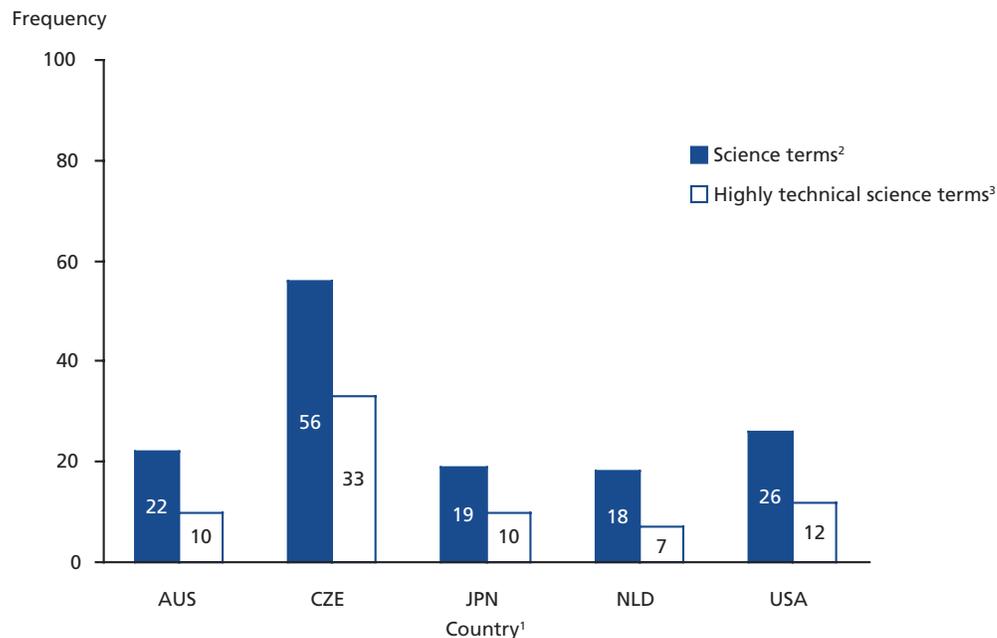
- Lessons in the Czech Republic contained more science terms and more highly technical science terms on average than lessons in all other countries (figure 5.4).

How Coherent is the Science Content?

In this section, the science lessons in the five countries are compared on three indicators of coherence that were observed in the lessons: (1) whether the pattern of content development focused on making connections or acquiring facts, definitions, and algorithms, (2) whether strong conceptual links were made among science ideas in the lesson, and (3) whether goal and summary statements were used to clarify the content organization of the lesson.

Patterns of Content Development

The participating countries were compared on observations of two primary ways teachers developed science content within the lesson: (1) making connections among experiences, ideas, patterns in

FIGURE 5.4. Average number of science terms and highly technical science terms per eighth-grade science lesson, by country: 1999

¹AUS=Australia; CZE=Czech Republic; JPN=Japan; NLD=Netherlands; and USA=United States.

²Science terms: CZE>AUS, JPN, NLD, USA; USA>NLD.

³Highly technical science terms: CZE>AUS, JPN, NLD, USA; USA>NLD.

NOTE: Analyses based on English language transcripts. The tests for significance take into account the standard error for the reported differences. Thus, a difference between averages of two countries may be significant while the same difference between two other countries may not be significant.

SOURCE: U.S. Department of Education, National Center for Education Statistics, Third International Mathematics and Science Study (TIMSS), Video Study, 1999.

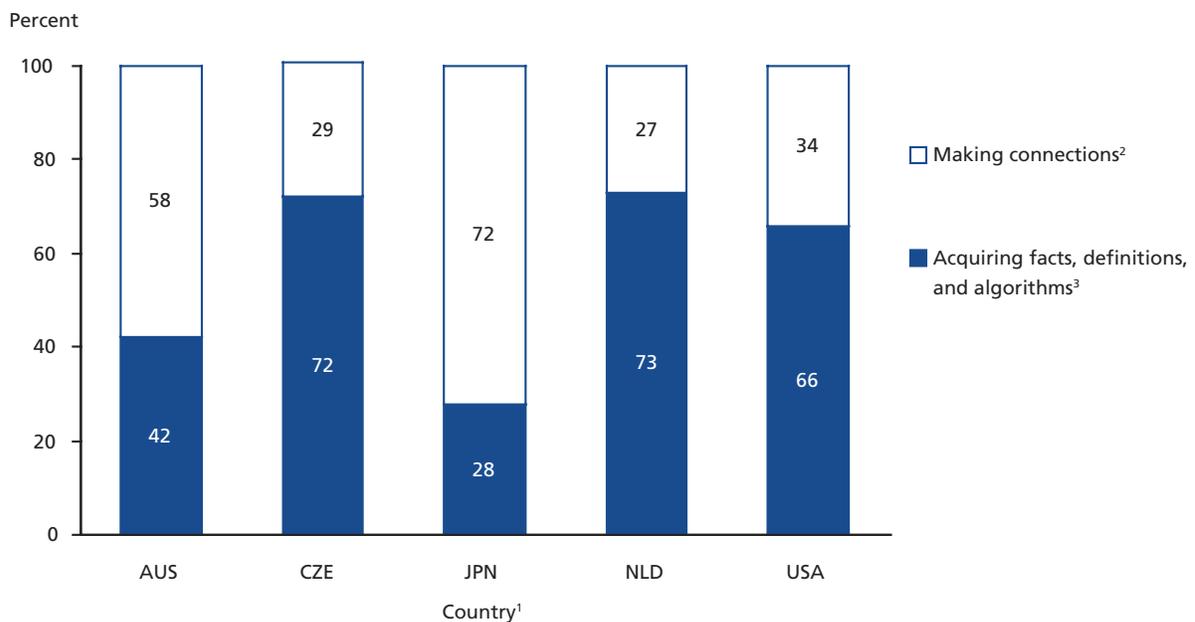
data, and explanations through pattern-based reasoning, and (2) acquiring facts, definitions, and algorithms through memorization and practice:

- **Making connections:** The primary approach of the lesson is to support students in making connections among experiences, ideas, patterns, and explanations. Teachers and/or students are engaged in pattern-based reasoning—that is, recognizing, explaining, and using patterns in data by working on such tasks as building a case or an argument to explain patterns observed in data, predicting patterns in data from scientific laws or theories, or collecting data to verify the predicted patterns. (📺 Video clip example 5.3)
- **Acquiring facts, definitions, and algorithms:** The primary approach in the lesson is to teach students a set of facts, definitions, or problem solving procedures that they will acquire primarily through memorization and practice. Problem solving is limited to following linear, step-by-step procedures. The information is presented as distinct pieces that are not organized within a larger conceptual framework that links experiences, data, and explanations.

Figure 5.5 displays the percentage of eighth-grade science lessons that primarily developed content by making connections or by acquiring facts, definitions, and algorithms.

- Within Japan, students were more likely to be in science lessons in which the content was developed primarily by making connections than in lessons with content developed by acquiring facts, definitions and algorithms (figure 5.5). Within the Czech Republic, the Netherlands, and the United States, on the other hand, students were more likely to be in science lessons in which the content was developed by acquiring facts, definitions, and algorithms than by making connections.
- Comparisons of the approach to developing content within each of the four science disciplines (excluding other areas; see figure 4.1) showed no clear relationship between the science discipline and the pattern of content development in the five countries (see table E.6, appendix E).

FIGURE 5.5. Percentage distribution of eighth-grade science lessons that developed science content primarily by making connections and by acquiring facts, definitions, and algorithms, by country: 1999



¹ AUS=Australia; CZE=Czech Republic; JPN=Japan; NLD=Netherlands; and USA=United States.

² Making connections: AUS, JPN>CZE, NLD; JPN>USA.

³ Acquiring facts, definitions, and algorithms: CZE, NLD>AUS, JPN; USA>JPN.

NOTE: Totals may not sum to 100 because of rounding.

SOURCE: U.S. Department of Education, National Center for Education Statistics, Third International Mathematics and Science Study (TIMSS), Video Study, 1999.

Types of Making Connections

The primary way in which connections were made between experiences, ideas, patterns in data, and explanations was identified in each of the eighth-grade science lessons based on the following definitions:

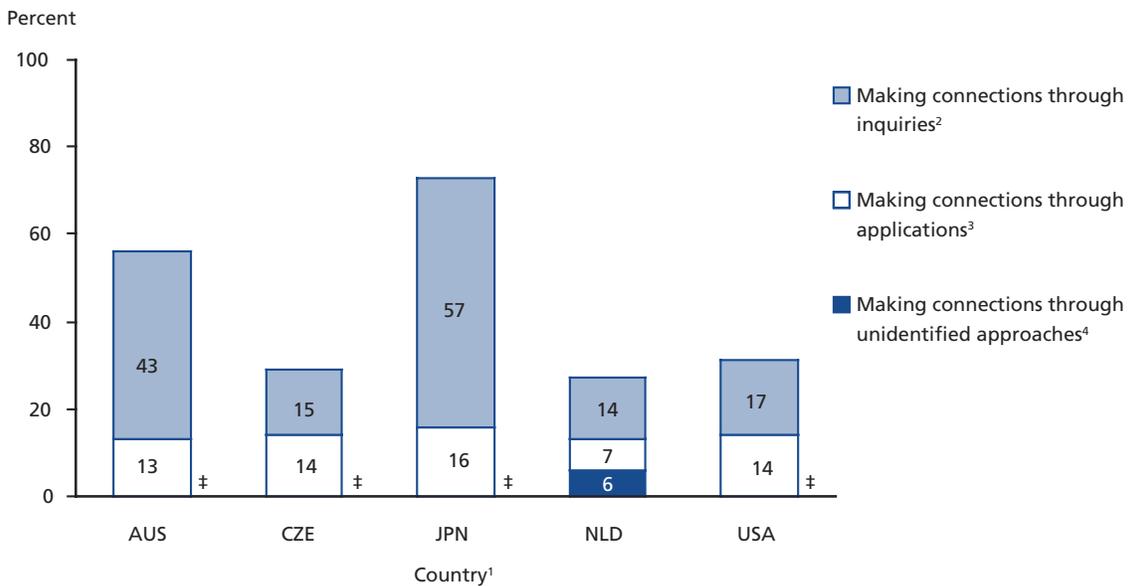
- **Inquiries:** Inductive approaches are used to construct explanations from patterns in data or experiences. The development of the science content involves posing a question, generating data, identifying patterns in the data, and constructing explanations for these patterns.
- **Applications:** Deductive approaches are used to apply scientific ideas or theories to describe, explain, or predict patterns in data or in experiences. Students first learn about the science content and then use or verify these ideas through analyses of data and experiences.

- **Unidentified approaches:** The teacher helps students make connections in a way that is not defined as primarily making connections through inquiries or primarily through applications.

Figure 5.6 displays the percentage of lessons that primarily developed science content by making connections through an inquiry or inductive approach or through an applications or deductive approach.

- Teachers in more Australian and Japanese science lessons used an inquiry or inductive approach to make connections among ideas, data, and experiences than did teachers of Czech, Dutch, and U.S. lessons (figure 5.6).
- Within Australia and Japan, more science lessons developed content by making connections primarily through an inquiry or inductive mode compared to lessons that developed content through an application or deductive mode; in the other three countries, there were no measurable differences detected (figure 5.6).

Figure 5.6. Percentage distribution of eighth-grade science lessons that primarily developed science content through various approaches for making connections, by country: 1999



†Reporting standards not met. Too few cases to be reported.

¹AUS=Australia; CZE=Czech Republic; JPN=Japan; NLD=Netherlands; and USA=United States.

²Making connections through inquiries: AUS, JPN>CZE, NLD, USA.

³Making connections through applications: No measurable differences detected.

⁴Making connections through unidentified approaches: No measurable differences detected.

NOTE: Only those lessons identified as developing science content primarily by making connections are included in the analysis. See figure 5.5 for the percentage of science lessons in each country that were coded as making connections. The unequal distribution of developing content by making connections among the five countries means that different ways of making connections will be unequally distributed among the countries as well. The analyses that follow highlight the relative emphasis of different ways of making connections within each country.

SOURCE: U.S. Department of Education, National Center for Education Statistics, Third International Mathematics and Science Study (TIMSS), Video Study, 1999.

Types of Acquiring Facts, Definitions, and Algorithms

The primary way in which facts, definitions, and algorithms were used to develop science content was also identified for each lesson. The different approaches to acquiring facts, definitions, and algorithms included: a focus on algorithms and techniques, a focus on sequences of events, a focus on discrete bits of information, and other approaches. See appendix D for further details on the types of acquiring facts identified in the lessons.

- Within the Czech Republic and the Netherlands, more eighth-grade science lessons developed content by helping students acquire facts by focusing on discrete bits of information than on algorithms and techniques or sequences of events. In the United States, lessons were as likely to focus on acquiring algorithms and techniques as on acquiring discrete bits of information. (see figure E.1, appendix E; see also  Video clip 5.4)

Conceptual Links

Conceptual links were identified as a second indicator of content coherence. The lessons were reviewed for the presence of statements or activities that organized ideas together in a conceptual framework (such as goal and summary statements, concept maps, highlighting statements, and outlines). The linking statements could be made by the teacher, supplied by the textbook or worksheet, the students, or some other source. The focus of each lesson was then categorized using the following definitions:

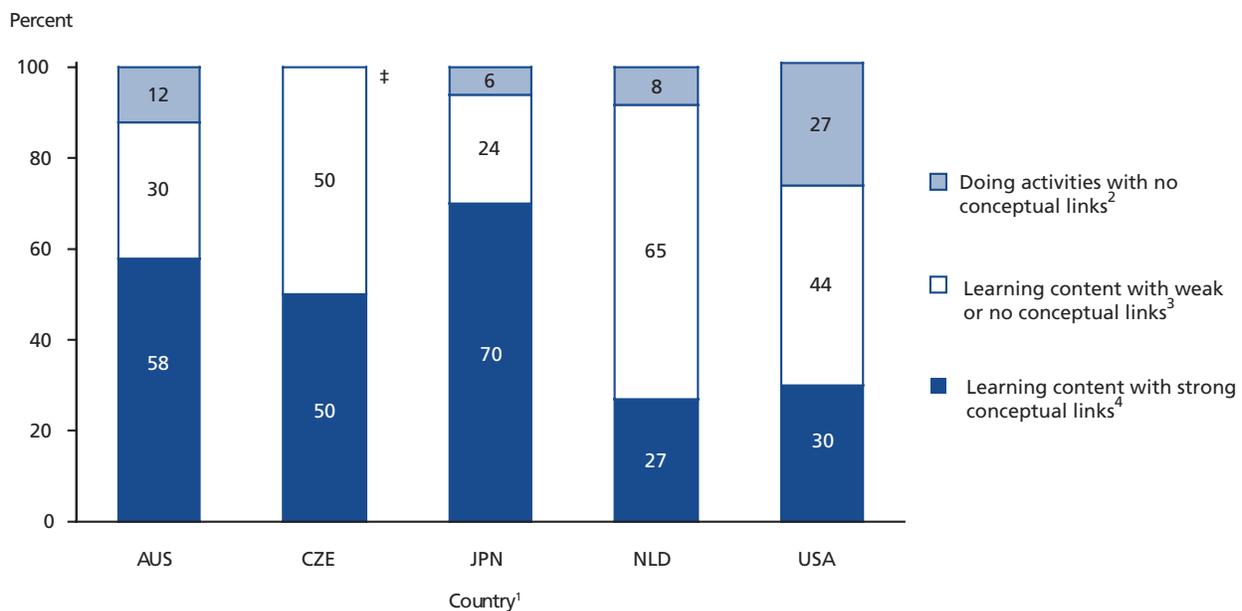
- **Doing activities with no conceptual links:** The teacher focuses students' attention primarily on carrying out an activity or a procedure rather than learning a content idea. Students may encounter some science content in the process of carrying out an activity, but the information is presented as isolated bits of information without being linked to a larger concept (see the earlier definitions associated with figure 5.2).
- **Learning content with weak or no conceptual links:** The lesson contains at least some content but there are only weak or no obvious conceptual links that integrate the information and activities. The information and tasks presented are connected only by a shared topic or by one or two concepts that tie together some of the ideas or activities but do not connect all the information together. An example of such lessons includes the following:
 - Information about the different parts of the heart and the different kinds of blood vessels and blood cells is presented. The teacher then briefly states that the heart, blood vessels, and blood cells are all part of the circulatory system and then engages students in an activity about pulse rate. The conceptual idea about the circulatory system is only briefly mentioned and is never connected to the pulse rate activity, developed further, or used by the students; it is not used as an organizing framework to tie together the ideas and activities in the lesson.
- **Learning content with strong conceptual links:** The lesson is focused on content with conceptual links that strongly connect and integrate the information and activities. The information presented consists primarily of interlocking ideas, with one idea building on another with strong conceptual links. The lesson contains a strong conceptual thread that weaves the entire lesson into an organized whole. An example of a content-focused lesson with strong conceptual links follows:

- The lesson begins with the teacher pointing to metals and nonmetals on the Periodic Table and saying: “Today we will explore the chemical differences between metals and nonmetals, and you will learn how all these metals here and these nonmetals here behave chemically in similar ways.” After demonstrating the differences in how sulfur (a nonmetal) burns compared to magnesium (a metal), the teacher instructs the students to carry out independently a series of reactions with metals and nonmetals to find patterns and common features across the different reactions. The teacher then helps students link these activities to concepts about metals and nonmetals through a discussion and interpretation of the results. At the end of the lesson, the teacher asks students to write their own conclusions, and then ends the lesson with a discussion and summary about the differences between metals and nonmetals.

Figure 5.7 presents the percentage of lessons that were judged to be activity-focused with no conceptual links, content-focused with weak or no conceptual links, and content-focused with strong conceptual links.

- More Australian and Japanese eighth-grade lessons focused on learning content with strong conceptual links compared to Dutch and U.S. lessons (figure 5.7). More Czech lessons also included content with strong conceptual links than did lessons in the Netherlands.

Figure 5.7. Percentage distribution of eighth-grade science lessons by focus and strength of conceptual links, by country: 1999



#Reporting standards not met. Too few cases to be reported.

¹ AUS=Australia; CZE=Czech Republic; JPN=Japan; NLD=Netherlands; and USA=United States.

² Doing activities with no conceptual links: USA>JPN, NLD.

³ Learning content with weak or no conceptual links: CZE>JPN; NLD>AUS, JPN.

⁴ Learning content with strong conceptual links: AUS, JPN>NLD, USA; CZE>NLD.

NOTE: Totals may not sum to 100 because of rounding and data not reported.

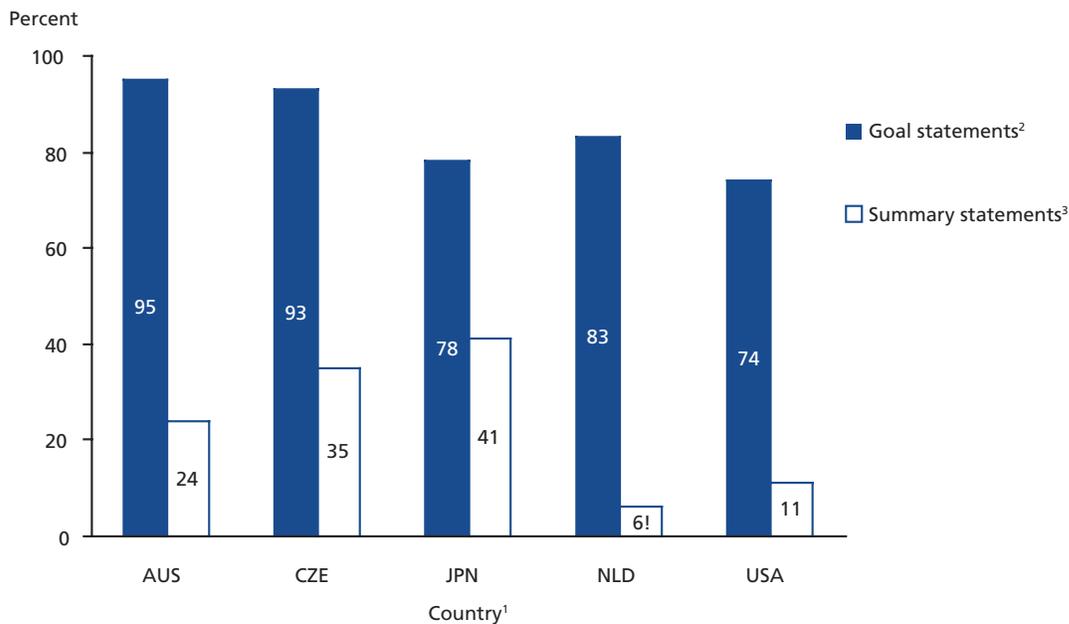
SOURCE: U.S. Department of Education, National Center for Education Statistics, Third International Mathematics and Science Study (TIMSS), Video Study, 1999.

Goal and Summary Statements

One way teachers can make the content organization of a lesson more explicit for students is by providing goal and summary statements for a lesson.

- Teachers in more Australian eighth-grade science lessons explicitly conveyed the goal of the lesson than did teachers in Japanese and U.S. science lessons (figure 5.8). Teachers in more Czech lessons explicitly conveyed the lesson goal compared to teachers in U.S. lessons.
- Goal statements in Japanese lessons were more likely to include a main idea presented as a research question compared to lessons in the Czech Republic, the Netherlands, and the United States (figure 5.9) (🎥 Video clip example 5.5).
- Goal statements that mentioned the topic only occurred in more Czech lessons compared to all the other countries and in more U.S. lessons compared to Australian and Japanese lessons (figure 5.9 (🎥 Video clip example 5.6).).
- Summary statements were more common in Czech and Japanese lessons than in U.S. lessons (figure 5.8).
- Goal and summary statements of any type occurred in more Czech and Japanese lessons than in U.S. lessons (figure 5.10).
- Both goal and summary statements included more than just naming a topic in more Japanese lessons than in Czech lessons (figure 5.10).

FIGURE 5.8. Percentage of eighth-grade science lessons with goal statements and summary statements, by country: 1999



!Interpret data with caution. Estimate is unstable.

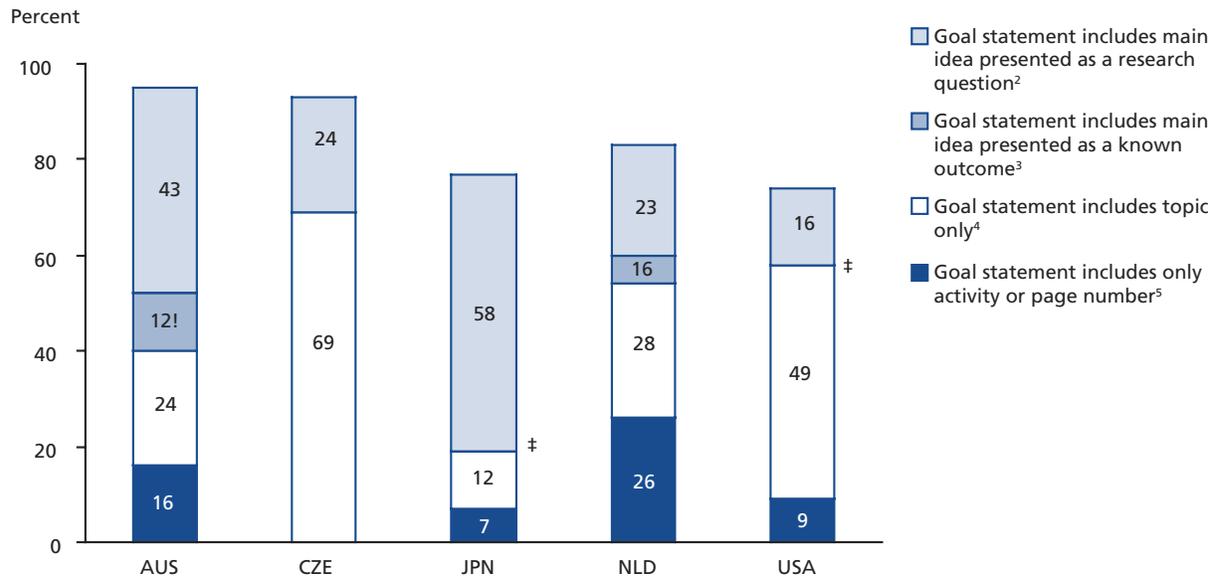
¹ AUS=Australia; CZE=Czech Republic; JPN=Japan; NLD=Netherlands; and USA=United States.

² Goal statements: AUS>JPN, USA; CZE>USA.

³ Summary statements: AUS, CZE, JPN>NLD; CZE, JPN>USA.

SOURCE: U.S. Department of Education, National Center for Education Statistics, Third International Mathematics and Science Study (TIMSS), Video Study, 1999.

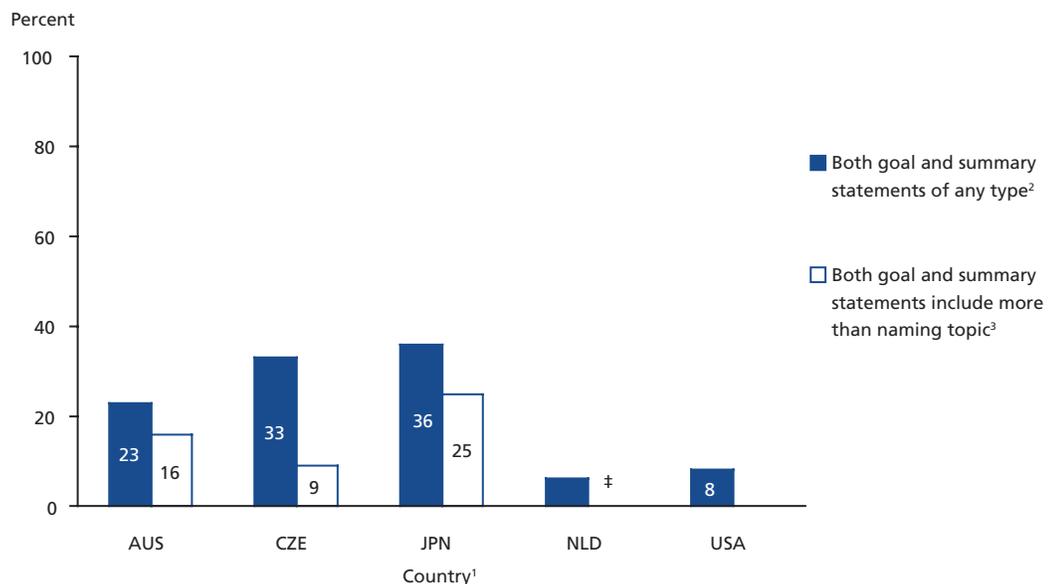
FIGURE 5.9. Percentage distribution of eighth-grade science lessons with various types of goal statements, by country: 1999



!Interpret data with caution. Estimate is unstable. Country¹
 ‡Reporting standards not met. Too few cases to be reported.
¹AUS=Australia; CZE=Czech Republic; JPN=Japan; NLD=Netherlands; and USA=United States.
²Main idea presented as a research question: AUS>USA; JPN>CZE, NLD, USA.
³Main idea presented as a known outcome: No measurable differences detected.
⁴Topic only: CZE>AUS, JPN, NLD, USA; USA>AUS, JPN.
⁵Activity or page number only: NLD>JPN.

NOTE: Totals may not sum to 100 because of rounding and data not reported. Lessons without goal statements are not included in analyses. See figure 5.8 for percentages of lessons with goal statements.
 SOURCE: U.S. Department of Education, National Center for Education Statistics, Third International Mathematics and Science Study (TIMSS), Video Study, 1999.

FIGURE 5.10. Percentage of eighth-grade science lessons with both goal and summary statements, by country: 1999



‡Reporting standards not met. Too few cases to be reported.
¹AUS=Australia; CZE=Czech Republic; JPN=Japan; NLD=Netherlands; and USA=United States.
²Both goal and summary statements of any type: CZE, JPN >NLD, USA.
³Both goal and summary statements include more than naming topic: JPN>CZE.
 NOTE: See figure 5.9 for a list of types of goal statements.
 SOURCE: U.S. Department of Education, National Center for Education Statistics, Third International Mathematics and Science Study (TIMSS), Video Study, 1999.

How Challenging is the Science Content?

The level of challenge of science content can be examined in various ways. For example, content may be judged as challenging if a lesson is dense with many canonical ideas. Using this measure, Czech lessons would appear to be more challenging than Japanese lessons, for example (see figure 5.3). But the level of challenge of the content can also be assessed in terms of the quality of the content, rather than the quantity. Two indicators are used to assess the level of challenge of the content in the eighth-grade lessons: (1) the difficulty and complexity of the ideas for eighth-grade students, and (2) the inclusion of more abstract, theoretical knowledge.

Challenging and Basic Science Content

National standards or curriculum documents on science describe content that some experts believe is appropriate for eighth graders to learn (AAAS 1993; Australian Education Council 1994; Czech Ministry of Education 1996; Dutch Ministry of Education 1998; NRC 1996). Based on the definitions in these documents, the concepts and/or procedures used to teach science in the eighth-grade science lessons were rated for their complexity and challenge to the students.

For these analyses, a science content coding team was assembled to separately evaluate each lesson (see appendix B for a list of team members). Because the lessons varied in terms of the disciplinary areas covered (e.g., biology, chemistry, geology, or physics), team members coded lessons within their disciplinary expertise for the level of challenge. When disagreements were encountered among the coding team, differences were resolved through discussion. Training and reliability checks assured consistent judgments based on the inherent complexity of the science content being taught and the level of challenge of the information for eighth graders according to a review of the curricular and standards documents from the five countries. The science content coding team achieved at least 98 percent agreement within and across pairs during the monitoring of reliability.

To code the lessons, the science content coding team followed these definitions:

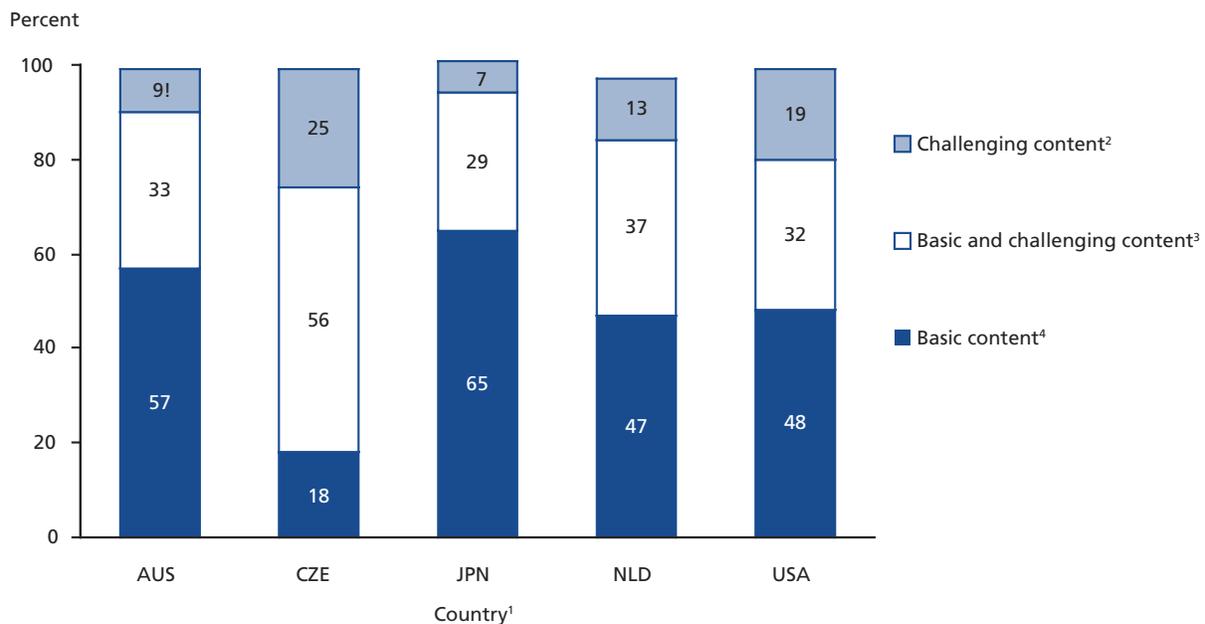
- **Challenging content:** The science information includes a substantial amount of difficult and/or complex ideas for eighth-grade students, relative to the overall information presented in the lesson. Ideas were judged as difficult if they were represented as standards or curriculum goals for students in grades or at ages above those participating in the study in the participating countries. Ideas were considered complex if they involved multiple steps or interrelated parts, if they required putting different pieces of information together, or required higher level thinking in order to be understood (🎥 Video clip example 5.7). Examples of challenging content include discussions of nuclear reactions, the role of adenosine triphosphate (ATP) in cell respiration, differences between organic and inorganic materials, oxidation/reduction reactions, balancing chemical equations, radioactivity, electromagnetic forces within atoms, heat and energy patterns inside the earth, wave theory, mathematical calculations about sound travel, and mathematical representations of Archimedes's Law.
- **Basic and challenging content:** The science information includes mostly simple and basic ideas in the overall lesson, but there are also some challenging or complex ideas for eighth-grade science. For example, a lesson on electricity may focus on presenting students with basic definitions and examples of parallel and series circuits, but also include some attention to the more challenging concept of Ohm's law.

- **Basic content:** The science information includes predominantly simple and basic ideas in the overall lesson, which are likely to be more easily understood by eighth-grade students. In a lesson containing predominantly basic science content and procedures, the teacher may discuss the physical characteristics of acids and bases (for example, acids taste sour and corrode metal; bases taste bitter and feel slippery), instruct students on how to use litmus paper, and require students to test several household liquids to determine whether they are acids or bases.

Figure 5.11 displays the percentage of eighth-grade science lessons that the science content coding team judged to contain challenging content, a mix of basic and challenging content, and basic content.

- Students were presented with predominantly basic content in 47 percent to 65 percent of the eighth-grade science lessons in all the countries except the Czech Republic (figure 5.11).
- More Czech lessons presented students with a mix of basic and some challenging content compared to Australian, Japanese, and U.S. lessons (figure 5.11).
- More Czech lessons presented students with predominantly challenging content (25 percent) compared to Japanese lessons (7 percent) (figure 5.11).
- Only in the Czech Republic were lessons more likely to present a mix or more challenging content than basic content (figure 5.11).
- Comparisons within the countries identified few instances in which the content of one science discipline was more challenging than another (see table E.7, appendix E for details).

FIGURE 5.11. Percentage distribution of eighth-grade science lessons that were judged to contain challenging content, basic and challenging content, and basic content, by country: 1999



!Interpret data with caution. Estimate is unstable.

¹AUS=Australia; CZE=Czech Republic; JPN=Japan; NLD=Netherlands; and USA=United States.

²Challenging content: CZE>JPN.

³Basic and challenging content: CZE>AUS, JPN, USA.

⁴Basic content: AUS, JPN, NLD, USA>CZE.

NOTE: Totals may not sum to 100 because of rounding. The level of challenge in the science content could not be determined in 3 percent of Dutch lessons and 1 percent each of Australian, Czech, and U.S. lessons because these lessons did not include publicly presented canonical ideas.

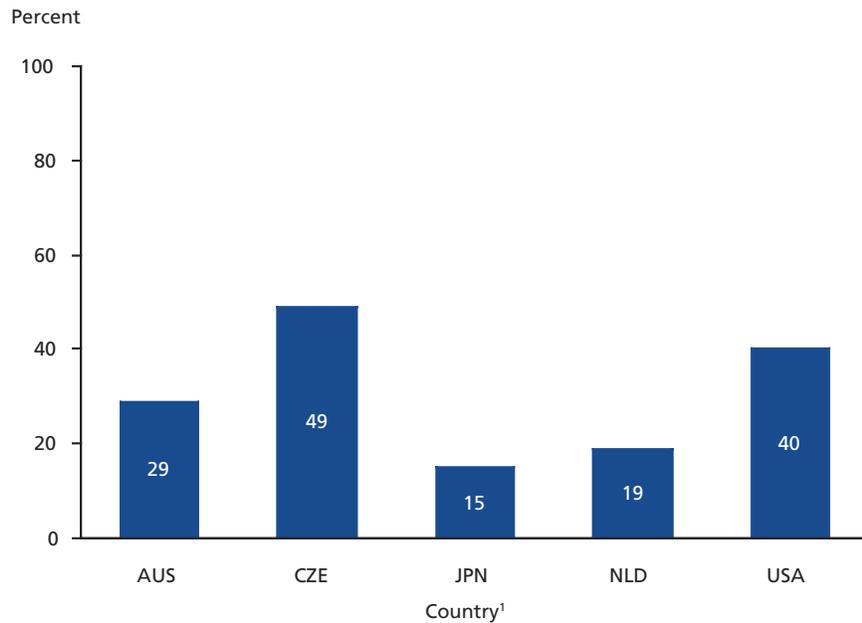
SOURCE: U.S. Department of Education, National Center for Education Statistics, Third International Mathematics and Science Study (TIMSS), Video Study, 1999.

Scientific Laws and Theories

Scientific laws and theories are publicly presented generalized explanations of patterns of data and events in the real world that have been established and more or less verified to account for known facts and phenomena. Laws and theories predict across a large range of phenomena or contexts that students cannot directly observe. Examples include Newton’s First Law of Motion, the conservation of mass, and Archimedes’ Law. Theoretical ideas include, for example, explanations of sound behavior based on the particulate theory of matter, plate tectonics and the relationship to earthquakes, and evolution (📺 Video clip example 5.8).

- Scientific laws and theories were observed being publicly presented in more Czech science lessons than in Japanese or Dutch lessons (figure 5.12). More U.S. lessons included the public presentation of scientific laws and theories than lessons in Japan.

FIGURE 5.12. Percentage of eighth-grade science lessons that publicly presented scientific laws and theories, by country: 1999



¹ AUS=Australia; CZE=Czech Republic; JPN=Japan; NLD=Netherlands; and USA=United States.

NOTE: CZE>JPN, NLD; USA>JPN.

SOURCE: U.S. Department of Education, National Center for Education Statistics, Third International Mathematics and Science Study (TIMSS), Video Study, 1999.

Summary

This chapter identified country differences in the source and organization of lesson content, the pattern of content development, the coherence of the lesson, and the level of challenge of the content. Interesting country patterns include the observation that the textbook provided the content organization in a high percentage of Dutch lessons. Australian and Japanese lessons were distinguished for organizing content in a “making connections” pattern and for using strong conceptual links to create content coherence. In contrast, over a quarter of U.S. lessons involved students in doing activities without providing the conceptual links that would enable students to have the opportunity to learn science content from these activities. Czech lessons contained more challenging content and more highly technical science terms than some of the other countries. These findings contribute important pieces in the construction of country patterns of science teaching.

6

Chapter 6 Using Evidence to Develop Science Ideas

This chapter focuses on the evidence used to develop the science content in eighth-grade science lessons. A central practice of the scientific community is supporting knowledge claims with various forms of evidence such as data, natural phenomena, and visual representations of data and phenomena (Kelly and Chen 1999; Lemke 1990). Investigating the extent to which science knowledge in the lessons is supported by various kinds of evidence provides an important picture of how science is represented in the classroom.

Research Background

A substantial body of research suggests that the use of first-hand data, observations of real phenomena, and visual representations of ideas and data may support student learning of science by providing concrete contexts and examples that help students make sense of more abstract ideas. For example, some studies have found that strategic use of data, phenomena, and visual representations can help students bridge the gap between their initial, more intuitive ideas and scientific concepts and explanations (Guzetti et al. 1993; Leach and Scott 2000; Minstrell 1982, 1989, 1992; NRC 2000; Roth 1990-91; Scott, Asoko, and Driver 1992; Sokoloff and Thornton 1997; Wandersee, Mintzes, and Novak 1994). Other research indicates that coordinating different types of evidence, such as data, phenomena, and graphical representations, may enable students to acquire scientific discourse practices (for example, identifying patterns in data, generating scientific explanations, and evaluating the fit between evidence and theory) (Lehrer and Schauble 2000, 2002; Samarapungavan 1993). Furthermore, an association between changes in students' knowledge and reasoning abilities and their opportunities to engage in these processes has been found (Lehrer and Schauble 2002; Rosebery, Warren, and Conant 1992).

Although using evidence in the classroom can provide a concrete context for science learning (Kesidou and Roseman 2002), some studies have indicated that students might fail to transfer the knowledge they learn to new situations when learning focuses too heavily on one context or one set of phenomena (Bjork and Richardson-Klavhen 1989; Cognition and Technology Group at Vanderbilt 1997; Gick and Holyoak 1983; NRC 2000). There is growing empirical support for the usefulness of multiple representations of knowledge to promote a broad transfer of learning in science and in other subject-matter learning (Ainsworth 1999; Brenner et al. 1997; Stenning 1998; Wilson, Shulman, and Richert 1987). The ability to move among

different types of representations and data sources is also an important characteristic of scientific practice (Anderson 2003; Duschl 2000; Kelly and Chen 1999; Lehrer and Schauble 2002; Lemke 1990).

Teaching a subject in multiple contexts, with multiple representations (e.g., graphs, figures, formulas, and 3-dimensional models) or multiple phenomena supporting the same idea demonstrates the connectedness of ideas and the wide applications of what is being taught, and may encourage students to develop understandings that are flexible and transferable to new situations (Brenner et al. 1997; Gick and Holyoak 1983; Posner et al. 1982). For example, students' understanding of electric current may be enhanced if they have the opportunity to see and make sense of different phenomena using variations of a simple series circuit (e.g., with one battery-one bulb-one wire, with multiple wires, with multiple bulbs, with switches, and so forth), to observe and diagram the interior of a light bulb, and to study a diagram of a light bulb. This kind of teaching may help students to make sense of key ideas and to coordinate ideas, phenomena, experiences, and data in meaningful ways (Ainsworth 1999; Anderson and Smith 1987a; Posner et al. 1982; Stenning 1998).

Country Perspectives

The stated goals of science education in each of the participating countries provide rationales for investigating the extent to which ideas are supported by evidence in the eighth-grade science lessons. Describing how data, phenomena, and visual representations are used in instructional practices informs the science education community about the extent to which these goals are being implemented.

In Australia, one stated goal is for students to use scientific language appropriately to create visual representations such as drawings and graphs. In addition, practical work in which students generate data is emphasized for its value in enabling students to “work back and forth between theoretical ideas and direct experience” (Australian Education Council 1994, p. 6). In the Czech Republic, the use of evidence to support science learning plays an integral role in both general and subject-specific goals. For example, *Didaktika*, a Czech curriculum guide (Nelesovska and Spalcilova 1998), calls for students to learn by experiencing phenomena through observations and experiments in which they generate, record, and evaluate data to find explanations for various phenomena. Czech teaching goals emphasize the importance of balance between theoretical knowledge and empirical knowledge developed through demonstrations and independent practical work (Nelesovska and Spalcilova 1998). In Japan, current secondary school reforms emphasize scientific ways of thinking, which include drawing on direct experience and observation to construct analytical and integrated points of view (Goto 2001). A goal of science education in the Netherlands is to enable students to describe and interpret phenomena from a scientific point of view. This goal includes acquiring abilities such as observing, data collecting and representing, and relating scientific concepts and skills to phenomena observable in daily life (Dutch Ministry of Education, Culture, and Science 1998; Schmidt et al. 1997). Documents in the United States emphasize the need for students to engage in scientific inquiries in which they actively collect data and represent data in different forms in order to detect patterns and communicate findings to others. Teachers are encouraged to focus these inquiries predominantly on real phenomena and to use these phenomena to support conceptual understandings and to provide experiences with multiple representations, phenomena, and data sets to give students opportunities to apply new ideas in multiple contexts (AAAS 1990, 1993).

Chapter 6 focuses on two main questions:

- What types of evidence are used in the lessons?
- Are main ideas supported with multiple sets and types of evidence?

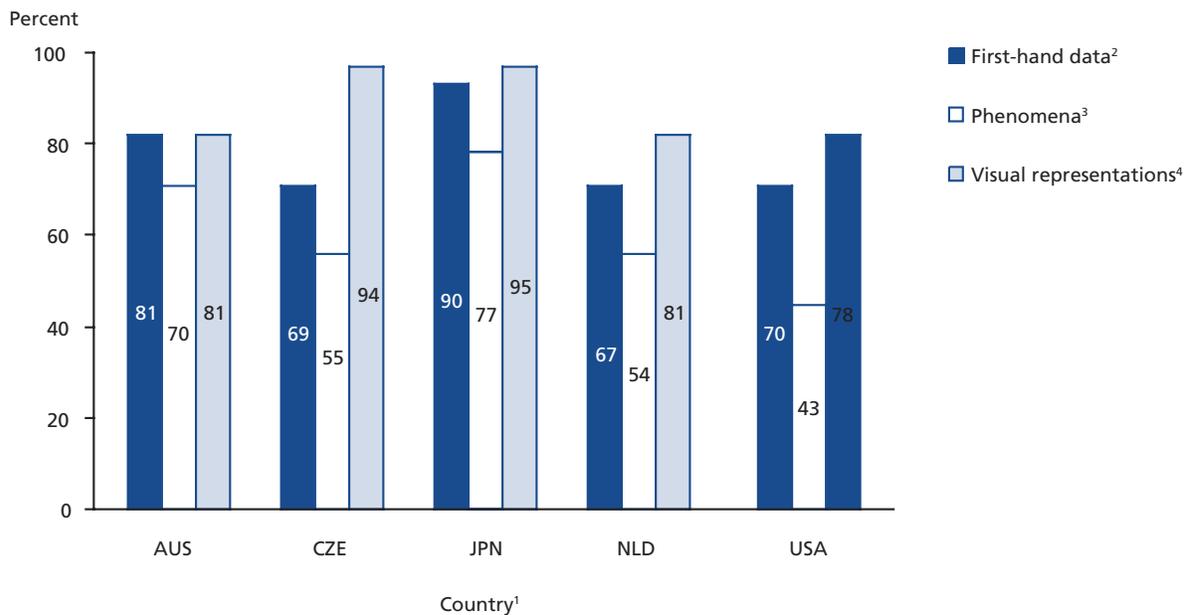
What Types of Evidence Are Used in the Lessons?

This section describes the kinds of evidence that teachers use to support the development of the science content, either publicly or privately, in eighth-grade science lessons. Three types of evidence were used to develop and illustrate the different types of scientific knowledge described in chapter 4: first-hand data, phenomena, and visual representations. These types of evidence are defined as follows:

- **First-hand data:** Observations or measurements of specific change events (phenomena) or real-world objects observed by students in the classroom. Examples include both phenomena (the sound that a tuning fork produces; the brightness of a light bulb observed by students while building electric circuits; or the air temperature in sunny and shady locations on the playground) and real-world objects (the teacher displays a jar of vinegar as an example of a common acidic substance; the teacher passes around a rock as an example of a sedimentary rock) (🎥 Video clip example 6.1).
- **Phenomena:** Change events of scientific interest that students have the opportunity to observe and/or experience. Phenomena are a subcategory of first-hand data. Except for simulated phenomena, phenomena always generate first-hand data, whereas first-hand data can be produced without the occurrence of observable phenomena in the classroom (e.g., observing different kinds of rocks). The teacher demonstrating the use of a tuning fork is an example of a phenomenon, with the change in sounds being the “change event.” Other examples of phenomena include the teacher melting ice in a glass so that students can see condensation appear on the sides of the glass, or students observing a pea plant at different stages of development to learn about plant growth. Phenomena are commonly produced by the teacher or students through first-hand observations; however, phenomena may occur through simulated experiences as well (🎥 Video clip example 6.2).
- **Visual representations:** Visual images that provide compact descriptions or drawings to illustrate real objects, data, processes, or procedures. Visual representations often include words along with some kind of organizing framework to help students imagine or better understand the real object, process, or procedure. For example, students observe a diagram, a 3-dimensional model, or a photograph of a human heart, rather than an actual heart. The diagram can include arrows and words that help students visualize the process of blood flow. Thus, the visual representation highlights concepts and processes as well as the object or data (🎥 Video clip example 6.3).
- First-hand data were used to develop the science content of most eighth-grade science lessons, ranging from 67 percent in the Netherlands to 90 percent in Japan (figure 6.1).
- Japanese lessons were more likely to include first-hand data to support science ideas than lessons in the Czech Republic and the Netherlands (figure 6.1).

- Observations of phenomena were incorporated into more Japanese science lessons than in the science lessons of the other countries except Australia (figure 6.1).
- Visual representations were incorporated into most science lessons, from 78 percent of U.S. lessons to 95 percent of Japanese lessons (figure 6.1).
- Visual representations were used more often than phenomena within all the countries except in Australia (figure 6.1).

Figure 6.1. Percentage of eighth-grade science lessons that incorporated at least one instance of first-hand data, phenomena, and visual representations, by country: 1999



¹AUS=Australia; CZE=Czech Republic; JPN=Japan; NLD=Netherlands; and USA=United States.

²First-hand data: JPN>CZE, NLD.

³Phenomena: AUS>USA; JPN>CZE, NLD, USA.

⁴Visual representations: JPN>AUS.

NOTE: The tests for significance take into account the standard error for the reported differences. Thus, a difference between averages of two countries may be significant while the same difference between two other countries may not be significant.

SOURCE: U.S. Department of Education, National Center for Education Statistics, Third International Mathematics and Science Study (TIMSS), Video Study, 1999.

Types of Visual Representations

Five distinct types of visual representations were observed as incorporated into the lessons: three-dimensional (3-D) models, graphic representations, diagrams, formulas, and other visual representations.

- Diagrams were used more often in Japanese lessons than in the lessons of any of the other countries except the Czech Republic (see figure E.2, appendix E).
- Formulas were used more often in Czech science lessons than in the lessons of any of the other four countries (figure E.2, appendix E) and 3-D models were used more often in Czech lessons than in Japanese (5 percent) and U.S. lessons (see figure E.2, appendix E).

- Countries did not differ on the use of graphic representations which were used in 36 percent of the lessons in the Netherlands to 53 percent of the lessons in Australia (see figure E.2, appendix E).
- Teachers in Czech lessons were more likely to present eighth-graders with multiple distinct types of visual representations compared to the other four countries. Seventy-three percent of Czech science lessons used at least two types of visual representations, and 36 percent included at least three types of visual representations (data not shown). In all the other countries, 40 to 47 percent of the lessons used at least two types of visual representations and 7 to 11 percent used at least three types of visual representations.

Are Main Ideas Supported with Multiple Sets and Types of Evidence?

This section of the chapter describes to what extent the science content in the lesson was supported with multiple instances of evidence in the form of first-hand data, phenomena, or visual representations. As described in the introduction to this chapter, numerous studies indicate that the use of multiple examples, phenomena, and representations of ideas may be linked to increased understanding of science ideas and ability to transfer learning to new situations (Ainsworth 1999; Brenner et al. 1997; Lehrer and Schauble 2000; Minstrell 1989, 1992; Rosebery, Warren, and Conant 1992; Roth 1990-91; Stenning 1998). The opportunity to examine different ways of supporting and representing ideas may help students see the usefulness of science ideas in different contexts, thus allowing for deeper understanding (Hewson and Hewson 1984; Posner et al. 1982; Roth 2002).

Main Ideas

To portray accurately how teachers develop and support science content with multiple instances of evidence, it is of most interest to identify all the evidence used to support the same science idea. To achieve this, the evidence used to develop and support each individual main idea related to science knowledge was identified in each lesson. Main ideas were defined as follows:

- **Main idea:** A main idea was defined as a set of related information that includes ideas, procedures, activities, and/or other types of knowledge that are explicitly connected by the teacher, text, or instructional materials. A main idea explicitly combines smaller, related ideas and activities that are developed by the teacher or worked upon by the students at some length (not just a quick reference). A main idea can be developed during public and private interactions, and it can address any type of science knowledge described in chapter 4 (canonical, procedural, societal issue, safety, and nature of science).

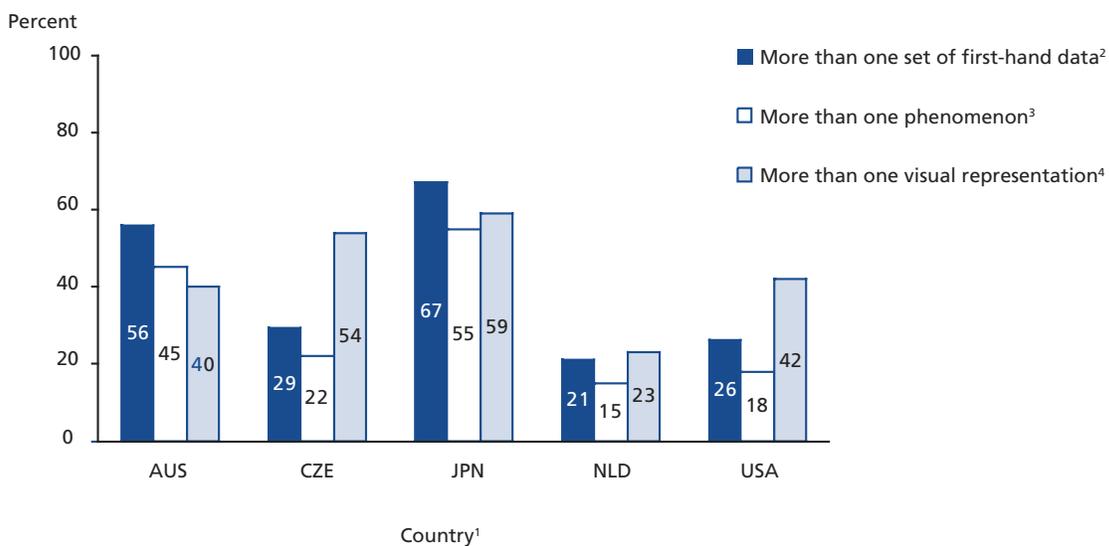
In a lesson with one main idea, all of the ideas and activities in the lesson are explicitly related to each other. In a lesson with two or more main ideas, there are no explicit connections made between any of the main ideas.

Multiple Sets of the Same Type of Evidence

Countries were compared on percentages of lessons in which teachers developed all main ideas with more than one set of first-hand data, more than one phenomenon, and/or more than one visual representation (figure 6.2).

- In Australia and Japan, more eighth-grade science lessons incorporated multiple sets of first-hand data and multiple sets of phenomena to support all of the main ideas than in the science lessons of the other three countries (figure 6.2).
- More Czech and Japanese lessons supported all of the main ideas with multiple visual representations compared to lessons in the Netherlands (figure 6.2).
- Czech and U.S. science lessons more often used visual representations to support all of the main ideas than first-hand data or phenomena (figure 6.2).

Figure 6.2. Percentage of eighth-grade science lessons that supported all main ideas with more than one set of first-hand data, phenomena, and visual representation, by country: 1999



¹AUS=Australia; CZE=Czech Republic; JPN=Japan; NLD=Netherlands; and USA=United States.

²More than one set of first-hand data: AUS, JPN>CZE, NLD, USA.

³More than one phenomenon: AUS, JPN>CZE, NLD, USA.

⁴More than one visual representation: CZE, JPN>NLD.

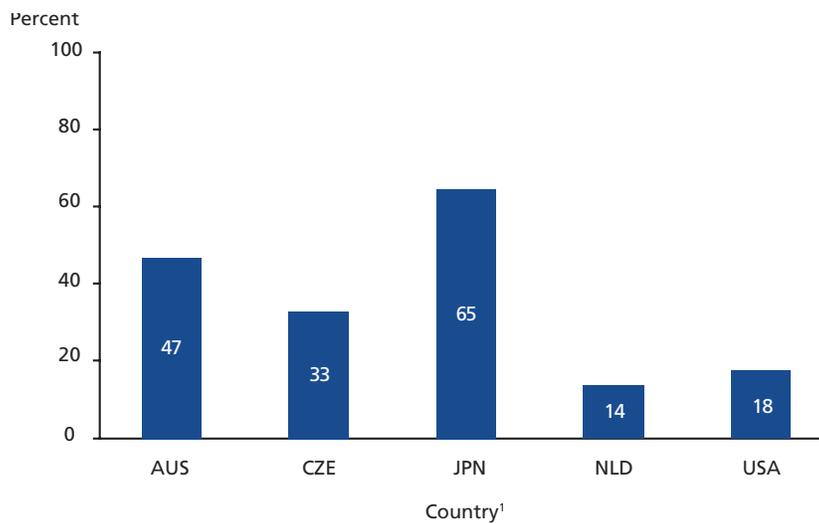
SOURCE: U.S. Department of Education, National Center for Education Statistics, Third International Mathematics and Science Study (TIMSS), Video Study, 1999.

Multiple Types of Evidence

Figure 6.3 displays the percentage of eighth-grade science lessons in which all of the main science ideas were supported with three distinct types of evidence: first-hand data, phenomena, and visual representations. That is, each main idea was supported by at least one example of each type of evidence.

- More Japanese science lessons used all three types of evidence (first-hand data, phenomena, and visual representations) to support main ideas than the science lessons in the other four countries (figure 6.3).
- Australian lessons were more likely to incorporate all three types of evidence to support all main ideas than Dutch and U.S. lessons (figure 6.3).

Figure 6.3. Percentage of eighth-grade science lessons that supported all main ideas with first-hand data, phenomena, and visual representations, by country: 1999



¹AUS=Australia; CZE=Czech Republic; JPN=Japan; NLD=Netherlands; and USA=United States.

NOTE: AUS>NLD, USA; CZE>NLD; JPN>AUS, CZE, NLD, USA.

SOURCE: U.S. Department of Education, National Center for Education Statistics, Third International Mathematics and Science Study (TIMSS), Video Study, 1999.

Summary

The findings presented in chapters 5 and 6 describe instructional practices designed to develop science content in eighth-grade science lessons (chapter 5) and to support science content ideas with evidence (chapter 6). While first-hand data, phenomena, and visual representations were used in many lessons across all the countries, a higher percentage of Japanese lessons included phenomena, supported all main ideas with more than one phenomenon, and supported all main ideas with more than one set of first-hand data than all of the other countries except Australia. More Japanese lessons also supported each main idea with all three types of evidence than all the other countries.

Portraying how teachers develop science knowledge through cohesive lessons and challenging content, and support science ideas with concrete and varied evidence informs us about the content students have the opportunity to learn. This picture lays the groundwork for understanding how students learn science, but it does not describe how students actively work on this content when they participate in “doing” science. The next five chapters explore ways in which students were engaged in doing science work during the lesson, starting with an examination in chapter 7 of the opportunities provided for students to engage in hands-on, practical and science inquiry activities.

7

Chapter 7 Doing Inquiry with Practical Activities

This chapter examines the ways in which students in the eighth-grade science lessons were engaged in science through participation in practical activities and through the use of various science inquiry practices. Chapter 3 defined practical activities as opportunities for students to observe and/or manipulate science-related objects, and described the amount of time spent on such practical activities. Practical activities provide students with the opportunity to observe and/or interact first-hand with objects and related phenomena. They include both traditional laboratory experiments and other hands-on interactions with objects such as producing and observing phenomena, building models, designing and testing technological solutions to problems, classifying materials, and drawing observations of objects. As discussed in Chapter 3, practical activities can be carried out independently by students working in small groups or individually. They also can occur during whole-class interactions, typically when the teacher performs a demonstration for the entire class to view and discuss together. This chapter explores the nature of these practical activities.

Inquiry practices describe scientific actions that students are asked to do in relationship to their practical activities. The facets of the science inquiry process included in this analysis focus on students' work with first-hand data and phenomena:

- asking questions to investigate;
- designing procedures for investigation;
- making predictions;
- gathering qualitative or quantitative data;
- making observations and recording data;
- manipulating data into graphs or charts; and
- interpreting data and linking predictions to results.

Research Background

Practical activities often are justified as important because they reflect the nature of work in the larger science community, where heavy reliance on the use of empirical evidence supports the building of knowledge (Jenkins 1999; Ntombela 1999;

Solomon 1980; Watson 2000). However, there are other reasons given for including practical activities in science lessons. Many research and reform documents suggest that the opportunity to use science inquiry actions in science classes will enhance students' understanding of both science and science inquiry processes (Assessment Performance Unit 1982, 1985; Carey et al. 1989; Harmon, Smith, and Martin 1997; Klopfer 1990; Lazarowitz and Tamir 1994; Metz 1998; NRC 1996; Schauble, Klopfer, and Raghavan 1991; White 1994). In particular, some assert that first-hand data and observations of phenomena help students to build and understand scientific concepts by making the ideas more concrete or by challenging students' experience-based but scientifically naive conceptions (Hodson 1993; Lazarowitz and Tamir 1994; Watson 2000). Others believe that practical activities stimulate and maintain student interest and engagement (Ben-Zvi et al. 1977; Henry 1975) or provide students with opportunities to practice using science inquiry skills, tools, or processes (Bryce and Robertson 1985; Hegarty-Hazel 1990; Klopfer 1990; Tamir, Nussinovitz, and Friedler 1982; Woolnough and Allsop 1985). Still others advocate for the usefulness of practical work in helping students learn to cooperate and to understand the collaborative nature of science (Beatty and Woolnough 1982; Kerr 1964; Watson 2000).

Despite the apparent widespread inclusion of practical activities in the science curriculum in many countries, critiques of practical work in science teaching abound (Millar and Driver 1987; Millar, LeMarechal, and Tiberghien 1999; Tiberghien 1999; Watson 2000). Many of the critiques of practical work point to the mixed evidence regarding the effectiveness of practical activities in helping students attain these learning goals (Gott and Duggan 1995; Harmon, Smith, and Martin 1997; Hodson 1993; Jones et al. 1992; Kempa and Dias 1990). Reviews of the literature by Hodson (1993), Sjoberg (1990), and White (1996) revealed little evidence that practical work improves student understanding of science concepts and even suggested that it is sometimes less effective than other methods (Watson 2000). In fact, many qualitative studies show that without carefully structured guidance in which teachers selectively and gradually assist students, students sometimes use first-hand data to develop ideas unintended by the curriculum (Leach and Scott 2000; McRobbie, Roth, and Lucas 1997; Roth 1990-91; Smith and Anderson 1984; Watson, Prieto, and Dillon 1995). These unintended ideas are sometimes about the nature of science. For example, students carrying out inquiry practices (e.g, predicting, measuring, and graphing) in isolation of the development of conceptual knowledge may develop the belief that science is only about observing and predicting and that these inquiry activities have no connection to the development of conceptual knowledge (Millar and Driver 1987; Roth 1990-91). Studies also raise doubts about the effectiveness of practical activities in helping students develop positive attitudes toward science (Head 1982; Lynch and Ndyetabura 1984) or in improving students' skills in carrying out practical tasks (Assessment Performance Unit 1982, 1985; Gott and Duggan 1995).

In spite of these critiques, some science educators continue to study the ways in which practical activities may be structured to achieve more success with student learning, such as involving students in first-hand inquiry activities that increase student interest and improve student understanding of the nature of science (NRC 1996; Psillos and Niedderer 2003; Schauble et al. 1995; White 1993) or increase student responsibility for their science learning by having them ask their own questions and design their own investigations (Jenkins 1999; Moje et al. 2001; Roth, W-M. 1995; Roth and Bowen 1995). Researchers are also examining the ways in which project-based, "authentic" science inquiries, such as a study of a local stream, may better support student learning (Blumenfeld et al. 2000; Krajcik 2001; Woolnough 2000). In connection with hands-on science work, many researchers

TABLE 7.1. Relative emphasis given to using laboratory equipment, performing science experiments, and designing and conducting scientific investigations of science instruction in the intended curriculum, by country: 1999

Function	Australia (AUS)	Czech Republic (CZE)	Japan (JPN)	Netherlands (NLD)	United States (USA)
Using laboratory equipment	Moderate	Minor/none	Major	Moderate	Major
Performing science experiments	Moderate	Minor/none	Major	Moderate	Major
Designing and conducting scientific investigations	Moderate	Minor/none	Major	Moderate	Major

NOTE: Data provided by TIMSS national research coordinators.
SOURCE: Martin et al. (2000). TIMSS 1999 International Science Report: Findings from IEA's Repeat of the Third International Mathematics and Science Study at the Eighth Grade. Exhibit 5.8. Chestnut Hill, MA: Boston College.

These three facets of practical work received a moderate emphasis in Australia and the Netherlands, and minor or no emphasis in the Czech Republic. The companion TIMSS 1999 Video Study generally concurs, showing that in four of the five participating countries, there is some degree of emphasis on students doing practical work independently, while in the Czech Republic there is less emphasis on such practical work (see chapter 3, table 3.5 and figure 3.7).

As previously shown in chapter 3, the eighth-grade science lessons in the countries, with the exception of lessons in the Czech Republic, allocated more instructional time for students to work on independent practical activities than on whole-class practical activities (figure 3.7). Therefore, the primary focus of this chapter is on different aspects of students' independent work on practical activities, although selected aspects of inquiry during whole-class work will be described.

Chapter 7 focuses on three main questions about student participation in practical activities and through the use of various inquiry behaviors:

- What are the features of independent practical activities?
- What science inquiry actions do students practice during independent work?
- What science inquiry actions do students practice during whole-class work?

What Are the Features of Independent Practical Activities?

Types of Independent Practical Activities

The percentages of eighth-grade science lessons that provided students with any opportunity to engage in independent practical activities presented in table 3.5 ranged from 23 percent of Czech lessons to 74 percent of Australian lessons. The proportions of instructional time over the entire science lesson spent on a single segment of an independent practical activity varied in each of the five countries, ranging from 6 to 100 percent in Australia (2 to 49 minutes), 1 to 68 percent in the Czech Republic (1 to 30 minutes), 3 to 95 percent in Japan (1 to 46 minutes), 16 to 99 percent in

support increased attention to “minds on” work in science in which students predict, analyze, represent, and interpret first-hand data to build scientific arguments and to support science ideas (Driver et al. 1994; Kesidou and Roseman 2002; Lehrer and Schauble 2000, 2002; Michaels and O’Connor 1990; Rosebery et al. 1992; Roth 2002).

Country Perspectives

Engaging students in practical work in the science classroom is addressed in all of the curricula and standards documents of the five countries in this study. The documents in all the participating countries specify that during such practical work students should learn to use science inquiry practices (AAAS 1993; Australian Education Council 1994; Czech Ministry of Education 1996; Dutch Ministry of Education, Culture and Science 1998; Goto 2001; NRC 1996). In Australia, Japan, and the United States, curriculum and standards documents emphasize students’ involvement in generating questions and designing procedures for investigating these questions (AAAS 1993; Australian Education Council 1994; Ministry of Education, Science, and Culture [*Monbusho*] 1999; NRC 1996). In the United States, the *National Science Education Standards* (NRC 1996) also include the following as abilities necessary to do science inquiry that eighth-grade students should develop: gathering, analyzing, and interpreting data; developing descriptions, explanations, predictions, and models using evidence; and communicating their inquiry work to their peers. The Australian curriculum profile identifies “working scientifically” as a major strand throughout the science curriculum, (Australian Education Council 1994). The Japanese Course of Study (Ministry of Education, Science, and Culture [*Monbusho*] 1999) prioritizes experimentation and scientific observation, with the overall objective being to enable students to “develop the capacity to undertake investigations in a scientific manner” (Goto 2001, p. 32). Dutch attainment goals include “designing tests to investigate simple problems” as a goal within the physics and chemistry strand (Dutch Ministry of Education, Culture, and Science 1998, p. 64). Czech documents put more emphasis on content learning goals, but students are also expected to learn how to conduct simple experiments and to develop skills such as observing and using scientific tools (e.g., the microscope) (Czech Ministry of Education 1996).

In addition to developing the ability to carry out scientific inquiry practices, eighth-grade students in the United States and Australia are also expected to learn about the nature of science and scientific knowledge. Nature of science learning goals described in the national standards and curriculum documents from these countries include: understanding about the importance of skepticism in science inquiry, the need to scrutinize methods used in investigations, and the provisional and incomplete status of scientific knowledge (AAAS 1993; NRC 1996; Australian Education Council 1994).

Data from the TIMSS 1999 achievement study indicate that the goals described in these documents are reflected in the intended eighth-grade science curriculum in both Japan and the United States. These curricula placed a major emphasis on three aspects of practical work—involving students in performing science experiments, using laboratory equipment, and designing and conducting scientific investigations (table 7.1; data from Martin et al. 2000).

the Netherlands (5 to 42 minutes), and 3 to 95 percent in the United States (1 to 67 minutes). The unequal distribution of independent practical activities observed among the five countries (see table 3.5, chapter 3) means that lesson features that may be related to practical activities (e.g., conducting experiments, posing research questions, interpreting results) are likely to be unequally distributed among the countries as well. In order to keep the overall analysis on independent practical activities in perspective, the analyses that follow are shown to highlight the relative emphasis of particular features of practical activities within each country.

During the eighth-grade science lessons collected for this study, students were observed engaging in the following types of practical activities:

- **Create models:** The activity requires students to design and make models or prototypes. Models may be designed for the purpose of illustrating scientific principles. For example, students may be asked to use materials to build a model of a cell, or they may be asked to use materials to demonstrate one of Newton's Laws. Alternatively, models or prototypes may be built for the purpose of testing a design to see if it will work better than another design. For example, students may design and build hovercrafts and then race them to see which design is fastest.
- **Display or classify objects:** The activity requires students to learn how to present an object, or set of objects, to display certain features of it clearly. For example, students carry out a dissection to show the parts of the circulatory system in a frog or organize a set of rocks into categories (📺 Video clip example 7.1).
- **Use tools, procedures, and science processes:** The activity requires students to practice using a scientific instrument or to master a scientific procedure. The main focus is on learning the procedure or science process skill rather than on generating data to be used to support idea development. For example, students learn how to use the microscope or to carry out a filtration procedure.
- **Conduct an experiment:** The activity is a traditional controlled scientific experiment or "fair test" that involves making comparisons of a control and a test case. An independent variable is manipulated to have an effect on a dependent variable, while controlling all other relevant variables. For example, students may conduct an experiment to determine if the temperature of water rises faster when heating water alone, when heating water with copper in it, or when heating water with gold in it. Observations of phenomena are a key part of a controlled experiment.
- **Produce or observe phenomena:** The activity requires students to produce or observe phenomena that are not part of a controlled experiment. For example, students observe a series of chemical reactions and, for each one, describe evidence that a chemical reaction has taken place. Or students may use batteries, bulbs, and wires to build a circuit that will enable a bulb to light (📺 Video clip example 7.2).

Table 7.2 presents the percentage of eighth-grade science lessons by the different types of independent practical activities described above.

- Producing or observing phenomena during one continuous segment of science instruction time was the most common type of independent practical activity observed in the science lessons of the five participating countries (table 7.2).

TABLE 7.2. Percentage distribution of eighth-grade science lessons in which students performed various types of independent practical activities, by country: 1999

Student activity	Country				
	Australia (AUS)	Czech Republic (CZE)	Japan (JPN)	Netherlands (NLD)	United States (USA)
Created models ¹	3!	‡	‡	‡	7
Displayed or classified objects ²	5!	‡	‡	‡	7!
Used tools, procedures, and science processes ³	8	3!	‡	4	3
Conducted an experiment ⁴	8	‡	‡	5!	‡
Produced or observed phenomena ⁵	50	16	65	21	26

!Interpret data with caution. Estimate is unstable.

‡Reporting standards not met. Too few cases to be reported.

¹Created models: No measurable differences detected.

²Displayed or classified objects: No measurable differences detected.

³Used tools, procedures, and science processes: No measurable differences detected.

⁴Conducted an experiment: No measurable differences detected.

⁵Produced or observed phenomena: AUS, JPN>CZE, NLD, USA.

NOTE: Totals may not sum to percentage of lessons with independent practical activities because of rounding and data not reported. See table 3.5, chapter 3 for total percentage of lessons with independent practical activities.

SOURCE: U.S. Department of Education, National Center for Education Statistics, Third International Mathematics and Science Study (TIMSS), Video Study, 1999.

Setting Up Independent Practical Activities

Set-Up Talk

To help students undertake practical activities independently, teachers may set up the activities with discussions about how the activity will proceed, or what the purpose of the activity is, for example. When teachers include such discussions, students may be asked to generate hypotheses, be provided with theoretical background information, or be given instructions for completing the activity. In order to understand how science teachers prepared students for the independent practical activities, each lesson was examined for the following characteristics:

- **No set-up talk:** The teacher provides no explicit discussion of the nature or purpose of the practical activity prior to its commencement. For example, the teacher gives students a set of written procedures and immediately sends them off to work independently.
- **Primarily procedures:** The teacher primarily discusses with students the procedures to be followed during the practical activity. Ideas are mentioned at the topic level only or are focused only on how to use tools or how procedures and equipment worked.
- **Mix of procedures and ideas:** The teacher discusses both procedures and the idea(s) that relate to the main purpose of the independent practical activity. Discussion of ideas exceeds simply naming the topic or stating the goal of the activity. For example, prior to a practical activity in which students will investigate whether saliva plays a chemical or a physical role in digestion, the teacher leads a discussion about differences in starch and sugar molecules and reviews the differences between physical and chemical changes (🎥 Video clip example 7.3).

Figure 7.1 displays the percentage of eighth-grade science lessons in which the teacher set up the independent practical activities in different ways.

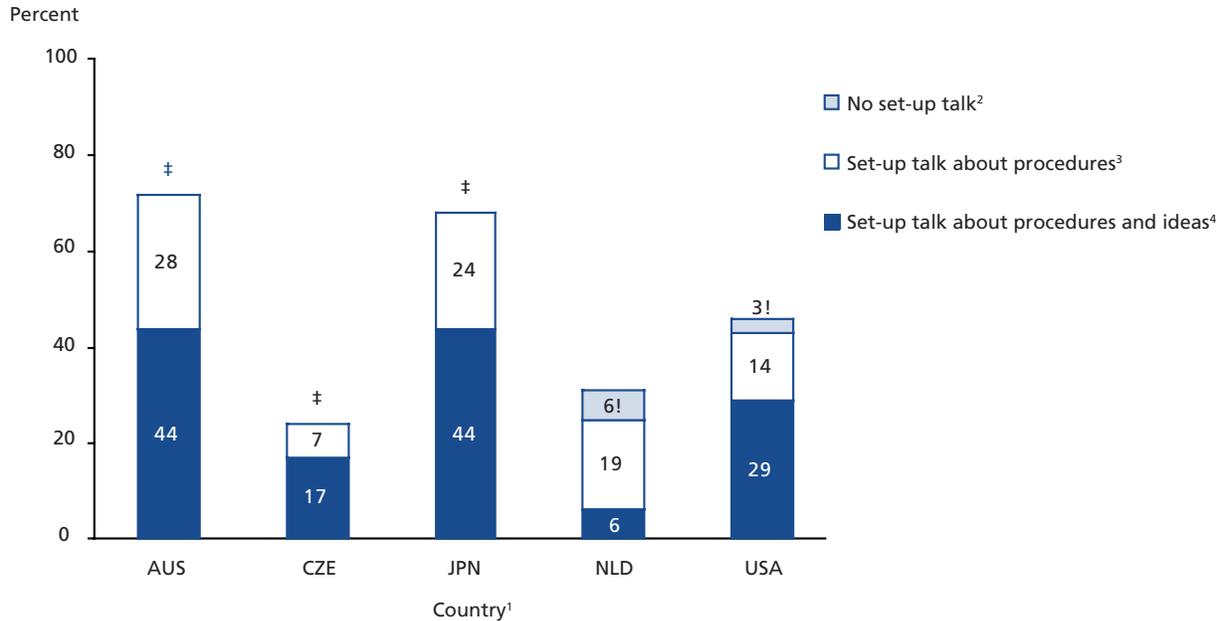
- Preparation for the independent practical activities in the eighth-grade science lessons involved discussions of procedures in all five countries (figure 7.1).
- Japanese and Australian eighth-grade science lessons more often included discussions of both procedures and the ideas of an independent practical activity than Czech and Dutch lessons (figure 7.1).
- Dutch lessons more often set up independent practical activities through discussions of procedures only than both discussions of procedures and ideas. In contrast, more Japanese lessons set up independent practical activities with both ideas and procedures (figure 7.1).

Purpose of the Practical Activity

Another way students were prepared for independent practical activities was through explanations about the purpose, or learning goal, of the activity. This was done in three different ways:

- Verifying knowledge: The teacher, text, or worksheet communicates the scientific knowledge, fact, or idea that will be demonstrated through the practical activity. For example, a teacher may

FIGURE 7.1. Percentage distribution of eighth-grade science lessons in which the teacher explicitly set up an independent practical activity, by country: 1999



! Interpret data with caution. Estimate is unstable.

† Reporting standards not met. Too few cases to be reported.

¹ AUS=Australia; CZE=Czech Republic; JPN=Japan; NLD=Netherlands; and USA=United States.

² No set-up talk: No measurable differences detected.

³ Set-up talk about procedures: AUS>CZE.

⁴ Set-up talk about procedures and ideas: AUS, JPN>CZE, NLD; USA>NLD.

NOTE: Totals may not sum to percentage of lessons with independent practical activities because of rounding and data not reported. See table 3.5, chapter 3 for total percentage of lessons with independent practical activities.

SOURCE: U.S. Department of Education, National Center for Education Statistics, Third International Mathematics and Science Study (TIMSS), Video Study, 1999.

explain to students that light travels in straight lines, using the practical activity to “demonstrate that this is true.” Or the teacher may review the formula for density and then have students practice calculating the densities of a various objects by collecting data about their mass and volume (🎥 Video clip example 7.4).

- Following procedures: The teacher, text, or worksheet identifies an observation, measurement, or procedure that will be conducted through the practical activity but does not state why students will be making these observations, or measurements (e.g., there is no knowledge outcome to be verified and no question to be investigated). For example, a teacher may tell students that they will “measure the current in a series circuit” or “observe different kinds of rocks” (🎥 Video clip example 7.5).
- Exploring a question: The teacher, text, or worksheet poses a main question or idea that students will explore through the practical activity (the intended learning outcome is unknown to students). For example, a teacher may explain to students that in the practical activity they “will measure current to determine if there are differences between series and parallel circuits” (🎥 Video clip example 7.6).

Figure 7.2 presents the percentage of eighth-grade science lessons in which the teacher, text, or worksheet oriented students to the purpose of a practical activity.

- Teachers of Japanese and Australian science lessons were more likely to present a question as the purpose of a practical activity than teachers of Czech and U.S. lessons (figure 7.2).
- Students more often were provided with a question to explore than with knowledge to be verified within Australian lessons (figure 7.2).
- Within U.S. lessons, students were more often provided with knowledge to be verified than with a question to be explored (figure 7.2).

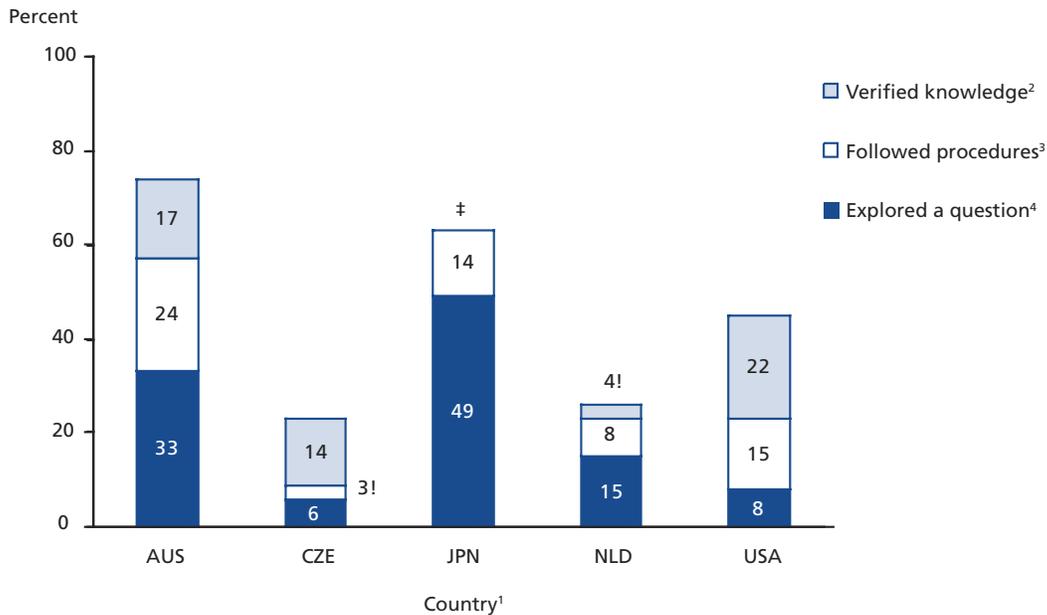
Following up Independent Practical Activities

Discussion of Results

Following the independent practical activities in the eighth-grade science lessons, the class could engage in public discussions of the results of the activities. When discussions are held, some might focus only on the data and observations (🎥 Video clip example 7.7) while others might focus on making interpretations and drawing conclusions. Multiple conclusions could be raised or mentioned without emphasizing or linking them together to draw a larger, overarching conclusion. In other cases, the class could discuss how the outcomes of the practical activity were connected to and supported a single main conclusion or idea (🎥 Video clip example 7.8). Appendix D includes a more detailed description of four types of discussion of results observed in the lessons.

- In the Netherlands, 30 percent of lessons involved students in working on independent practical activities (table 3.5), and in 25 percent of lessons the results of the independent practical activities were not discussed (figure 7.3).
- Looking within Australia and Japan, students more often engaged in discussions following independent practical activities than not (figure 7.3). In Japanese lessons, discussions about the results of practical activities were most often focused on drawing one main conclusion (figure 7.3)

FIGURE 7.2. Percentage distribution of eighth-grade science lessons in which students were oriented to the purpose of an independent practical activity, by country: 1999



! Interpret data with caution. Estimate is unstable.

† Reporting standards not met. Too few cases to be reported.

¹ AUS=Australia; CZE=Czech Republic; JPN=Japan; NLD=Netherlands; and USA=United States.

² Verified knowledge: AUS>CZE, USA>NLD.

³ Followed procedures: AUS>CZE, NLD.

⁴ Explored a question: AUS, JPN>CZE, USA; JPN>NLD.

NOTE: Totals may not sum to percentage of lessons with independent practical activities because of rounding and data not reported. Lessons with no known outcome are not included in the analyses. See table 3.5, chapter 3 for total percentage of lessons with independent practical activities.

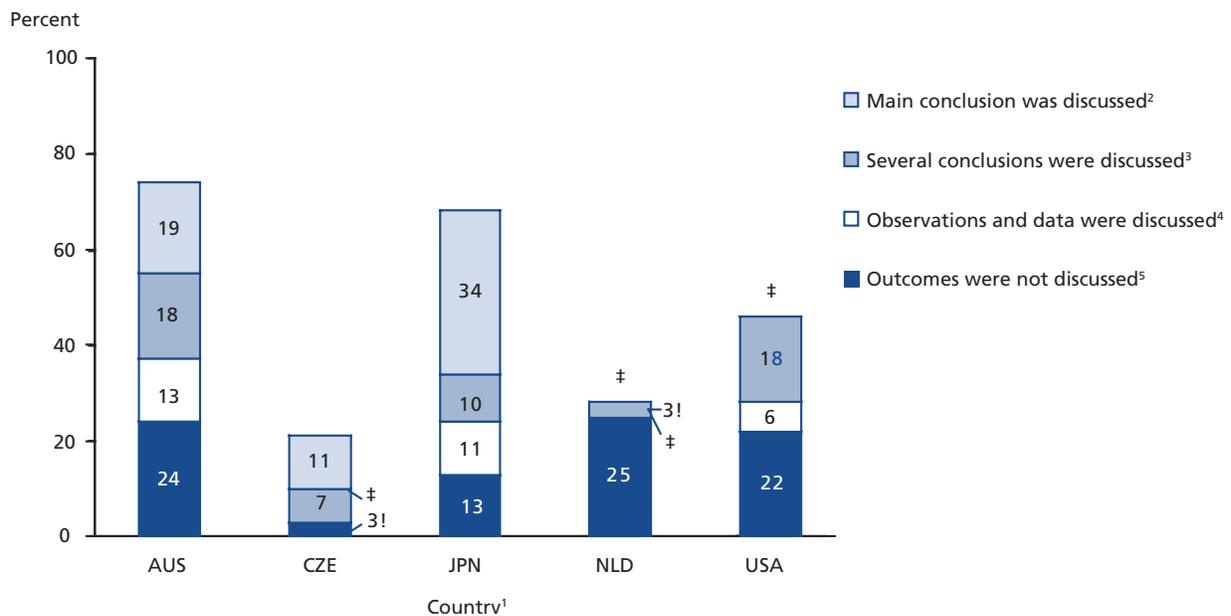
SOURCE: U.S. Department of Education, National Center for Education Statistics, Third International Mathematics and Science Study (TIMSS), Video Study, 1999.

Critique Methods and Raise New Questions

Teachers can help students learn about the nature of scientific knowledge and thinking in many ways. For example, the class may discuss why a certain procedure was used and consider the limits and possible inaccuracies of the data provided by the procedure (📺 Video clip example 7.9). Alternatively, the teacher may help students raise a new question to be asked, demonstrating that scientific knowledge is always tentative, incomplete, and subject to further exploration.

- Eighth-graders evaluated or critiqued the procedures and limitations of the independent practical activities in 4 to 17 percent of the science lessons across the five countries (figure 7.4).
- By the end of the lesson, students developed new questions to be investigated derived from their practical activities in 18 percent of Japanese and 8 percent of Australian science lessons (figure 7.4).

FIGURE 7.3. Percentage distribution of eighth-grade science lessons in which outcomes of independent practical activities were discussed publicly, by country: 1999



! Interpret data with caution. Estimate is unstable.

‡ Reporting standards not met. Too few cases to be reported.

¹ AUS=Australia; CZE=Czech Republic; JPN=Japan; NLD=Netherlands; and USA=United States.

² Main conclusion was discussed: JPN>CZE.

³ Several conclusions were discussed: AUS>NLD.

⁴ Observations and data were discussed: No measurable differences detected.

⁵ Outcomes were not discussed: AUS, NLD, USA>CZE.

NOTE: Totals may not sum to percentage of lessons with independent practical activities because of rounding and data not reported. See table 3.5, chapter 3 for total percentage of lessons with independent practical activities.

SOURCE: U.S. Department of Education, National Center for Education Statistics, Third International Mathematics and Science Study (TIMSS), Video Study, 1999.

What Science Inquiry Actions Do Students Practice During Independent Work?

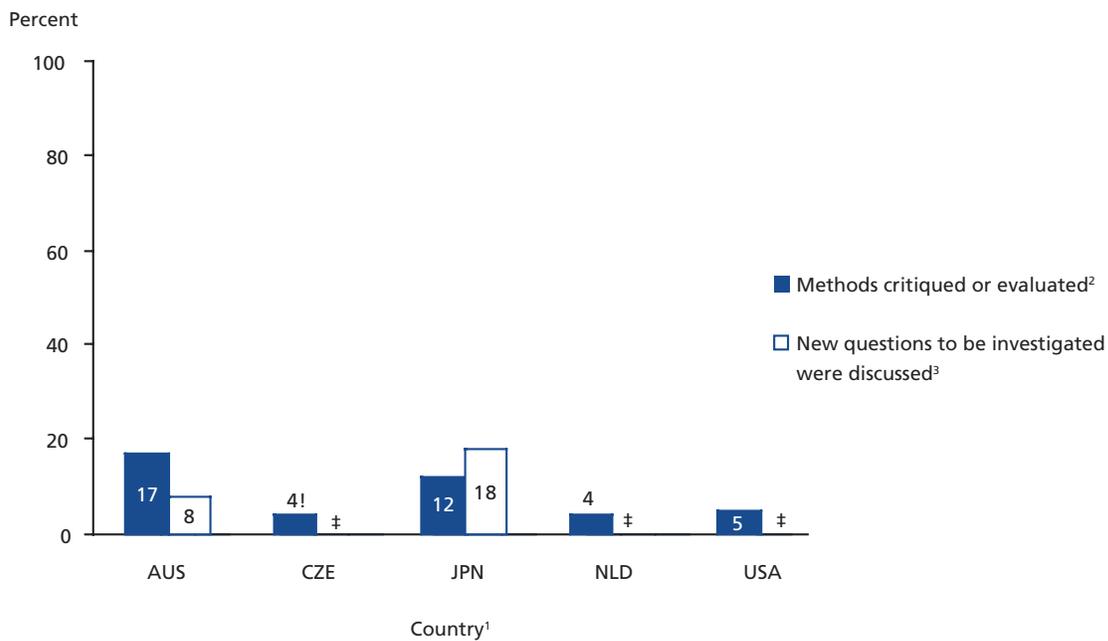
Teachers sometimes provide opportunities for students to engage in different types of inquiry practices before, during, and after independent practical activities. Before independent practical work, students may be expected to generate research questions, design procedures to investigate the research question, or make predictions about the outcomes. During independent practical work, students may collect and record data. After the investigation, students may be expected to manipulate the data collected, or to interpret the data.

Patterns of Student Use of Science Inquiry Practices

The types of inquiry activities that were related to independent practical work and in which students engaged before, during, and after the independent practical work were defined as follows.

- **Students generate the research question:** Students generate the research questions related to a practical activity, with either complete freedom or with several options provided by the teacher

Figure 7.4. Percentage of eighth-grade science lessons in which methods of the independent practical activity were evaluated or critiqued and new questions to investigate were discussed, by country: 1999



! Interpret data with caution. Estimate is unstable.

‡ Reporting standards not met. Too few cases to be reported.

¹ AUS=Australia; CZE=Czech Republic; JPN=Japan; NLD=Netherlands; and USA=United States.

² Methods critiqued or evaluated: No measurable differences detected.

³ New questions to investigate were discussed: No measurable differences detected.

NOTE: See table 3.5, chapter 3 for total percentage of lessons with independent practical activities.

SOURCE: U.S. Department of Education, National Center for Education Statistics, Third International Mathematics and Science Study (TIMSS), Video Study, 1999.

- **Students design procedures for investigation:** Students design procedures for their own investigation related to a practical activity, with either complete freedom or with several options provided by the teacher
- **Students make predictions:** Students predict the outcome of a practical activity. Students also can provide the reason for the predictions (📺 Video clip example 7.10).
- **Students interpret data or phenomena:** Students use first-hand data or phenomena from the independent practical activity as evidence to explain patterns, draw conclusions, make generalizations, and/or link the first-hand data or phenomena to predictions or hypotheses made before beginning the activity. Students may work independently on generating interpretations of their first-hand data or phenomena (either individually or in pairs/small groups), or the teacher may guide students in making interpretations during public, whole-class discussions (📺 Video clip example 7.11).
- **Students collect and record data:** Students are involved in recording first-hand data or observations of phenomena during independent practical activities (📺 Video clip example 7.12).
- **Students organize or manipulate data collected independently:** Students independently organize or manipulate first-hand data or observations into tables, graphs, or charts. They design the structure or form of the table, graph, or chart (📺 Video clip example 7.13).

- **Students organize or manipulate collected data as directed by the teacher or the textbook:** First-hand data or observations are organized or manipulated into tables, graphs, or charts under the direction of the teacher or textbook. In many cases, the teacher, textbook, or workbook provides the table, graph, or chart templates, and students fill in the data. In other cases, the teacher uses student-generated data and demonstrates on the board or overhead how to organize the data into a graph or chart.

Table 7.3 displays the percentage of lessons in which students engaged in the following types of inquiry activities related to and occurring before, during, and after independent practical work.

- Independent practical activities in the eighth-grade science lessons seldom involved students in generating their research questions or designing their investigations (table 7.3). Students generated research questions related to the independent practical activities in 3 percent of Australian science lessons, and they designed procedures for investigation in 10 percent of Australian science lessons and in 5 percent of Japanese and U.S. science lessons (table 7.3).
- Students made predictions or hypotheses about the independent practical activities in 4 to 23 percent of the eighth-grade science lessons in the countries except in the Czech Republic (table 7.3). Further analyses revealed that students were expected to give reasons for their predictions in 6 percent of Australian science lessons and 8 percent of Japanese lessons (data not shown).
- Students had opportunities to collect and record first-hand data or phenomena related to independent practical activities in more Australian and Japanese science lessons than in Czech, Dutch, and U.S. science lessons (table 7.3).
- Within all countries where reliable estimates could be made, eighth-graders were more likely to interpret results of the independent practical activities during science lessons than to make predictions (table 7.3).
- In Czech science lessons, students were more likely to be asked to interpret results than to collect and record data (table 7.3).
- Students organized and manipulated data collected independently in no more than 9 percent of lessons in any of the countries. In Australia, such work was done more often under the guidance of the teacher or textbook than independently (table 7.3)

What Science Inquiry Actions Do Students Practice During Whole-Class Work?

Teachers can also engage students in science inquiry practices during whole-class practical activities such as demonstrations, although the range of possible inquiry practices may be more limited. In the videotaped lessons, students were asked to generate predictions, to interpret the first-hand data or phenomena, and to organize and manipulate first-hand data into tables, graphs, or charts during whole-class practical activities. However, since whole-class practical activities involve students in watching someone else (usually the teacher) generate and collect the data, students in the videotaped lessons were not observed formulating their own questions to investigate, designing procedures to investigate their questions, or collecting their own first-hand data from observations during whole-class practical activities.

TABLE 7.3. Percentage of eighth-grade science lessons in which students engaged in different inquiry activities before, during, and after independent practical work, by country: 1999

Student activity	Australia (AUS)	Czech Republic (CZE)	Japan (JPN)	Netherlands (NLD)	United States (USA)
Generated the research question ¹	3!	‡	‡	‡	‡
Designed procedures for investigations ²	10	‡	5!	‡	5
Made predictions ³	11	‡	23	4!	8
Interpreted the data or phenomena ⁴	56	20	43	24	33
Collected and recorded data ⁵	62	8	59	29	31
Organized or manipulated data collected independently ⁶	9	‡	‡	8	8
Organized or manipulated collected data guided by teacher or textbook ⁷	27	3!	37	8	19

!Interpret data with caution. Estimate is unstable.

‡Reporting standards not met. Too few cases to be reported.

¹Students generated the research question: No measurable differences detected.

²Students designed procedures for investigations: No measurable differences detected.

³Students made predictions: JPN>NLD.

⁴Students interpreted the data or phenomena: AUS>CZE, NLD; JPN>CZE.

⁵Collected and recorded data: AUS, JPN, NLD, USA>CZE; AUS, JPN>NLD, USA.

⁶Organized or manipulated data collected independently: No measurable differences detected.

⁷Organized or manipulated collected data guided by teacher or textbook: AUS, JPN>CZE, NLD; USA>CZE.

NOTE: Totals for students organized or manipulated data on their own or under the direction of the teacher or textbook do not sum to students collected and recorded data because students do not always manipulate collected data. See table 3.5, chapter 3 for total percentage of lessons with independent practical activities.

SOURCE: U.S. Department of Education, National Center for Education Statistics, Third International Mathematics and Science Study, Video Study, 1999.

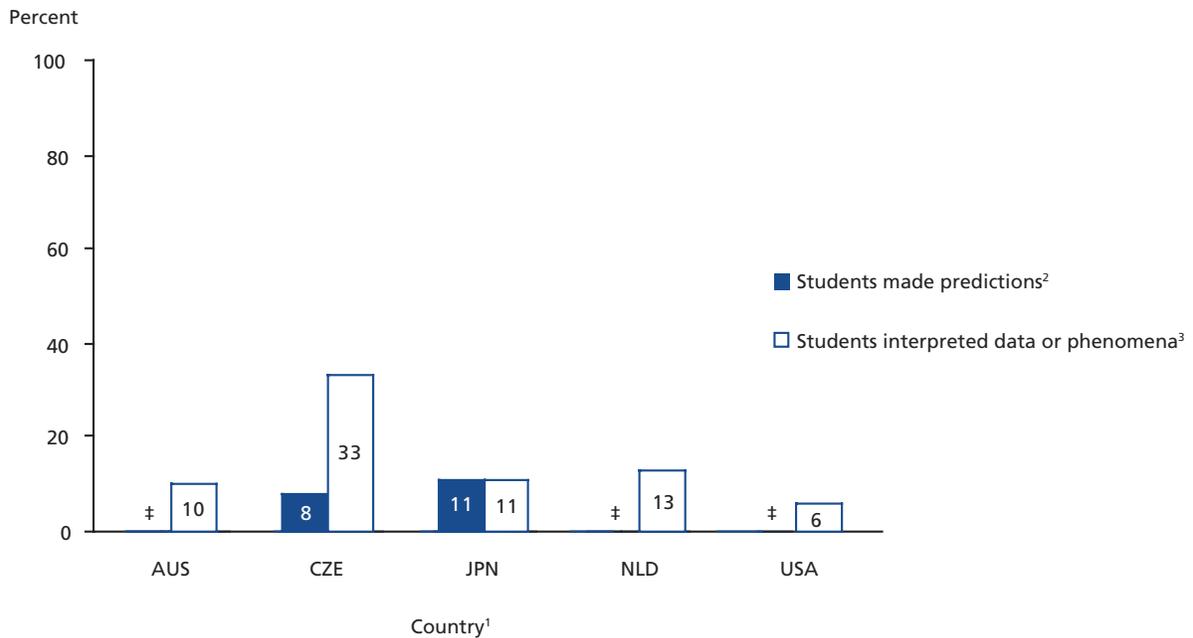
Students participated in whole-class practical activities in a large percentage of the eighth-grade science lessons in all the participating countries, ranging from 62 percent in the Netherlands to 81 percent in Australia (see table 3.5, chapter 3). Countries were not found to vary on the distribution of lessons with whole-class practical activities unlike the distribution of independent practical activities (see table 3.5, chapter 3). However, as described in chapter 3, it is important to keep in mind that even though practical whole-class activities occurred in a large percentage of the science lessons, countries allocated a small average proportion of time to whole-class practical activities, ranging from 4 to 10 percent of total science instruction time (figure 3.7).

Students Make Predictions and Interpret First-Hand Data or Phenomena

Predictions can be derived from previously known science knowledge, such as science theories or laws of science, with the expectation that students will be able to generate an accurate prediction. Alternatively, teachers can ask students to make predictions in situations where students do not have enough information to necessarily make a correct prediction (🎥 Video clip example 7.14). In these situations, the teacher may expect a wider array of student responses. Students can also be expected to interpret the results of the whole-class practical activities by explaining patterns, drawing conclusions, making generalizations, and/or linking the data or phenomena to predictions they made before the activities (🎥 Video clip example 7.15).

- No more than 11 percent of the eighth-grade science lessons in any of the five countries provided opportunities for students to make predictions related to whole-class practical activities (figure 7.5).
- Students were more likely to interpret the first-hand data or phenomena related to the whole-class practical activities in Czech science lessons (33 percent) than lessons in the other four countries (figure 7.5).
- More opportunities were provided within Czech science lessons for interpreting the results of these activities than making predictions (figure 7.5).

FIGURE 7.5. Percentage of eighth-grade science lessons in which students made predictions and interpreted data or phenomena related to whole-class practical activities, by country: 1999



‡Reporting standards not met. Too few cases to be reported.

¹ AUS=Australia; CZE=Czech Republic; JPN=Japan; NLD=Netherlands; and USA=United States.

² Students made predictions: No measurable differences detected.

³ Students interpreted the first-data or phenomena: CZE>AUS, JPN, NLD, USA.

NOTE: See table 3.5, chapter 3 for total percentage of lessons with independent practical activities.

SOURCE: U.S. Department of Education, National Center for Education Statistics, Third International Mathematics and Science Study (TIMSS), Video Study, 1999.

Summary

The opportunities for eighth-grade science students to participate in independent practical activities were described and compared across the participating countries in this chapter, revealing similarities and differences among the countries. Across all of the countries, the most common type of independent practical activity was generating and observing phenomena (rather than creating models, conducting experiments, classifying or dissecting objects, or using tools or science processes). Students rarely were engaged in critiquing or evaluating procedures and methods or considering new questions to be investigated.

Investigating practical activities revealed distinct patterns in Japan, the Netherlands, and the Czech Republic. Independent practical activities in Japan most often engaged students in exploring a question with an answer unknown to the students, included set up talk about science ideas as well as procedures, and were followed up with discussions that focused on one main idea or conclusion. Independent practical activities in the Netherlands, in contrast, were preceded most often with talk about procedures (not ideas) and were not followed by any discussion of the activity. Dutch students were most often given the instructions and sent off to work independently until the end of the period. Czech students were given fewer opportunities to participate in independent practical activities than at least three other countries resulting in fewer opportunities to make predictions, collect data, manipulate and organize data, or interpret data related to these activities. Even with these activities limited to 23 percent of Czech lessons, Czech students did interpret data in 20 percent of all the lessons. In addition, Czech students had opportunities to interpret data related to whole-class practical activities in a higher percentage of lessons than all of the other countries.

One aspect of students' practical work not discussed in this chapter is the social organization of the science classroom. The next chapter describes students' opportunities to work collaboratively during both practical and seatwork activities.

8

Chapter 8 Collaboration

This chapter describes the ways in which the eighth-grade science lessons provided opportunities for students to work collaboratively in small groups independently of the teacher.

Research Background

In science lessons, teachers have traditionally grouped students together to work on laboratory activities for two major reasons: to share limited materials and to provide opportunities for students to collaborate with their peers. Peer collaboration has been studied for its role in fostering student learning through social interactions (Bianchini 1997; Cohen 1994; Collins, Brown, and Newman 1989; Johnson, Johnson, and Holubec 1993; Kelly and Green 1998; Slavin 1995, 1996). In the field of science education, collaborative work is viewed by some researchers as particularly important because it can mirror the nature of work in scientific communities (Garfinkel, Lynch, and Livingston 1981; Gooding 1992; Latour and Woolgar 1986). It has been noted in the research literature, however, that students often work in groups without collaborating with each other—they may share materials and talk with each other but complete the tasks individually (Cohen 1994). Nonetheless, collaborative work continues to be a regular feature of science teaching.

Many educators across the world also have overarching citizenship goals for student learning that cross disciplinary learning boundaries. These goals often include the importance of learning to work collaboratively in groups. For example, in the Netherlands, there are general attainment targets that specify that students should learn to converse and work as part of a team (Dutch Ministry of Education, Culture, and Science 1998). In Japan, there is emphasis on building harmony and cooperation within the school and the classroom; competition among individual students in the classroom is discouraged. Teachers work to develop team spirit, and grouping is an important technique to build a cooperative atmosphere (Matsubara et al. 2002). The *National Science Education Standards* in the United States point out that collaborative group work enhances students' respect for each other by encouraging interdependency among group members and heightening students' awareness of the different kinds of expertise brought by different group members (NRC 1996, p. 36).

Seven features of groupwork are presented in this chapter in an effort to ascertain whether groupwork activities involved students in collaborating versus simply sharing materials. These seven features, though not exhaustive of all possibilities, provide a

multifaceted description of students' opportunities to collaborate on their science work. The features of small groupwork investigated in this study include

- students are sitting together;
- students are sharing materials;
- students are talking with their group members;
- the task is designed to require collaboration;
- students are assigned roles within groups;
- students are expected to make a group product; and
- the gender composition of the groups is mixed.

These features were selected because the research literature suggests that effective groupwork depends on genuine collaboration among students, and that the teacher can encourage such collaboration by assigning roles within the group, designing tasks that require students to collaborate, requiring a group product, and including a mix of students in each group (ability, gender, and ethnicity; Cohen 1994; Johnson, Johnson, and Holubec 1993). The structural features of groupwork described in this section provide some indication of the degree to which groupwork in the eighth-grade science classrooms involved students in collaborating with one another.

Country Perspectives

Although groupwork is emphasized as an important goal in most of the curriculum and standards documents of the participating countries, it should be noted that individual work and responsibility are also highlighted as important goals in some of the countries. In the Czech Republic, for example, students are expected to work and think individually (to find and organize information independently, to develop new knowledge through independent thinking, and so forth), while groupwork and collaboration are not explicitly named as curriculum goals (Czech Ministry of Education 1996). In the Netherlands, both individual learning and collaborative learning are emphasized. One of the three overarching, cross-disciplinary curriculum goals is to develop "active, independent learning" students with an emphasis on student-directed education, while more specific attainment targets focus on working with people who are different from oneself, conversing and working as part of a team, and dealing with similarities and differences between the sexes (Dutch Ministry of Education, Culture, and Science 1998, pp. 7-12).

Thus, for various reasons, national standards and curriculum documents or other policy documents in some of the countries encourage teachers to involve students in groupwork activities. This chapter explores two main questions:

- How much did students work in pairs or groups versus individually?
- What features characterized students' collaboration during group work?

The descriptions of collaborative work presented in this chapter focus on students' independent pair or group work (apart from the teacher) and not on whole-class interactions. It is only during such independent work that students may have the opportunity to experience the kinds of social interactions in which they learn to converse with each other and work as part of a team—activities students engage in apart from the teacher. For reference, the data in figure 3.6 and table 3.5 in chapter 3 indicated that, with the exception of the Czech Republic, the proportion of time that students spent in independent work was not found to differ measurably from the proportion of time spent in whole-class work. In Australia, Japan, the Netherlands, and the United States, around half of lesson time, on average, was spent in independent student work (ranging from 45 to 52 percent of science instruction time; figure 3.6). In the Czech Republic, 17 percent of science instruction time was spent having students work independently. The time students worked in groups or individually is most likely linked to the pattern of differences between countries found for the opportunities for independent work described above. Although pair/group work could be linked to the content of the lesson, the science lessons were selected across the school year to assure that a variety of content topics would be sampled, giving us a typical sample of lessons from each country.

How Much Did Students Work in Pairs or Groups Versus Individually?

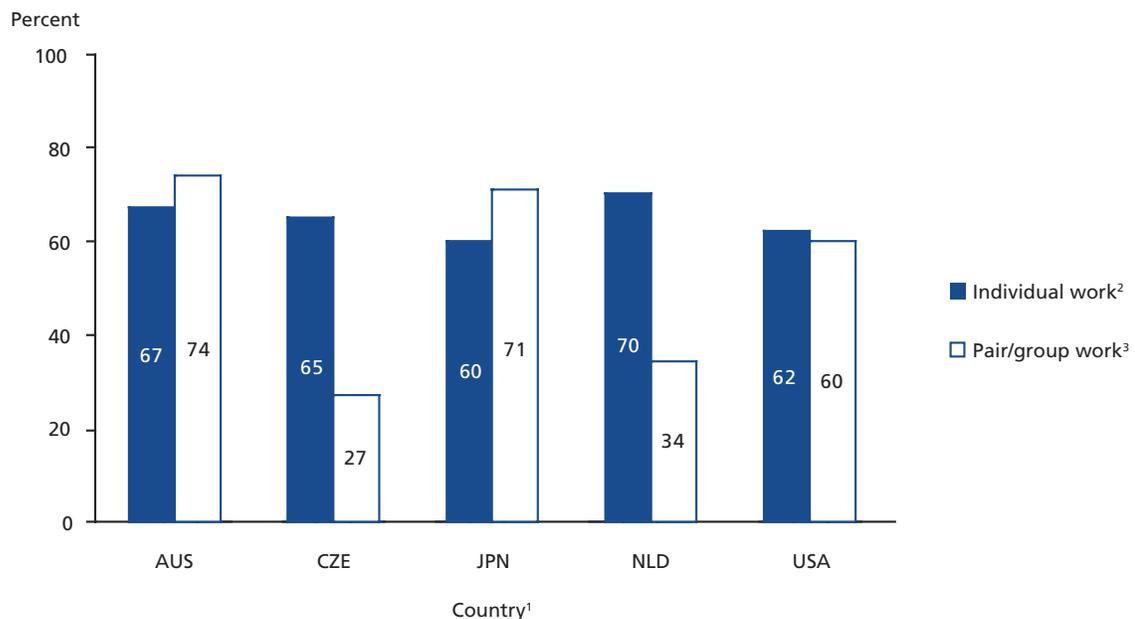
This section begins with a description of the percentage of lessons and the percentage of science instruction time when students, independent of the teacher, worked in different social participation structures: individually or in pairs/groups. Next, the social organization is compared during practical and seatwork activities: Were students engaged in groupwork only during practical, hands-on activities, or did groupwork also characterize seatwork activities such as paper-and-pencil tasks? To assess students' opportunities to collaborate in pairs or small groups, two predominant types of social participation structures¹⁰ were defined:

- **Individual work:** The teacher instructs students to work alone, or the task is structured in a way that suggests that students should work alone (e.g., “Think about the hypothesis and write it down in your notebook”). At least half of the students are observed to be working alone for more than 50 percent of the independent work time.
- **Pair/group work:** The teacher instructs students to work in groups of two or more, or the task is structured in a way that suggests students should work together in pairs or small groups. At least half of the students are observed to be working in pairs or small groups during more than 50 percent of the independent work time.

Figure 8.1 presents the percentage of eighth-grade science lessons that provided opportunities for independent individual and pair/group work. Figure 8.2 displays the percentage of science instruction time allocated to independent individual and pair/group work.

- Eighth-graders worked in groups of two or more in a greater number of Australian, Japanese, and U.S. science lessons than in Czech and Dutch lessons (figure 8.1).

¹⁰ A third social participation structure occurred when students moved back and forth between individual and pair/group structures during independent work. Such changing of social participation structures was observed in 3 percent of Australian and U.S. eighth-grade science lessons; there were not enough cases in the other three countries to calculate reliable estimates. Due to its relatively rare occurrence, information on this social participation structure was not included in figures and tables in this chapter.

Figure 8.1. Percentage of eighth-grade science lessons with independent individual work and pair/group work, by country: 1999


¹ AUS=Australia; CZE=Czech Republic; JPN=Japan; NLD=Netherlands; and USA=United States.

² Individual work: No measurable differences detected.

³ Pair/group work: AUS, JPN, USA>CZE, NLD.

NOTE: Percentage of lessons does not include lessons where students moved freely between independent and pair/group work. This occurred in no more than 3 percent of U.S. and Australian lessons, and was observed too infrequently in the other countries to produce reliable estimates.

SOURCE: U.S. Department of Education, National Center for Education Statistics, Third International Mathematics and Science Study (TIMSS), Video Study, 1999.

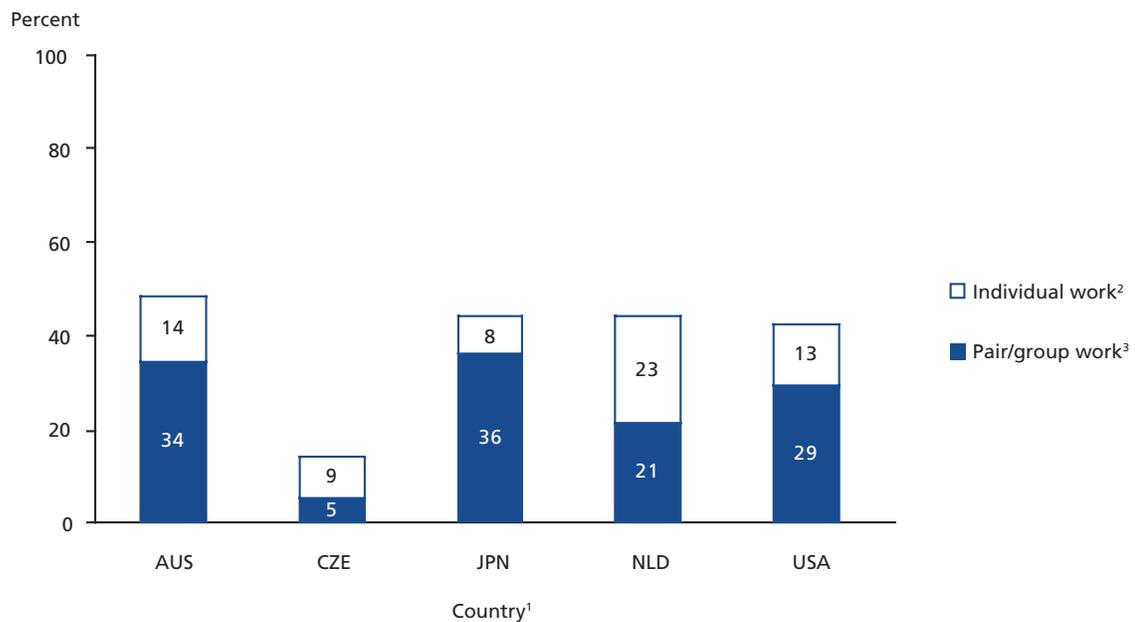
- Compared to Czech lessons, eighth-grade science lessons in Australia, Japan, the Netherlands, and the United States devoted a greater average percentage of science instruction time to students working in groups of two or more (figure 8.2).
- Dutch students worked individually for a larger proportion of science instruction time than students in Czech and Japanese lessons (figure 8.2).

Groupwork During Independent Practical and Seatwork Activities

Figure 8.3 presents the percentage of science instruction time devoted to individual work and pair/group work during independent practical and seatwork activities.

- Students in Czech eighth-grade science lessons worked in groups of two or more for a smaller percentage of independent practical work time than in all of the other countries (figure 8.3).
- During independent seatwork activities, students in Dutch lessons worked individually for a larger average percentage of science instruction time than all the other countries except the United States (figure 8.3).

Figure 8.2. Average percentage distribution of science instruction time during eighth-grade science lessons devoted to individual work, and pair/group work, by country: 1999



¹ AUS=Australia; CZE=Czech Republic; JPN=Japan; NLD=Netherlands; and USA=United States.

² Individual work: NLD>CZE, JPN.

³ Pair/group work: AUS, JPN, NLD, USA>CZE; JPN>NLD.

NOTE: Percentage of science instruction time devoted to changing social participation structures, taking notes and silent reading, divided class work, and whole class work are not presented (see chapter 3, figure 3.7).

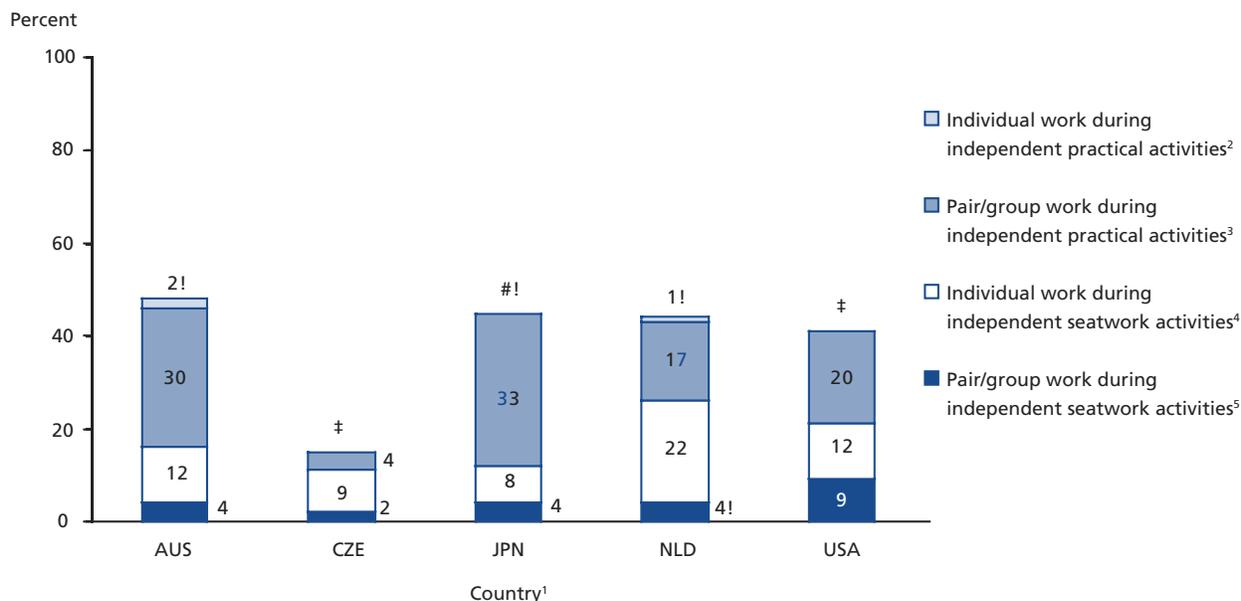
SOURCE: U.S. Department of Education, National Center for Education Statistics, Third International Mathematics and Science Study (TIMSS), Video Study, 1999.

- When students were given the opportunity to work independently on practical activities, it was done typically in pairs or groups (figure 8.3). Students in eighth-grade science lessons were rarely observed to work individually during practical, hands-on activities (figure 8.3).
- When given the opportunity to work on independent seatwork activities, students more often worked individually than in pairs or groups within the countries where reliable estimates could be made, except within the United States where no measurable differences were found (figure 8.3).

What Features Characterized Students' Collaboration During Groupwork?

Students can be organized to work collaboratively in groups in many ways. In some eighth-grade science lessons, students were observed sitting together and sharing materials, but they created individual products. Thus, in these lessons, group collaboration was limited to sharing materials and talking to each other. In other lessons, the group task was designed to encourage greater collaboration among students either by requiring multiple hands/minds to complete the task successfully, assigning different roles to different students within the group, and/or requiring a group product. The groupwork research literature suggests that features that encourage interaction among students may enhance student learning (Cohen 1994; Johnson, Johnson, and Holubec 1993).

FIGURE 8.3. Average percentage distribution of science instruction time during eighth-grade science lessons devoted to individual work and pair/group work during independent practical and seatwork activities, by country: 1999



#Rounds to zero

! Interpret data with caution. Estimate is unstable.

‡Reporting standards not met. Too few cases to be reported.

¹ AUS=Australia; CZE=Czech Republic; JPN=Japan; NLD=Netherlands; and USA=United States.

² Individual work during independent practical activities: No measurable differences detected.

³ Pair/group work during independent practical activities: AUS, JPN, NLD, USA>CZE; JPN>NLD.

⁴ Individual work during independent seatwork activities: NLD>AUS, CZE, JPN.

⁵ Pair/group work during independent seatwork activities: No measurable differences detected.

NOTE: Percentage of science instruction time devoted to changing social participation structures, copying notes and silent reading, divided class work, and whole class work are not presented (see chapter 3, figure 3.7).

SOURCE: U.S. Department of Education, National Center for Education Statistics, Third International Mathematics and Science Study (TIMSS), Video Study, 1999.

Seven features were identified that characterize students’ opportunities to collaborate during pair/group work. These features enable a multifaceted description of students’ opportunities to collaborate that extends beyond simple identification of the occurrence of pair/group work. Did students merely share materials, or were they required to collaborate in order to complete the task successfully? How often did pair/group work include features that encourage collaboration, such as assigned roles within the group and group products? The seven features of pair/group work investigated are:

- **Sitting together:** Students’ desks are set up for groupwork; two or more desks are joined together or students sit in groups of two or more at tables.
- **Sharing materials:** Students share special materials (beyond paper, pencils, worksheets, textbooks) with other students in their group. Students work together with the materials, even if one student is doing the manipulating at a given time. Such special materials include lab equipment, chemicals, science tools such as Bunsen burners, specimens to be studied such as rocks or plants, maps, globes, and construction tools (scissors, glue, rulers). In fact, groups are sometimes formed specifically for students to share a limited supply of special materials (Video clip example 8.1).

- **Talking among students:** A few or many students constantly talk with each other in their groups. Little talking among a few students or occasional interactions are not included.
- **Working on tasks requiring collaboration:** The group task is designed in such a way that students have to work together to complete it successfully; the task is not carried out by one student alone. The task is not completed unless the group members work together because it is designed in such a way that each student contributes a part of the process or the end product of the task. Students collaborate with each other in several ways. One type of collaboration task requires physical as well as mental collaboration. For example, the task requires one student to throw a ball, another student to catch it, and another student to measure the time the ball spent in the air. Another experiment requires multiple simultaneous actions such as reading the temperature of several liquids at exactly the same time. A second type of collaboration task requires students to survey one another. For example, students interview each other and collect and compute statistics, or students in a group share opinions and then build a group consensus. A third type of collaboration task requires each student to provide different information that has to be shared with the group members. For example, the group works on constructing a presentation that includes information gathered by each group member (📺 Video clip example 8.2).
- **Assigning roles to group members:** The teacher assigns particular roles to students within a group, or students assign roles within their groups. For example, one student is designated as the recorder for the group, another as the person who retrieves and returns materials, and another as the group facilitator.
- **Creating science group products:** Students are assigned to produce a science product as a group such as a completed worksheet, a lab report, a written design for an experiment, or a constructed 3-dimensional model or object. Each group is responsible for its science group product (📺 Video clip example 8.3).
- **Working in all mixed gender groups:** All of the observed pairs/groups include both girls and boys regardless of the type of other groupwork features described above. This category includes those situations where an uneven number of boys and girls in the class required some students to work in a single gender group, but the intent was to create a mix of gender groups for the entire class.

Table 8.1 presents the average percentage of science instruction time in the eighth-grade science lessons allocated to pair/group work and to the seven features of pair/group work.

- Eighth-graders in the science lessons sat together, shared materials, and talked to each other during almost the entire average time devoted to pair/group work time in the five countries (table 8.1).
- Students in Japanese science lessons spent more instructional time creating science group products than students in Czech lessons, and spent more time working in all mixed gender groups than students in U.S. lessons (table 8.1).
- Within all the countries with enough lessons to calculate reliable estimates, students spent less instructional time working on tasks requiring collaboration, creating science group products, or working with assigned roles than sitting together, sharing materials, or talking among themselves (table 8.1).

TABLE 8.1. Average percentage of science instruction time in eighth-grade science lessons allocated to pair/group work and selected features of pair/group work, by country: 1999

Features of pair/group work	Australia (AUS)	Czech Republic (CZE)	Japan (JPN)	Netherlands (NLD)	United States (USA)
Total ¹	34	5	36	21	29
Sitting together ²	33	5	36	18	27
Sharing materials ³	32	5	35	18	26
Talking among students ⁴	34	5	36	21	29
Working on tasks requiring collaboration ⁵	4	†	3	†	6
Assigning roles to group members ⁶	3	†	2	†	6
Creating science group products ⁷	6	2	10	5!	9
Working in all mixed gender groups ⁸	1!	†	15	†	3

!Interpret data with caution. Estimate is unstable.

†Reporting standards not met. Too few cases to be reported.

¹Pair/group work: AUS, JPN, NLD, USA>CZE; JPN>NLD.

²Sitting together: AUS, JPN, NLD, USA>CZE; AUS, JPN>NLD.

³Sharing materials: AUS, JPN, NLD, USA>CZE; AUS, JPN>NLD.

⁴Talking among students: AUS, JPN, NLD, USA>CZE; JPN>NLD.

⁵Working on tasks requiring collaboration: No measurable differences detected.

⁶Assigning roles to group members: No measurable differences detected.

⁷Creating science group products: JPN>CZE.

⁸Working in all mixed gender groups: JPN>AUS, USA.

NOTE: Percentage of science instruction time devoted to changing social participation structures, individual work, divided class work, and whole class work are not presented (see chapter 3, figure 3.7).

SOURCE: U.S. Department of Education, National Center for Education Statistics, Third International Mathematics and Science Study (TIMSS), Video Study, 1999.

Summary

Presented in this chapter were descriptions of students' opportunities to collaborate independently in the eighth-grade science lessons. Across countries, the most common features of groupwork were students talking with each other, students sharing materials, and students seated together. Other features of groupwork, such as assigned roles, group products, and tasks that required collaboration, occurred infrequently. Dutch students spent more time than students in all of the other countries except the United States working individually during independent seatwork activities. Japanese students spent more time working in groups of two or more than students in the Czech Republic and the Netherlands.

Collaboration provides opportunities to learn and practice talking about science among students and with experts. Chapter 9 explores students' opportunities to communicate in the eighth-grade science lessons.

9

Chapter 9 Communicating Science

This chapter describes students' opportunities to talk, write, and read about science. Both the research literature and the curriculum and standards documents for the countries involved in this study indicate that students' opportunities to communicate in these ways about science is an important issue to examine in science lessons.

Research Background

Research literature suggests at least three reasons why students should be supported in talking, writing, and reading about science. First, communication is viewed as an essential, not adjunct, feature of science and the scientific inquiry process (Hand, Prain, and Yore 2001; Norris and Phillips 2003; Osborne 2002). From this perspective, discussion, writing, and reading are just as much a part of “doing science” as carrying out experimental, hands-on work (AAAS 1993; Goldman and Bisanz 2002; Halliday and Martin 1993; Hand et al. 2003; Wellington and Osborne 2001), and students should have the opportunity to do all aspects of scientific work.

Second, communication can play a critical role in supporting the science learning process (Jones 2000). Research on learning conducted in a variety of fields and from differing methodological approaches and theoretical perspectives¹¹ points to the need for the learner to play an active role in the sense-making process, interacting with experts (whether this is a teacher or text) to develop new understandings (Brown and Campione 1994; Collins, Brown, and Newman 1989; Gee 1999; Halliday and Martin 1993; Lemke 1990; NRC 2000; Posner et al. 1982; Rosebery, Warren, and Conant 1992; Saul 2003; Schoenfeld 1988, 2002; Vygotsky 1978). Consistent with these theoretical perspectives and findings, research on science teaching and learning suggests that students could benefit from being active learners rather than passive recipients of knowledge (Anderson, Holland, and Palincsar 1997; Millar, Leach, and Osborne 2000; NRC 2000; Wellington and Osborne 2001; Zohar and Nemet 2002). That is, students might benefit from speaking, listening, reading, and writing about science while interacting with others who can challenge and shape their thinking. A number of studies provide support for the position that writing tasks that require active processing and sense-making are effective in supporting students' science learning (Eggleston et al. 1976; Keys et al. 1999; Roth 1992).

Third, one goal of science education is to prepare students to function as scientifically literate citizens who can continue to learn about science throughout their lives (AAAS

¹¹Examples of other fields include cognitive psychology, literacy education, science education, and mathematics education. Examples of methodological approaches include expert/novice comparisons, discourse analysis, and design studies, and theoretical perspectives include cognitive apprenticeship, conceptual change, constructivist, and social constructivist.

1993; NRC 2000). For most individuals, this learning will occur primarily through interpretation of print and media accounts of science news and issues. Science teaching can support students in learning how to become critical listeners and readers who can communicate their ideas and responses clearly (Alvermann 2006; Goldman and Bisanz 2002; Hand, Prain, and Yore 2001; Hand et al. 2003).

Despite the important role of communication in supporting student learning about science, many studies suggest that there are few opportunities for students to communicate in science classes. For example, a variety of studies provide evidence that students do little talking in classrooms (Cazden 1986; Dillon 1994; Edwards and Mercer 1987; Goodlad 1984; Lemke 1990; Mehan 1979; Sinclair and Coulthard 1975); Tharp and Gallimore 1989; Wellington and Osborne 2001) and that students have few opportunities to read about science during science lessons (Davies 1984; Lunzar and Gardner 1979; Wellington and Osborne 2001). While some studies suggest that students spend a significant amount of time writing in science classes (e.g., Newton, Driver, and Osborne 1999), many researchers and educators are concerned that the increased focus on hands-on practical work and inquiry activities “pushes writing into the background, denying children access to the genres of science that store information” (Wellington and Osborne 2001, p. 67). In addition, writing in science classrooms can involve copying notes or low level, writing tasks that require only reproduction of knowledge by students (Davies 1984; Eggleston, Galton, and Jones 1976; Newton et al. 1999; Wellington and Osborne 2001). More generative writing that requires active processing on the part of the learner seems to occur less frequently (Eggleston et al. 1976; Keys et al. 1999).

Country Perspectives

Communication is of interest in this study because curriculum and standards documents in most of the participating countries indicate that learning to communicate is a goal of science education. In Australia, a national statement on science for Australian schools specified two of nine goals for science education related to communication: (1) to learn to communicate scientific understanding to different audiences for a range of purposes, and (2) to use scientific language to communicate effectively and to further one’s understanding of science. One of seven principles for effective learning experiences in science emphasizes the importance of helping students use scientific language appropriately:

The language students use, whether speaking, writing, or drawing, is a critical part of their learning as they try to express their ideas, grasp the ideas of others, and extend their understanding..... (Australian Education Council 1994, p. 8)

Standards documents in the United States also emphasize the importance of communication in science teaching (AAAS 1993; NRC 1996). The American Association for the Advancement of Science benchmarks document highlights communication skills as one of the five habits of mind that students should develop. The *National Science Education Standards* encourages teachers to require students to record their work and to use different forms of communication (spoken, written, pictorial, graphic, mathematical, and electronic) (NRC 2000).

In the Czech Republic and the Netherlands, communication goals are identified as important general attainment goals for education in all subject areas (Czech Ministry of Education 1996; Dutch Ministry of Education, Culture, and Science 1998; Kolavova 1998). The Czech standards call for students to be able to clearly articulate, listen, read with understanding, and interpret what is read. Students should be able to work independently with the textbook, to look for information, to organize it, and to make notes. In the Netherlands, one of the six general attainment target areas across subject areas is learning to communicate. In another general attainment category—learning to do, goals focus on comprehending written and spoken Dutch and English as well as speaking and writing correct Dutch. These communication goals are expected to contribute to the goals for physics/chemistry education and for biology education.

Chapter 9 focuses on three main questions about the different opportunities to communicate about science in the eighth-grade science lessons:

- What kinds of opportunities do students have to talk about science?
- What kinds of opportunities do students have to write about science?
- What kinds of opportunities do students have to read about science?

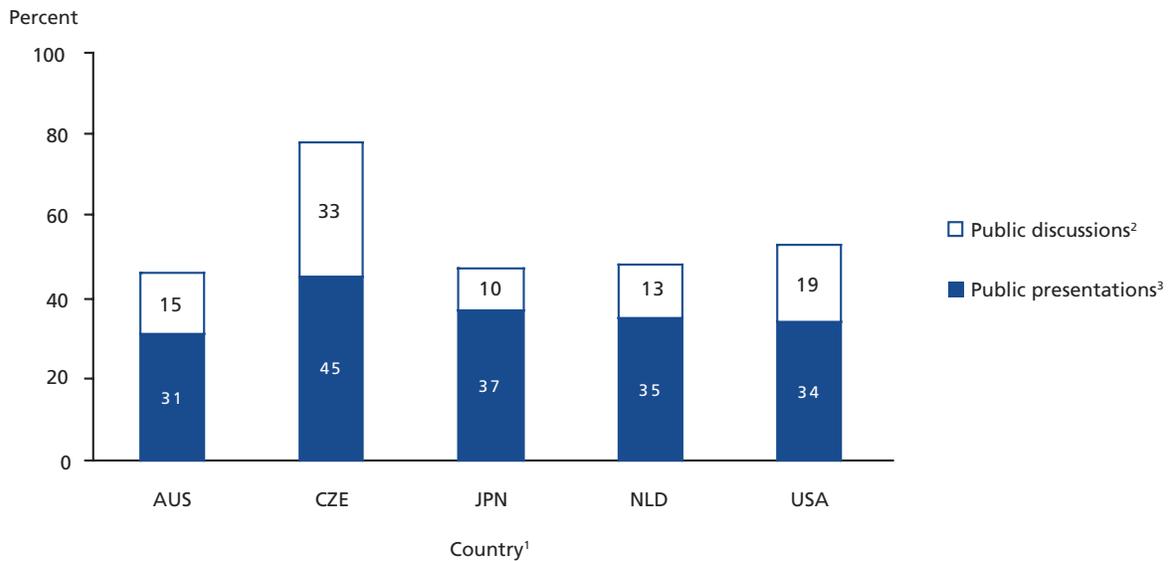
What Kinds of Opportunities Do Students Have to Talk About Science?

Teacher-Student Talk During Whole-Class Work

The lessons were analyzed for any type of whole-class discussion in order to identify students' opportunities to verbally interact with the teacher and/or other students in a public setting. In contrast to presentations by teachers, students, and/or other sources (🎥 Video clip example 9.1), discussions most often took the form of a series of teacher questions, student responses, and evaluations of the responses by the teacher known as the initiation-student response-teacher evaluation (IRE) pattern (Cazden 1986; Roth, Anderson, and Smith 1987; Sinclair and Coulthard 1975) (🎥 Video clip example 9.2). Discussions could include both everyday forms of talk and scientific terms. Discussions where students played a more central role, such as those described elsewhere as “highly interactive discourse structures” (Schoenfeld 2002), “argumentation discourse” (Kelly and Chen 1999), “diagnostic teaching” (Bell and Purdy 1985), and “science talks” (Gallas 1995), were rarely observed.

- Although discussions accounted for 10 to 33 percent of the instruction time (figure 9.1), they occurred in at least 81 percent of the lessons in all of the countries (data not shown). Lessons in the Czech Republic allocated a larger percentage of science instruction time, on average, to public discussions (33 percent) compared to all the other countries (figure 9.1).
- Within the science lessons of the five participating countries, whole-class talk was more likely to take the form of a public presentation (usually by the teacher) than a back and forth public discussion among students and teachers (figure 9.1).

FIGURE 9.1. Average percentage distribution of science instruction time per eighth-grade science lesson devoted to public presentations and discussions during whole-class work, by country: 1999



¹ AUS=Australia; CZE=Czech Republic; JPN=Japan; NLD=Netherlands; and USA=United States.

² Public discussions: CZE>AUS, JPN, NLD, USA; AUS, USA>JPN.

³ Public presentations: CZE>AUS, JPN, NLD, USA.

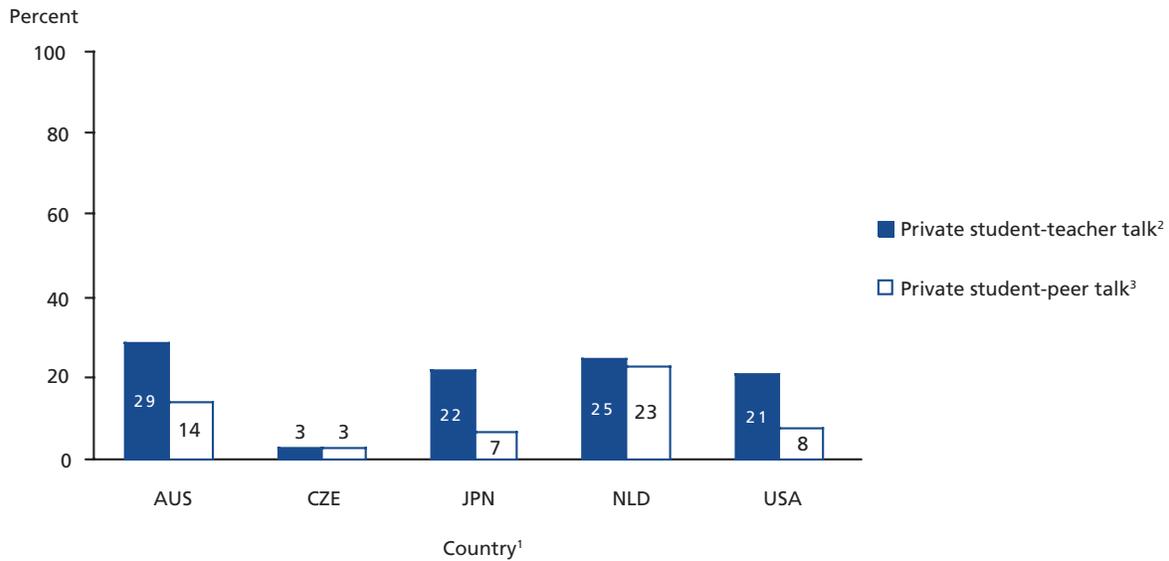
NOTE: Percentage of science instruction time devoted to public talk during independent work and to demonstrations is not reported. See figure 3.6, chapter 3 for the distribution of instruction time between whole-class and independent work.

SOURCE: U.S. Department of Education, National Center for Education Statistics, Third International Mathematics and Science Study (TIMSS), Video Study, 1999

Teacher-Student Talk and Student-Peer Talk During Independent Work

As students work independently, they may be given opportunities to talk privately with the teacher or with their peers. Each lesson was examined for the amount of time students were given to interact in these two ways. Teachers could speak privately with students, either individually or in small groups, as they worked on independent activities (see Video clip example 9.3). Since the teachers in the eighth-grade science lessons wore remote microphones, it was possible to transcribe their private talk with students during these interactions. The talk among students could have been related to science but it was not possible to identify the content of the talk. The intent of measuring private student-peer talk was to capture how much opportunity students had to talk about science with each other.

- Although Czech lessons provided students with more instruction time for public discussions than all the other countries (see figure 9.1), Czech students were less likely to have opportunities to discuss science privately with their teacher and with their peers than students in science lessons in all the other countries (figure 9.2).
- Compared to the Czech Republic, eighth-graders in all the other countries were provided with larger average percentages of science instruction time during independent work to communicate privately with their teacher (21 to 29 percent) and to talk with their peers (7 to 23 percent) (figure 9.2).

FIGURE 9.2. Average percentage of science instruction time in eighth-grade science lessons with student opportunity for private teacher-student talk and private student-peer talk, by country: 1999

¹ AUS=Australia; CZE=Czech Republic; JPN=Japan; NLD=Netherlands; and USA=United States.

² Private teacher-student talk: AUS, JPN, NLD, USA>CZE.

³ Private student-peer talk: AUS, JPN, NLD, USA>CZE.

NOTE: Percentage of science instruction time devoted to copying notes, silent reading, divided class work, and whole-class work is not reported.

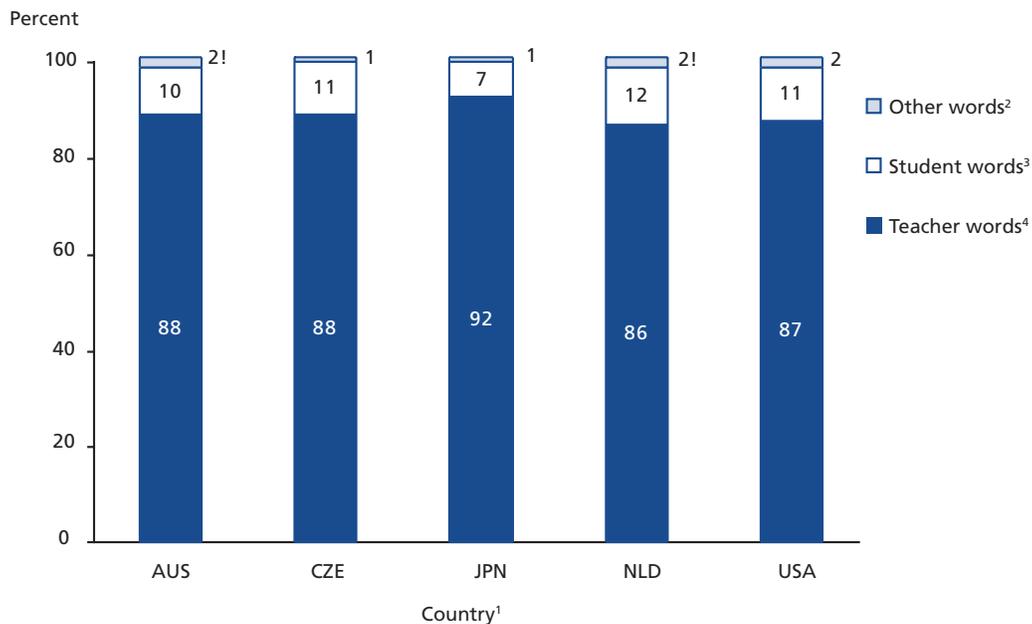
SOURCE: U.S. Department of Education, National Center for Education Statistics, Third International Mathematics and Science Study (TIMSS), Video Study, 1999.

Teacher and Student Words During Public Talk

Since public talk includes words spoken by both teachers and students, word-based measures were used as proxies to indicate the extent to which students talked publicly. These measures also were used to identify the average length of student utterances. It was assumed that an utterance of five words or more is likely to represent a sentence and, therefore, constitute a complete thought constructed by the student. Computer-assisted analyses were applied in the TIMSS 1999 Video Study to English-language transcripts of the public portions of eighth-grade science lessons.

- During public talk, Czech and Dutch students spoke a higher percentage of words than students in Japanese lessons (figure 9.3).
- When eighth-graders spoke publicly in Czech lessons, they were more likely to use five or more words than students in Australian, Dutch, and Japanese lessons. They were less likely to use five or more word utterances during private teacher-student talk than students in lessons in all the other countries (figure 9.4).
- Eighth-grade students within all of the five countries publicly spoke a lower percentage of total words compared to their teachers (figure 9.3).

FIGURE 9.3. Average percentage distribution of total words during public talk within science instruction per eighth-grade science lesson that were spoken by other sources, the student, and the teacher, by country: 1999



¹ Interpret data with caution. Estimate is unstable.

² AUS=Australia; CZE=Czech Republic; JPN=Japan; NLD=Netherlands; and USA=United States

³ Other talk: No differences detected.

⁴ Student talk: CZE, NLD>JPN.

⁵ Teacher talk: JPN>CZE, NLD, USA.

NOTE: Percentages may not sum to 100 because of rounding and percentages do not include private talk time. The tests for significance take into account the standard error for the reported differences. Thus, a difference between averages of two countries may be significant while the same difference between two other countries may not be significant. Other words include entire class responses, video, audio, adult teaching assistants, and words that were written on the chalkboard and included in the transcript.

SOURCE: U.S. Department of Education, National Center for Education Statistics, Third International Mathematics and Science Study (TIMSS), Video Study, 1999

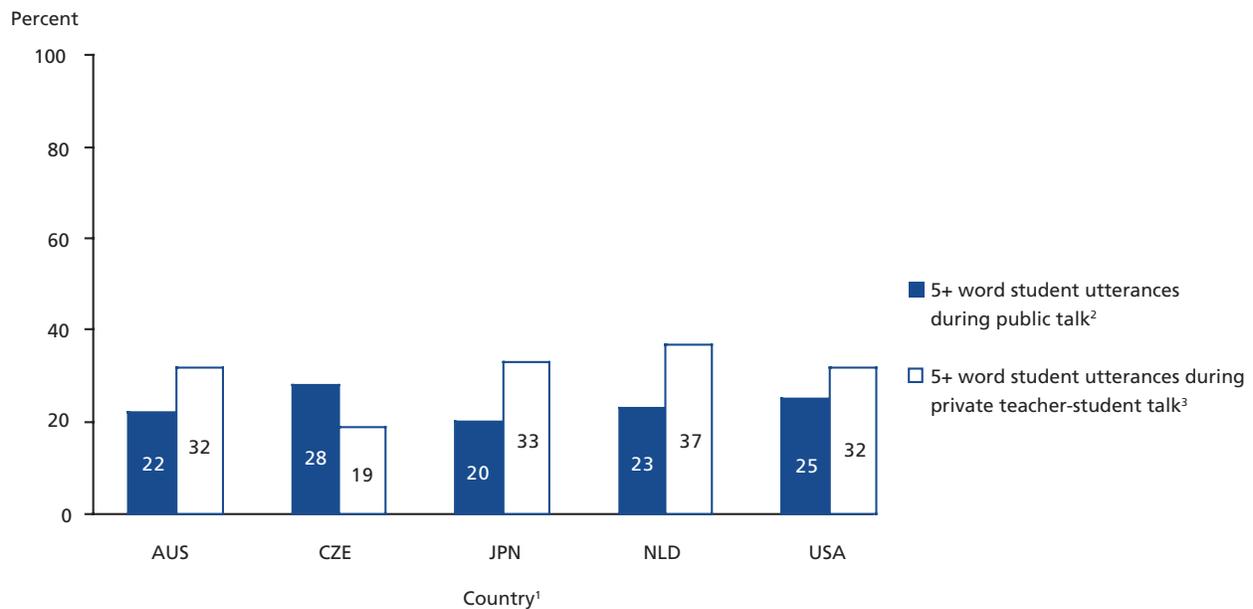
What Kinds of Opportunities Do Students Have to Write About Science?

Types of Writing

The lessons were examined for students' opportunities to engage in different types of writing that required students to only put letters or words on paper (versus diagrams, graphs, or mathematical representations). Writing ranged from less cognitively demanding tasks, such as taking notes during whole-class work and selecting answers during independent work, to potentially more cognitively demanding writing that required students to generate phrases, sentences, or paragraphs, such as lab report or essay writing. The types of writing that students were expected to do during whole-class and independent work were defined as follows.

- **Take notes:** Teachers set aside time during whole-class work for students to take notes from the blackboard, computer screens, overhead projectors, or some other source.
- **Select answers:** Students write only a letter or a few words, such as choosing an answer from a set of options, writing single words, or labeling diagrams, but they do not write sentences, during independent work.

FIGURE 9.4. Average percentage of student utterances that were 5 or more words per eighth-grade science lesson during public talk and private teacher-student talk, by country: 1999



¹ AUS=Australia; CZE=Czech Republic; JPN=Japan; NLD=Netherlands; and USA=United States.

² 5+ words student utterances during public talk: CZE>AUS, JPN, NLD.

³ 5+ words student utterances during private teacher-student talk: AUS, JPN, NLD, USA>CZE.

NOTE: Analyses based on English-language transcripts.

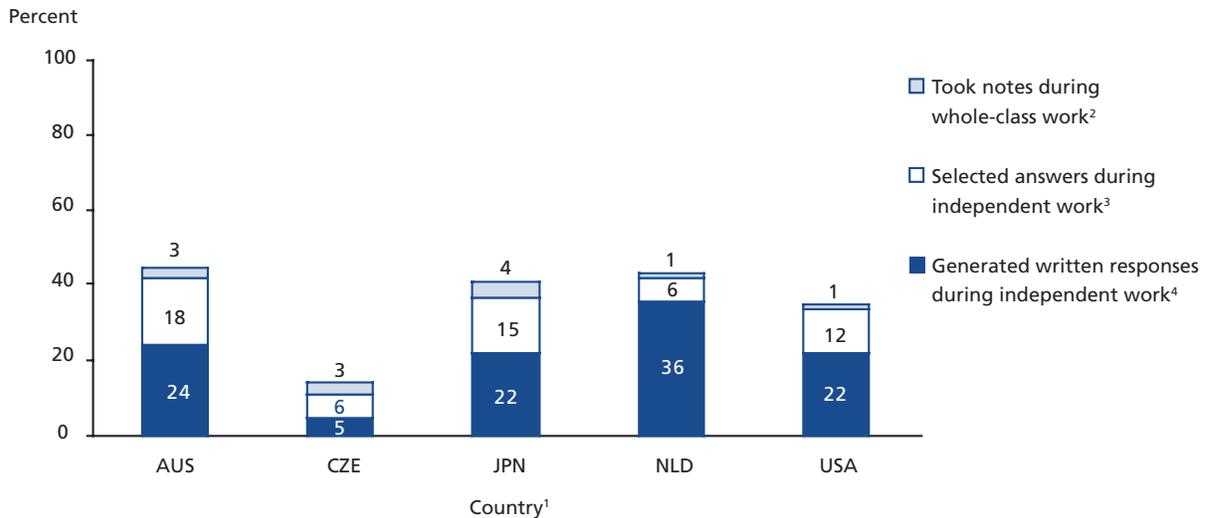
SOURCE: U.S. Department of Education, National Center for Education Statistics, Third International Mathematics and Science Study (TIMSS), Video Study, 1999.

- **Generate written responses:** Students generate phrases or sentences in their own words rather than copying, selecting, labeling, or providing one-word responses during independent work. For example, students write answers to a question or a sequence of questions. Each question requires students to generate at least a phrase or a one-sentence response. Alternatively, students could brainstorm multiple ideas and prepare a written list of phrases or sentences. Students also may produce an essay, a written report, journal entry, or a report about a topic (📺 Video clip example 9.4).

The eighth-grade science lessons were compared on the percentage of science instruction time in which students were expected to take notes during whole-class work, to select answers during independent work, and to generate written responses during independent work.

- Students in the eighth-grade science lessons in Australia, Japan, the Netherlands, and the United States were provided with more total instruction time, on average, to write about science (i.e., to take notes, select answers, and/or generate written responses) during independent and whole-class work combined than in Czech lessons (figure 9.5).
- Students in Czech science lessons were provided less average instruction time to generate written responses during independent work (5 percent) compared to all the other countries (22 to 36 percent; figure 9.5).
- In the Netherlands and the United States, students generated written responses for longer average proportions of instruction time than they selected answers or copied notes during independent work (figure 9.5).

Figure 9.5. Average percentage distribution of science instruction time in eighth-grade science lessons during which students took notes during whole-class work, selected answers during independent work, and generated written responses during independent work, by country: 1999



¹ AUS=Australia; CZE=Czech Republic; JPN=Japan; NLD=Netherlands; and USA=United States.

² Took notes during whole-class work: CZE, JPN>NLD, USA.

³ Selected answers during independent work: AUS>CZE, NLD; JPN>CZE.

⁴ Generated written responses during independent work: AUS, JPN, NLD, USA>CZE.

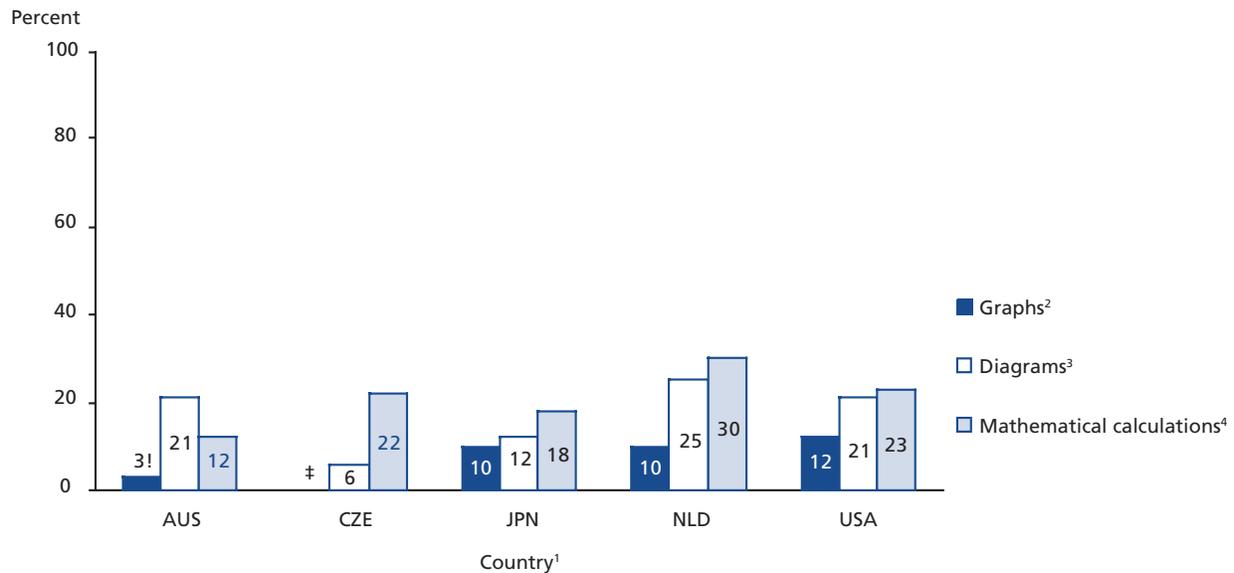
SOURCE: U.S. Department of Education, National Center for Education Statistics, Third International Mathematics and Science Study (TIMSS), Video Study, 1999.

- Similar patterns of differences appeared when countries were compared on the percentages of eighth-grade science lessons that provided any opportunity for students to engage in the different writing tasks. Again, compared to Czech science lessons, students independently generated written responses in more Australian, Dutch, and U.S. eighth-grade science lessons (70, 72, and 56 percent, respectively) (data not shown). Students in Dutch lessons also independently selected answers in fewer lessons (18 percent) than Australian, Czech, and Japanese lessons (54, 40, and 49 percent, respectively). Students took notes during whole-class work in more Czech and Japanese lessons (45 and 43 percent, respectively) compared to students in Dutch and U.S. lessons (13 and 16 percent, respectively).
- Students were expected to write at least a paragraph related to independent work in no more than 11 percent of the lessons in any of the participating countries (data not shown).

Diagrams, Graphs, and Mathematical Calculations

Students also independently worked on writing tasks that used representations other than words. These tasks required students to make graphs, diagrams (including concept maps), and mathematical calculations.

- Tasks that included graphs were observed in 3 to 12 percent of the science lessons, with too few observations in the Czech Republic to calculate reliable estimates (figure 9.6).
- Students were observed working independently on diagrams in 6 to 25 percent of the science lessons, and working on mathematical calculations in 12 to 30 percent of the science lessons (figure 9.6). Students worked on diagrams during independent work in more Dutch eighth-grade science lessons than Czech lessons.

FIGURE 9.6. Percentage of eighth-grade science lessons that included independent work on graphs, diagrams, and mathematical calculations, by country: 1999

! Interpret data with caution. Estimate is unstable.

‡ Reporting standards not met. Too few cases to be reported.

¹ AUS=Australia; CZE=Czech Republic; JPN=Japan; NLD=Netherlands; and USA=United States.

² Graphs: No differences detected.

³ Diagrams: NLD>CZE.

⁴ Mathematical calculations: No differences detected.

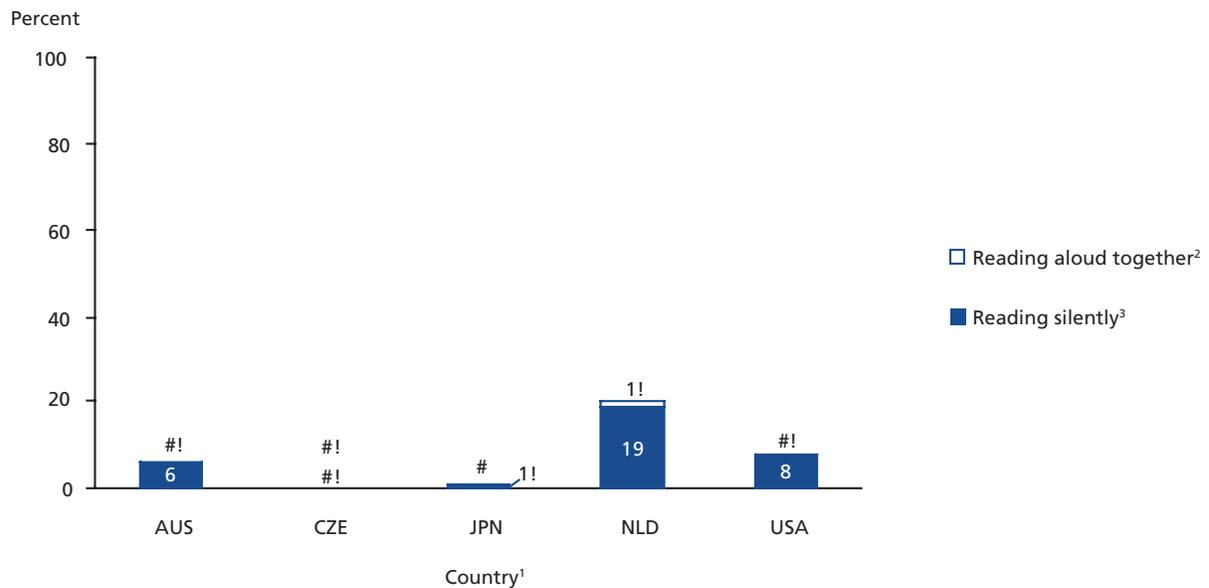
SOURCE: U.S. Department of Education, National Center for Education Statistics, Third International Mathematics and Science Study (TIMSS), Video Study, 1999.

What Kinds of Opportunities Do Students Have to Read About Science?

In the videotaped lessons, teachers provided students with opportunities to read about science aloud to the whole class and silently on their own. When reading to the class, a student would read from a source such as the textbook, a teacher-prepared worksheet, an Internet source, or an overhead transparency prepared by the teacher. When reading silently, students would read at least a paragraph of a book, magazine, or other source.

- Dutch eighth-grade science lessons provided a larger average proportion of instruction time for students to read about science compared to lessons in Australia (figure 9.7).
- Teachers allocated between 6 and 19 percent of instruction time for silent reading in Australian, Dutch, and U.S. lessons. Students read silently for longer average percentages of instruction time in Dutch lessons compared to lessons in Australia (figure 9.7).
- Students infrequently were observed reading aloud together in the eighth-grade science lessons in all the countries (figure 9.7).

FIGURE 9.7. Average percentage distribution of science instruction time in eighth-grade science lessons with reading aloud together and silently, by country: 1999



#Rounds to zero.

! Interpret data with caution. Estimate is unstable.

¹ AUS=Australia; CZE=Czech Republic; JPN=Japan; NLD=Netherlands; and USA=United States.

² Reading aloud together: No measurable differences detected.

³ Reading silently: AUS, NLD, USA>CZE; NLD>AUS, JPN.

SOURCE: U.S. Department of Education, National Center for Education Statistics, Third International Mathematics and Science Study (TIMSS), Video Study, 1999.

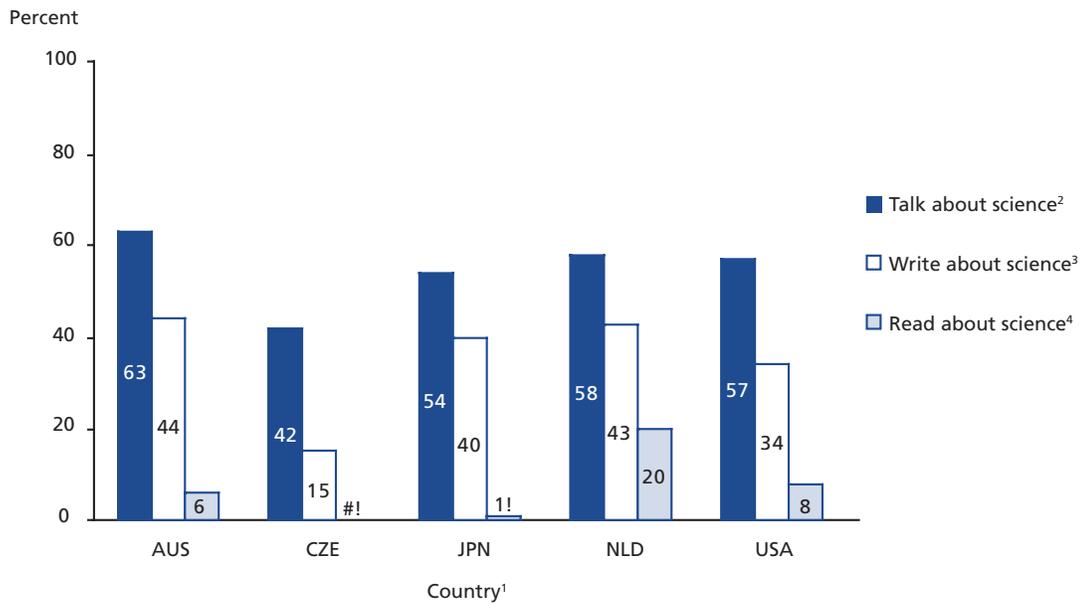
Do Students Have Different Kinds of Opportunities to Communicate Science?

The lessons were examined for the total amount of time that students had the opportunity to talk (either publicly or privately), write, and read (aloud and silently) about science.

- Compared to science lessons in the other four countries, lessons in the Czech Republic provided less instruction time, on average, for students to talk with their teacher and/or peers about science (42 percent) and to write about science (less than 1 percent) (figure 9.8).
- Dutch eighth-grade science lessons provided more instruction time for students to read about science (20 percent) compared to lessons in Australia (6 percent) (figure 9.8).
- Within all the countries where reliable estimates could be made, more instructional time, on average, was provided for students to talk about science than to write or read about science, and more time to write about science than to read about science (figure 9.8).

Opportunities to Communicate During Seatwork Activities

Further analyses examined differences between students' opportunities to communicate during practical and during seatwork activities. Of particular interest are the Dutch patterns that emerged.

FIGURE 9.8. Average percentage of science instruction time in eighth-grade science lessons allocated to opportunities for students to talk about science, to write about science, and to read about science, by country: 1999

#Rounds to zero.

! Reporting standards not met. Too few cases to be reported.

¹ AUS=Australia; CZE=Czech Republic; JPN=Japan; NLD=Netherlands; and USA=United States.

² Talk about science: AUS, JPN, NLD, USA>CZE.

³ Write about science: AUS, JPN, NLD, USA>CZE.

⁴ Read about science: NLD>AUS, CZE, JPN; AUS, USA>CZE.

NOTE: Talk about science is defined as students having opportunities to talk to their teacher or peers during discussion, private teacher-student talk, and independent work. Totals do not sum to 100 because instruction time could be provided for more than one type of opportunity to communicate about science.

SOURCE: U.S. Department of Education, National Center for Education Statistics, Third International Mathematics and Science Study (TIMSS), Video Study, 1999.

- During seatwork activities, Dutch science lessons provided more opportunities for students to communicate through talking, writing, and reading than in some other countries (data not shown). Dutch lessons allocated more instruction time, on average, for students to discuss science with their teacher and peers (39 percent) than Australian and Japanese lessons (29 and 20 percent, respectively); more instruction time per lesson for students to write about science (25 percent) than the Czech Republic and Japan (12 and 13 percent, respectively); and more time to read about science (16 percent) than Australia and Japan (4 and 1 percent, respectively) with too few lessons in the Czech Republic for reliable estimates.

Summary

Students' opportunities to learn how to communicate about science through talking, writing, and reading were described and compared across the participating countries in this chapter. The Czech Republic stands out as distinct from the other countries in terms of science talk. Czech students were allocated less total time to talk about science in science lessons (during whole-class discussions and independent work), and they had little opportunity to talk with each other or with the teacher

during independent work. However, they spent more time in whole-class discussions than students in all of the other countries, and they spoke longer utterances during these discussions than all of the other countries except the United States. In support of this, Czech teachers were often observed requesting students to restate their response in a sentence.

Opportunities for students to write and read about science were of particular interest in the Dutch lessons. Dutch students had the opportunity to write for a similar amount of time as three of the other countries, but in Dutch lessons most of this time was spent on more generative types of writing where they had to create their own statements rather than simply providing a word, label, list, definition, or copying notes. There was more time allotted for reading in the Dutch lessons than all the other countries except the United States. Analyses of students' opportunities to talk, write, and read during independent seatwork showed that Dutch students had more time allotted for talking with their peers and with their teacher, for writing about science, and for reading about science than some of the other countries.

The next chapter describes strategies that teachers in the eighth-grade science lessons used to also engage students' interest in learning science.