K-12 SCIENCE IN OHIO:
WHAT DISTRICTS INTEND TO TEACH, WHAT TEACHERS TEACH

A REPORT OF A SURVEY FOR THE OHIO MATHEMATICS AND SCIENCE COALITION

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When I learn, my students learn.
an Ohio teacher, November 1999

INTRODUCTION

The Ohio Mathematics and Science Coalition (OMSC) is an alliance of leaders from the education, business, and public sectors, working toward the common goal of systemic and sustained revitalization and improvement of Ohio's mathematics and science education at all levels—preschool to university. OMSC and its partners are building a consensus on the goals and attributes of world-class mathematics and science education systems for Ohio and laying out a continuous improvement plan to get there.

The North Central Regional Educational Laboratory (NCREL) was asked by OMSC to describe and compare the current state of Ohio's mathematics and science education systems. Central to NCREL's vision for this work is an awareness of the structure of the educational enterprise, a focus on the core issues that drive it, and an acknowledgement of the structural levels involved. At minimum, these include the student, the classroom, the school, the district, and the state. Each of these supports and constrains the work of teaching and learning. Above these are regional and national structures. Parallel to these structures are contingencies associated with parents and communities.

Within this context, four key questions shape an education system:

1. What should students learn?
2. Who delivers instruction?
3. How is instruction organized?
4. What have students learned?

Put another way, these questions address an educational system's *content*, its *capacity* to deliver that content, the organizational and pedagogical *cultures* and *conditions* that govern and constrain the delivery of content and the exercise of capacity, and the *consequences* it achieves.[1]

This report treats the first three of these questions with respect to science.[2] Our work in this report presents Ohio with some new evidence, based on the surveys NCREL conducted statewide in Ohio's schools. The surveys identified the topics in local schools' science curricula; the topics teachers teach; and aspects of how science is taught in Ohio. These surveys are excerpted from ones used by the Third International Mathematics and Science Survey (TIMSS) in 1995.[3]

Method and Procedure

NCREL's proposal to OMSC recommended that a sample of Ohio schools be surveyed in May 1999. This schedule proved optimistic and the survey was distributed in September 1999. The bulk of responses were received by late October 1999; the last survey was returned in February 2000.

Survey Instruments

Four survey forms were used. The first of these was a slightly modified version of the Generalized Topic Trace Mapping (GTTMs) instrument that each nation participating in TIMSS used to outline its curriculum. We asked the curriculum leader at each school in our sample to complete this form. It listed the topics in the TIMSS science framework, provided an extended definition for each, and asked the respondent to mark the grade(s) in his or her school at which each topic was taught. The form took about 30 minutes to complete in most cases.

We excerpted the other surveys from the longer TIMSS teacher surveys. Our surveys focused on the following:

- topics taught in science
- number of lessons devoted to each topic
- resources used for planning teaching and assessment;
- textbook use;
- descriptions of some of the class work students do;
- homework assignments;
- grades and subjects taught, teachers' qualifications, sex, and race.

We prepared science questionnaires for teachers working in grades 3, 4, 7, 8, and 12.[4] Each survey took from 30 to 45 minutes to complete.

Designing the Sample

The surveys were to be distributed to a random sample of Ohio public schools. Ideally, the sample should generalize to all Ohio schools. Standard procedures to assure this are well known. The ones we adopted are described below.

However, the sample should also generalize to the educational career of Ohio students matriculating from grade to grade anywhere in Ohio. We wanted to capture the full extent of exposure to science that a student being educated in Ohio's schools currently might expect over 13 years. To do this, we needed data from kindergarten through the senior year of high school. Clearly, we could not draw a sample of kindergarteners and wait 13 years (although that might be the best approach).

To solve these problems, we devised the following procedures to build a sample meeting our requirements:

1. Collapsing time

   To maximize the likelihood that we would tap a typical pattern of instruction from kindergarten to grade 12 over the educational career of a typical student in a sampled district,

   - We sampled 100 public high schools from Ohio's (then) 611 public school districts.[5]
   - For each high school, we randomly selected one middle school feeding students to it.
   - For each middle school, we randomly selected one primary feeder school.
   - In the few cases where there was no middle school, we randomly selected one K-8 school sending students to the sampled high school.

2. Sorting by geography

   Our population comprised all public high schools in Ohio.[6] To assure equal likelihood of selection across the geography of the state, we implemented a geographic serpentine. What this means is that on a map of Ohio, we drew a single line connecting every county systematically,

   - We started with Williams County in northwest Ohio.
   - From there, a line was drawn due south to Hamilton County in southwest Ohio
   - The line then stepped one county east to Clermont, and turned northward
   - The line continued this way, snaking through each Ohio county exactly once, until it reached Ashtabula County in the northeast corner.

   We then arranged the list of high schools by county according to this serpentine. We could now be sure our sample covered the full geography of the state without bias.

3. Sorting by school size

   School size is an obvious characteristic of high schools that affects the probability of selection of both students and schools. Within each county we sorted the high schools by size of enrollment, from smallest to largest in the first county (Williams) on the serpentine, largest to smallest in the second county (Defiance), smallest to largest again in the third, and so on, reversing the sort order for each county on the list. This generated a serpentine of size within the serpentine of geography, thereby reducing the selection bias favoring smaller schools.

4. Selecting the schools
   The last step was to select every seventh high school from this ordered list, beginning with a random number smaller than 7.

While this process cannot guarantee precise accuracy with respect to our need to be able to generalize to districts, schools, and students and over student careers, it represents a cogent compromise. The final sample contained 280 schools from 97 districts.

Collecting and Analyzing the Data

We mailed one science GTTM survey to each school. For the other teacher surveys, we sent each school a number calculated from grade-level enrollments, with the instructions that all teachers responsible for science instruction in grades 3, 4, 7, 8, and 12 complete and return them. To assure promptness and confidentiality, shipment both ways was arranged through Federal Express.

Since it was critical we be able to link the subsequent data back to the school from which it came, each survey was stamped with an identification code marking the school to which it was sent. In addition, the surveys asked the respondents to fill in the name of their school and district.[7] Teachers were not asked to identify themselves. However, we did request the curriculum leaders who completed the GTTMs to write in their names. Nearly all did. The cover letter attached to each survey, teacher or curriculum leader, promised complete confidentiality. On top of the entire package of forms was placed a letter from Dr. Susan Tave Zellman, endorsing the survey and the OMSC project.

Given the complexity of the sample and survey designs, no single overall figure for response rate makes sense. For the science GTTMs, 91 schools located in 64 districts returned usable forms. That is a district return rate of 66 percent and a school return rate of 33 percent.[8] Four hundred sixty-three (463) science teachers returned surveys. These teachers worked in 138 schools in 76 districts. The response rate for each of the teacher surveys was as follows:

Grade 3 and 4: 59 percent
Grade 7 and 8: 58 percent
Grade 12: 32 percent[9]

We entered the GTTM survey data into pre-formatted Microsoft Excel© worksheets, which generated a variety of data transformations, calculations, summaries, and plots. The teacher survey data were entered into the statistical package SPSS© and analyzed using its procedures.[10]

Science Content:
What Should Ohio's Students Learn?

Ohio's science teachers have numerous sources of guidance to assist them to determine what to teach.[11] Central among these are the model curricula prepared by the Ohio Department of Education.[12] However, while many classroom teachers do find these useful, they are targeted at district staff charged with curriculum development. Another source is the Learning Outcomes that Ohio's Proficiency Tests measure;[13] teachers in the affected grades know these very well. District and school curricula and syllabi also are prevalent.

This report cannot do justice to each of Ohio's districts, let alone each of its science teachers, in terms of what they feel should be taught. It can, however, provide perspective on how these choices come together in aggregate.

The content of a science curriculum may be treated as a finite number of topics. The TIMSS science framework, for instance, contains 79 topics. The topics as defined in TIMSS are conceptual: each topic brings with it new content and new procedural demands. Using this framework, it is possible to count the number of topics that nations, states, districts, or schools expect to be taught each year at each grade. Our GTTM survey estimates these numbers for Ohio. To provide context, we compare them to data drawn from the 1995 TIMSS data set.

Figure 1. **Number of Topics in Ohio Districts' Science Curricula**

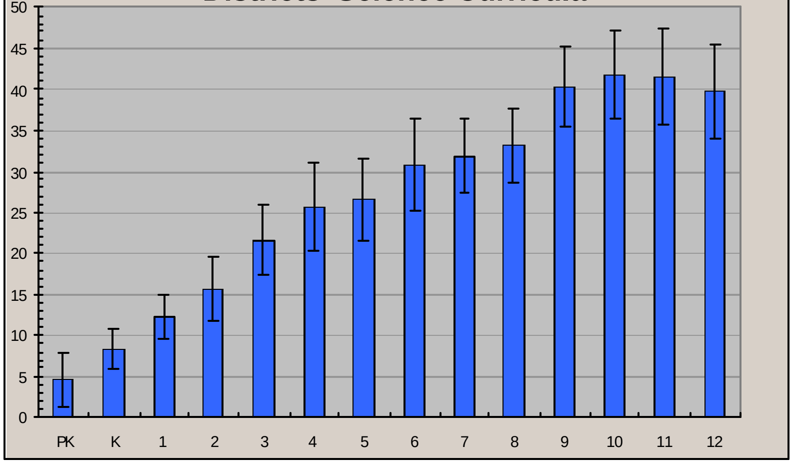


Figure 1 shows the steady growth from grade to grade in the number of topics in science that Ohio's districts intend teachers to teach and students to learn. Each bar in Figure 1 gives the average number of curriculum topics in science for a specific grade.[14]

By grade two, Ohio's districts expect students to have been introduced to about 15 science topics. That represents about 20 percent of all the science topics in the framework. This proportion jumps to over a quarter of all science topics by grade three. Over the middle grades the number increases to 33, or 42 percent of the topics by grade eight. This requires presentation of approximately one new science topic each week of the school year. Some of these topics each year build on prior learning; some are new that year.

In high school, the pace picks up a bit, the curricula including about 40 topics per year, half the total. However, the districts' intentions at high school—unlike at the elementary and middle schools level where all students are targeted by the curriculum—are for specific course sequences, and not all students take the same courses. In addition, many Ohio high schools do not require four years of science instruction of all their students.[15] In 1998, for instance, just less than three-quarters (74 percent) of Ohio's high school students were enrolled in a science course (Blank & Langesen, 1999, p. 22).[16] Still, for both high school and elementary school, the numbers presented in the last two paragraphs need to be put into perspective: Are they too much, too little, or about right?

Before addressing this question, however, we need to confirm that the averages do speak for most Ohio districts. Ohio prides itself on being a local control state. This could mean that local districts construct different curricula, fashioning instructional models that best suit local circumstances. That is to ask, do different districts teach different topics in science? That they teach differently is not evident in these survey data. Forty science topics, half the total, are present in well over 90 percent of all districts' curricula; over 80 percent of the districts indicate they intend to teach the same 66 topics, 84 percent of the topics in the TIMSS science framework.

Topics that do not appear in some districts' science curricula tend to be advanced: quantum theory, electro-chemistry, the relationships of mathematics and science. Typically, topics like these are reserved for Advanced Placement classes in high school, which some smaller districts do not have the resources to offer. Still, it is clear that most Ohio districts teach the same science topics at about the same rate of presentation. The question remains, is this pace too slow or too rapid?

Ohio Compared to the U.S. and Japan

One way to address this question is to compare Ohio's curricular intentions to intentions elsewhere. We concentrate on two issues: focus and challenge. By focus, we mean clarity and consistency in the pattern of teaching and opportunity to learn over time and across districts. By challenge, we mean the level of content teachers are expected to teach and the amount of learning expected of students.

We compare Ohio first to the U.S. and to Japan. By comparing to the U.S., it is possible to see if the charges of lack of curricular focus and content that is "a mile wide and an inch deep" leveled against the U.S. (Schmidt, McKnight & Raizen, 1997, p. 62, 121-3) apply to Ohio's science curriculum. In many of the international TIMSS analyses, Japan has been held up as one example of a high-performing nation that structures curriculum and instruction differently and successfully (Stevenson, 1998; Stevenson & Stigler, 1992; Stigler & Hiebert, 1999).

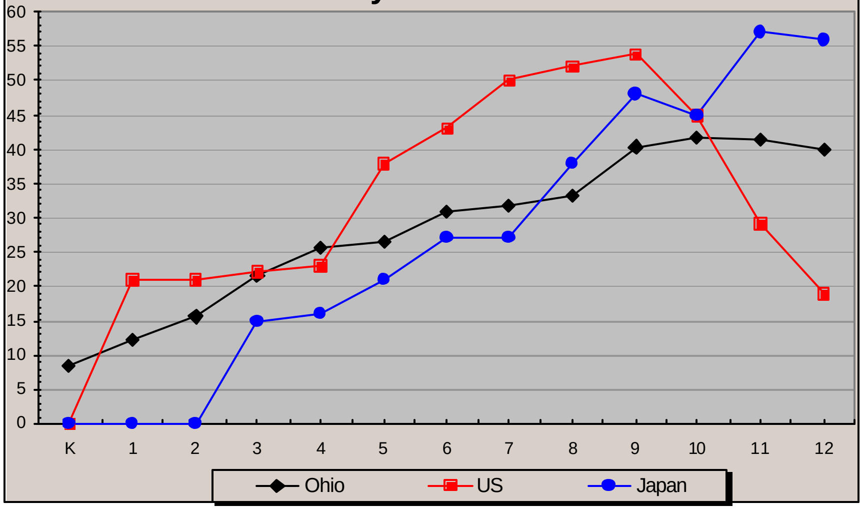


Figure 2. **Number of Science Topics, by Grade**

Figure 2 illustrates that in grades kindergarten to four, Ohio (indicated by black diamonds on the chart) intends to teach about the same number of topics as does the U.S. (the red squares). Thereafter, from grades five to nine, Ohio's districts continue to intend to teach more topics each year, but add considerably topics each year than is typical of the U.S.[17] However, for high school juniors and seniors the pattern reverses: the number of science topics in Ohio's districts' science curricula exceeds the number typical of most U.S. high schools.

Shifting the comparison to Japan (the blue circles in Figure 2), the similarity between the Ohio and Japanese profiles is close. The only differences are at the ends. Japan's curriculum does not expect teaching of science before grade three. And in late high school, more science topics are included than in Ohio. Elsewhere, the Ohio science curricula, at least in terms of the number of topics included, is a very close match with the Japanese profile.

Japanese curricula are often understood to establish the basics thoroughly before middle school and thereafter focusing curriculum each year on other topics (Stevenson & Stigler, 1992). U.S. curricula typically introduce topics earlier, teaching none deeply initially. Thereafter, they repeat topics annually, deepening instruction with time. This is the "spiral" pattern of curriculum exposure so common in U.S. schools.

Spiral patterns of curriculum development spread instruction in specific topics over many grades. More focused curricula tend to teach topics more exhaustively in fewer grades. In addition, as was evident in Figure 2, the U.S. spiral pattern touches on more topics each year than is typical in many other nations, many of which also have spiral elements in their science curricula. Teaching numerous topics each year is encouraged by, but is not a necessity of, spiral curricula.

Figure 3, on the next page, provides some evidence that speaks to these matters. However, an explanation of the graph is in order first. To the left appear the names of the categories and topics of the TIMSS science framework. For each

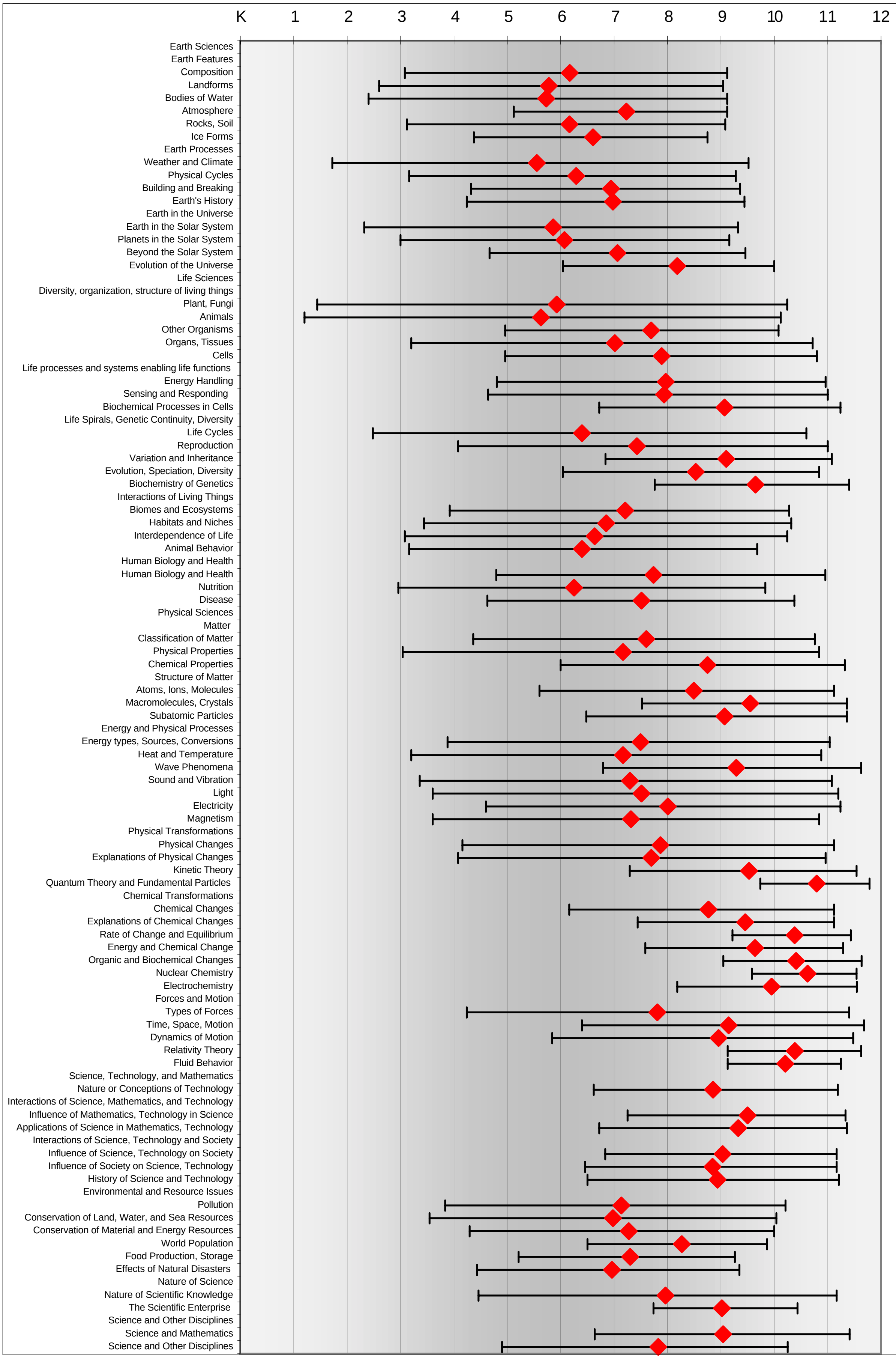


Figure 3. **Grade Range of Topics in Ohio Districts' Science Curricula**

topic, three data points appear on the graph. The red diamond indicates the average grade level, across the Ohio districts responding to our survey, at which a topic is expected to be taught. From this diamond, a line extends to the left until it reaches the grade level that represents where, on average across these districts, the topic is first introduced. To the right of the diamond, a line extends to the highest average grade level at which the topic is intended to be taught. Narrow extents from left to right suggest that students' exposure to a topic will be focused tightly, within few grades; broad extents suggest topics are taught repeatedly over multiple grades.

Figure 3 suggests a mix of focus and extent in Ohio. Just two science topics extend over ten grades in Ohio. These are both in the life sciences category, treating the structure and diversity of plants, fungi, and animals. These are very broad topics, able to be treated deeply in numerous ways. Almost half the topics (37) in the TIMSS science framework each span six grades in Ohio. Nine topics span no more than three grades. But, all 79 topics are addressed somewhere in most districts' intentions.

For the U.S. as a whole (see Figure 4 on the next page), some 17 science topics extend over ten grades.[18] Five topics span six grades. Another five topics span no more than three grades. Clearly, in terms of grade extents, the distributions of the science topics to be taught in the U.S. are less focused than is the case in Ohio. On the other hand, some 20 topics in the TIMSS science framework do not appear to be addressed at all in the typical U.S. school district.

Japan presents another alternative, as Figure 5, on page 11, confirms. Some 15 topics extend over ten grades, matching the U.S. in width. However, far fewer topics are omitted, 14 topics occur in three grades or less, four in six grades. The Japanese pattern within many categories of the TIMSS science framework is also distinct. More often than in the U.S. or in Ohio, Japan's pattern includes a broader extent for the basic knowledge in each framework category, followed by more focused instruction for the subsequent topics within that framework.

Figure 6, on page 12, provides one summary of these comparisons. It presents the average intended grade for each science topic for Ohio (black diamonds), the U.S. (red squares), and Japan (blue circles) and connects the dots to profile each science framework category. Despite the differences just discussed, at first glance, the profiles in Figure 6 appear to show considerable similarity between Ohio and Japan, with the U.S. showing the greater departures.

Ohio's districts intend that science topics be taught earlier than is the case in Japan. This is particularly true for four of the science framework categories:

- earth processes,
- earth in the universe,

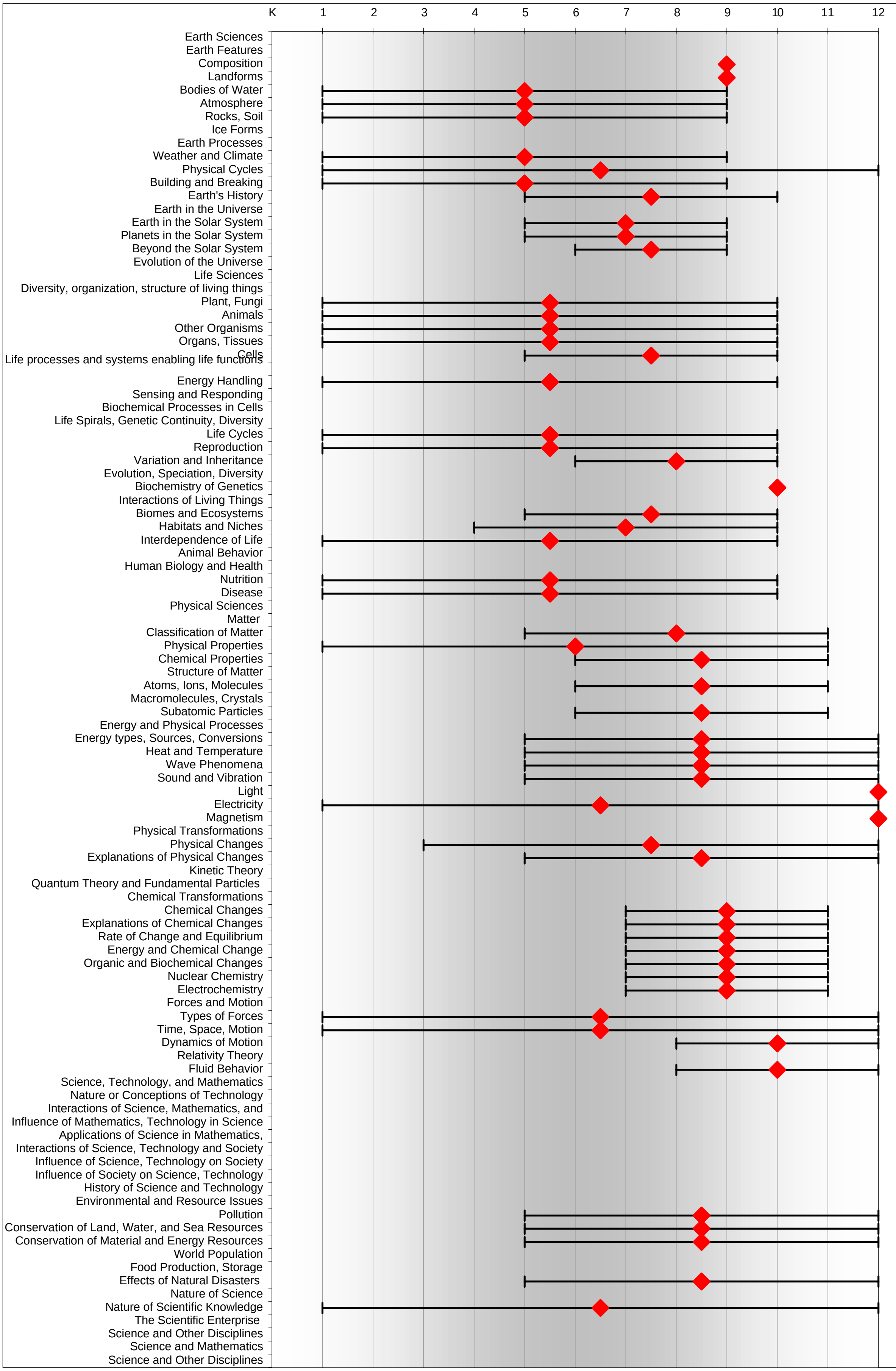


Figure 4. **Grade Range of Science Curriculum Topics in U.S.**

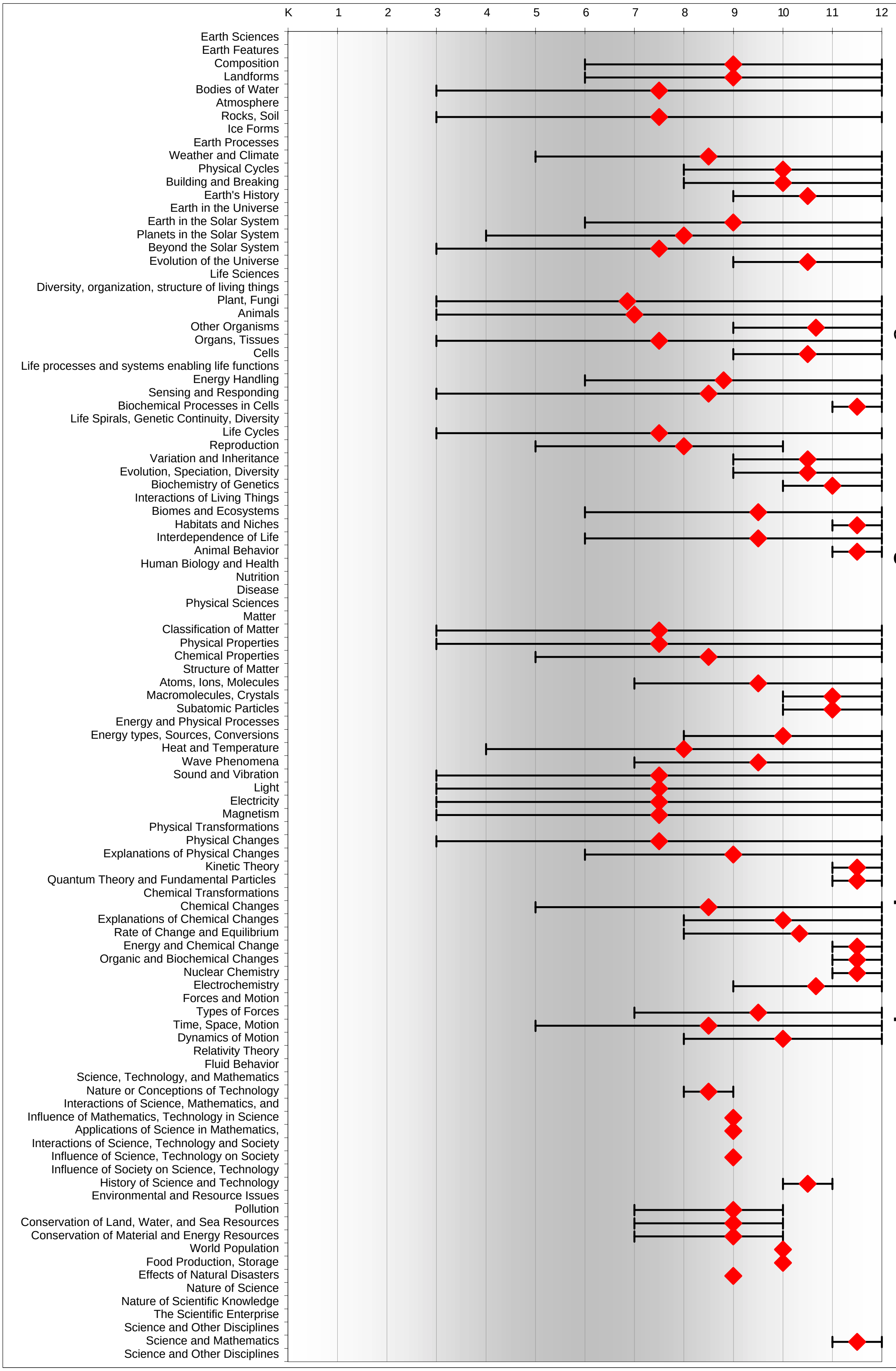


Figure 5. **Grade Range of Science Curriculum Topics in Japan**

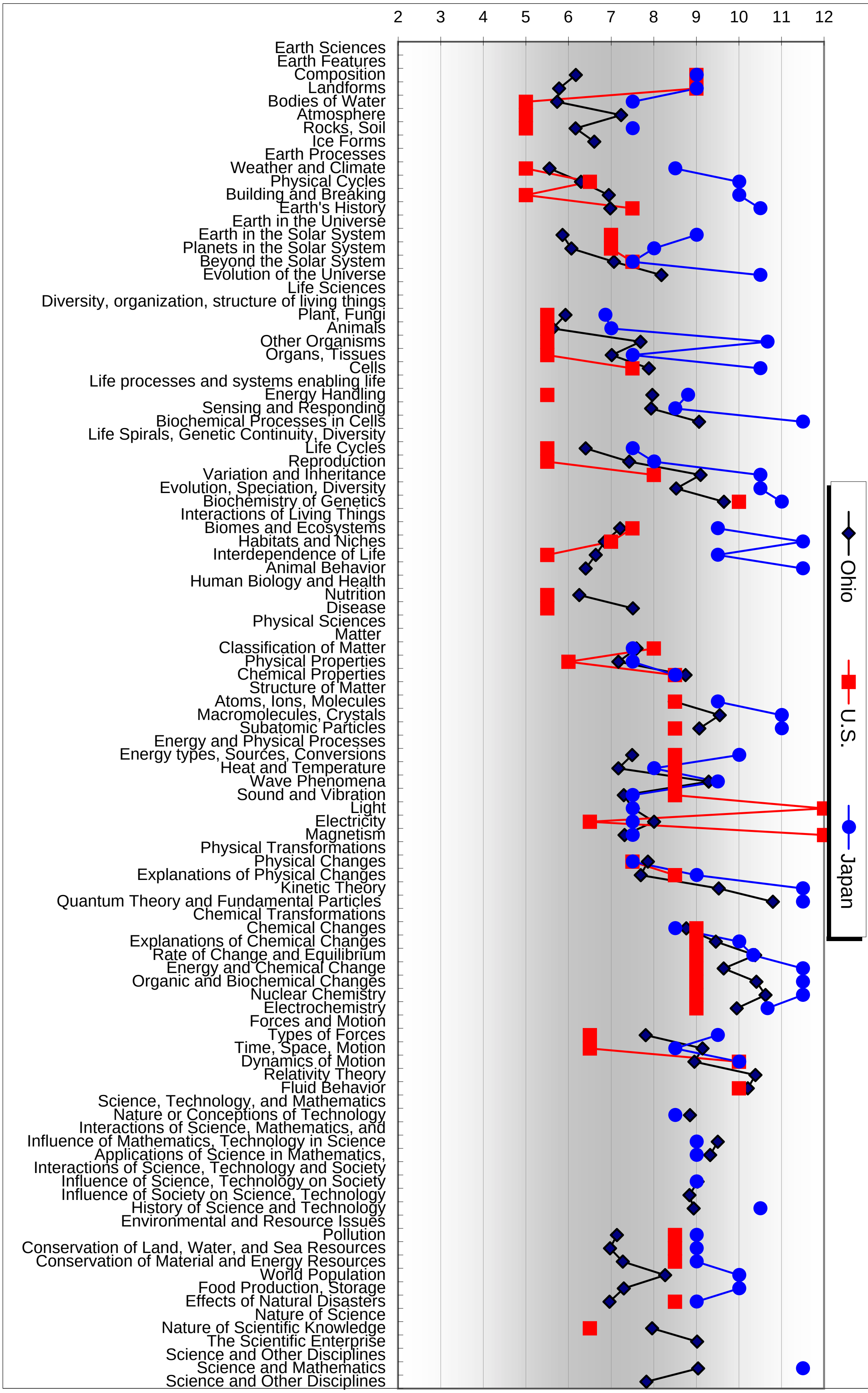


Figure 6. **Average Intended Grade for Science Topics, Comparing Ohio, U.S., and Japan**

- interactions of living things,
- environmental and resource issues.

Several other individual items also appear much later in Japan. Some, but not all of this is due to the lack of science in the curriculum of the lower primary grades in Japan.

More interesting are the profiles of intended progress through each category, as indicated by the lines connecting framework items within categories. The Japanese and Ohio profiles are strikingly similar, especially when contrasted to the U.S. data. For a number of categories in the science framework, Ohio shares both profiles and grade levels with Japan. These include the categories:

- matter,
- energy and physical processes,
- physical transformations,
- chemical transformations (excepting organic, nuclear, and electro-chemistry),
- forces and motion,
- history and philosophy of science and technology.

Most of these topics are treated in late middle and secondary school, both in Japan and in Ohio.

Compared to Ohio and to Japan, the U.S. expectations set many of the science topics in earlier grades. However, there is reason to be concerned about the accuracy of the U.S. data. They constitute a consensus agreement from a panel of national experts assembled by the U.S. National TIMSS Center[19] and are not the result of school staff reports, as are the Ohio data we use here. We expect that, had school and district staff been asked, the data in Figure 4 might look much different.

The following points serve to summarize this discussion of what Ohio's districts' science curricula expect:

- The addition of new topics to the science curriculum that districts intend schools to teach occurs steadily and systematically with grade, in less rapid fashion than for the U.S. as a whole. This bodes well for consistent teaching and learning.
- Like Japan, Ohio's intended science curriculum also frequently displays patterns of consistent growth in complexity within framework categories, unlike the U.S. pattern that has a less consistent appearance. This too bodes well for consistent teaching and learning.
- Still, Ohio's intended science curriculum contains a large number of topics, and many topics that are repeated, reinforced, or extended over numerous grades. No topic is excluded. Certainly, the Japanese pattern

is in this sense better articulated and more focused, with some elements of the TIMSS framework not taught at all and many confined to far fewer grades than is the case in Ohio. Even the U.S. science curriculum, at least as expressed by the data available to us, does not attempt to teach all 79 topics. With so many topics to teach, one has to wonder whether students' experiences in science will be deep enough to engage and challenge.

- With all the repetition in Ohio's curricular intentions, it is not clear how challenging this curriculum will be to students. If the spiraling is well done, with the steepness of the learning curve well matched to students' skills and knowledge, this repetition could provide challenging and deep exposure. However, it is also possible, if the curve is less steep, that instructional repetition and boredom, rather than learning, may be the typical experience for Ohio's students. Without careful planning and articulation, much of the science that eighth grade teachers teach may repeat what seventh graders were taught; worse, it may repeat what fourth graders were taught.

Many of Ohio's students no doubt are taught science well and with substance. However, these data leave open the possibility that some may receive much less. Still, what districts intend teachers to teach may, in fact, not be what teachers teach. We turn next to what Ohio's science teachers told us about their science teaching.

Science Content:
What Are Ohio's Students Taught?

On the next page, Figure 7 displays the science topics Ohio's teachers teach at grades 3 and 4. Similar figures will be presented for the other grades surveyed. We use this type of figure also to provide comparative data for the U.S. and for Japan. All the topics on these figures fall within the TIMSS framework. Still, somewhat different subtopics appear for different grade levels. In each case, the overall length of the horizontal bars gives the percentage of teachers who say they teach a topic. The shading within the bars indicates the average number of lessons devoted to each topic, with more teaching time showing darker and to the left.

Grades Three and Four

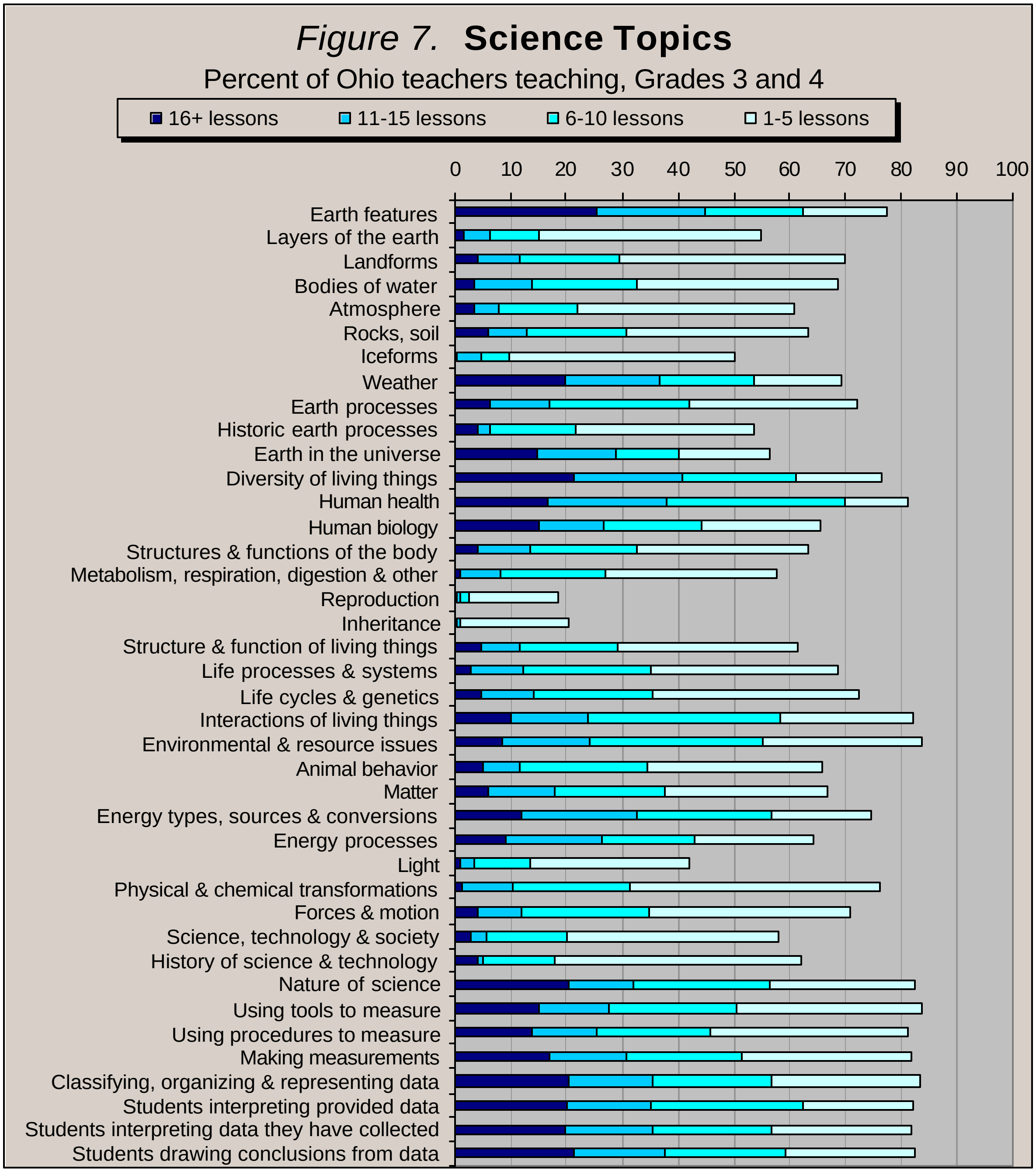
In Figure 7 on the next page, we can see that over 80 percent of Ohio's third and fourth grade science teachers spend some time teaching each of these topics:

- Human health
- Interactions of living things
- Environmental and resource issues
- Nature of science
- Using tools to measure
- Using procedures to measure
- Making measurements
- Classifying, organizing and representing data
- Interpreting provided data
- Interpreting own data
- Drawing conclusions from data

Another seven science topics are taught by 70 percent or more of Ohio's primary teachers, including:

- Earth features
- Earth processes
- Diversity of living things
- Life cycles
- Energy types
- Physical and chemical transformations
- Forces and motion

Roughly half the teachers say they teach all the topics in the TIMSS science framework. Only the topics of reproduction and inheritance are rarely taught at the primary level.



The Ohio model science curriculum contains four strands (Ohio Department of Education, 1999): Inquiry, Knowledge, Conditions, and Applications. A quick glance at Figure 7 shows many teachers spend considerable time on such TIMSS framework categories as nature of science, using tools and procedures to measure, making measurements, classifying and organizing data, interpreting data, and drawing conclusions. These are near the core of what the Ohio model science curriculum terms the Inquiry strand (although they do not tap it fully: the Ohio definition is richer and more complex).

From Figure 7 it is clear that, in the primary grades, the Inquiry strand is the dominant theme in science instruction for Ohio's public school students. Most of Ohio's primary level science teachers appear to devote at least a week or two to the Inquiry strand; about one quarter may spend as much as the equivalent of five weeks on this strand, possibly more.[20] This theme is an important one, and is consistent with the best current research on instruction.[21] However, its dominance for these teachers gives cause for wonder about the amount and nature of science content being taught.

Ohio's model science curriculum's Knowledge strand at grades three and four calls for instruction in motion and pattern, interrelationships and adaptability, elementary systems, elementary taxonomy, composition and structure, diversity, and change. The Applications strand calls for instruction about the environment and food chains, the natural and constructed worlds, ecology, and scientific and observation-based reasoning. This model, in the hands of a skilled and knowledgeable teacher, presents the student with a challenging and rich curriculum. However, in unskilled hands, it can easily turn into a content-less curriculum.

We cannot tell from Figure 7 that all Ohio third and fourth grade students are exposed to similar content. Although half these teachers say they teach 76 of the 79 topics in the TIMSS science framework, we do not know that these are the same teachers. Half could be teaching the topics in the top half of Figure 7, while the other half teaches those in the bottom half. We do know that three-quarters of the teachers agree they teach the same 18 topics. On the other hand, even data-based inquiry topics appear not to be taught by almost one in five teachers.

Figure 7 is also striking in terms of how much Ohio's teachers vary in how often each topic is taught. Teachers across the state do not report similar amounts. Typically, for most any topic, there are roughly equal proportions of teachers teaching it a lot or hardly at all. In fact, close inspection of our data suggests variation within districts and schools in this respect.[22] The science instruction Ohio students receive in grades three and four varies markedly from place to place.

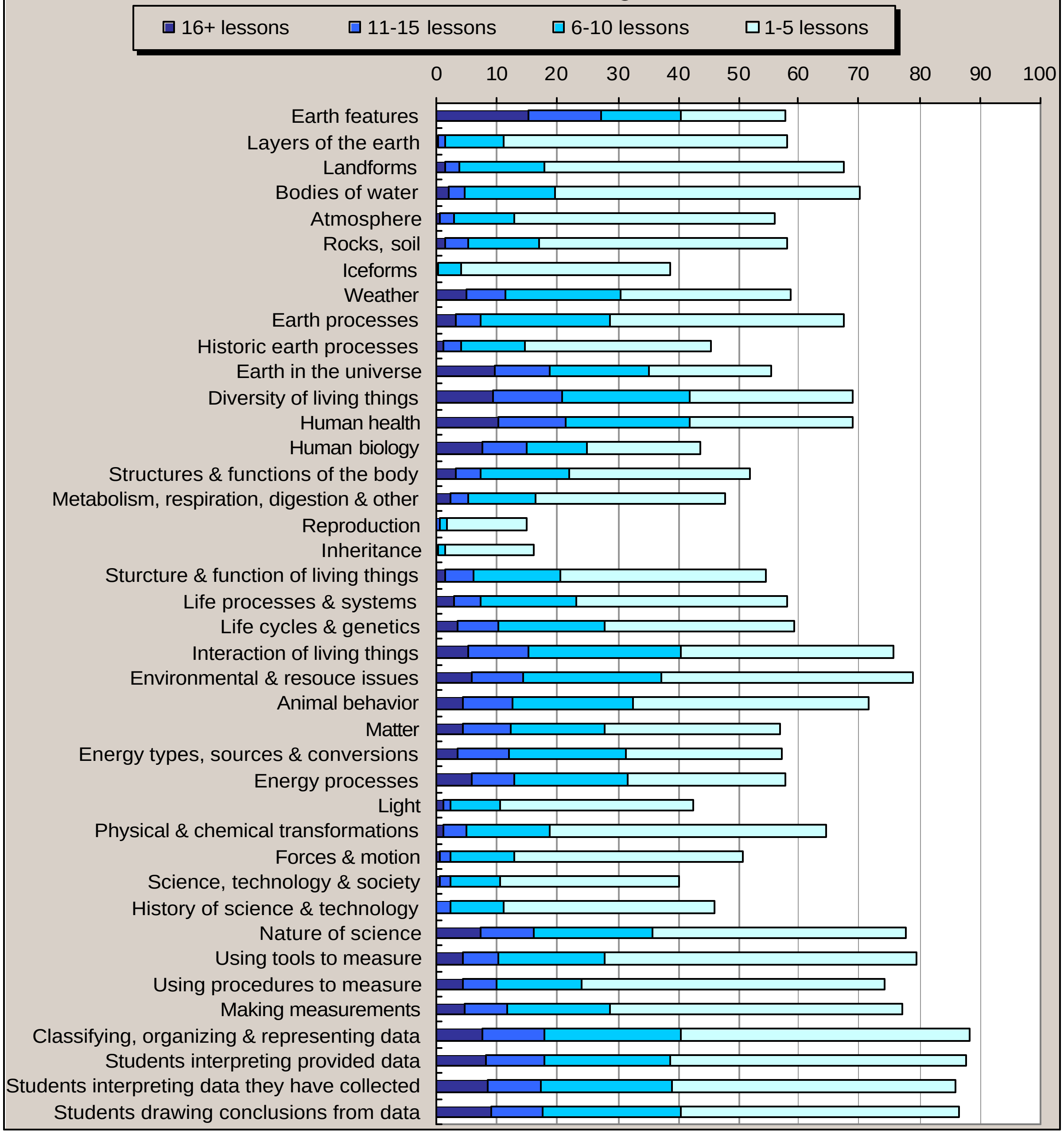
It is also necessary to compare this distribution of teaching time to the curriculum districts intend teachers to teach. Flipping back for a moment to Figure 3 on page eight provides some insight. None of these topics center in the primary grades; relatively few of them even reach into the primary grades. When the science topics are laid out in this form the procedural and analytic processes stressed in Ohio's Inquiry strand are subsumed under such topics as “Nature of Scientific Knowledge,” “The Scientific Enterprise,” and “Science and Mathematics.” Expressed in that form, they take on a philosophical aspect missing in the practical approaches Ohio's teachers, its model curriculum, and the national standards discussions favor.[23]

Many teachers do seem to be focusing on skills and knowledge the state, and presumably the districts, stress. Nevertheless, the lack of statewide consensus concerning topical content appears to produce a certain “looseness” in what content is taught, potentially undermining challenge and focus. This certainly adds difficulty to the task of well articulating the science curriculum an Ohio student experiences over his K-12 career.

It is useful to compare Ohio third and fourth grade teachers’ distribution of teaching time to that of similar teachers throughout the U.S. Figure 8 presents those data.

Figure 8. **Science Topics**

Percent of U.S. teachers teaching, Grades 3 and 4

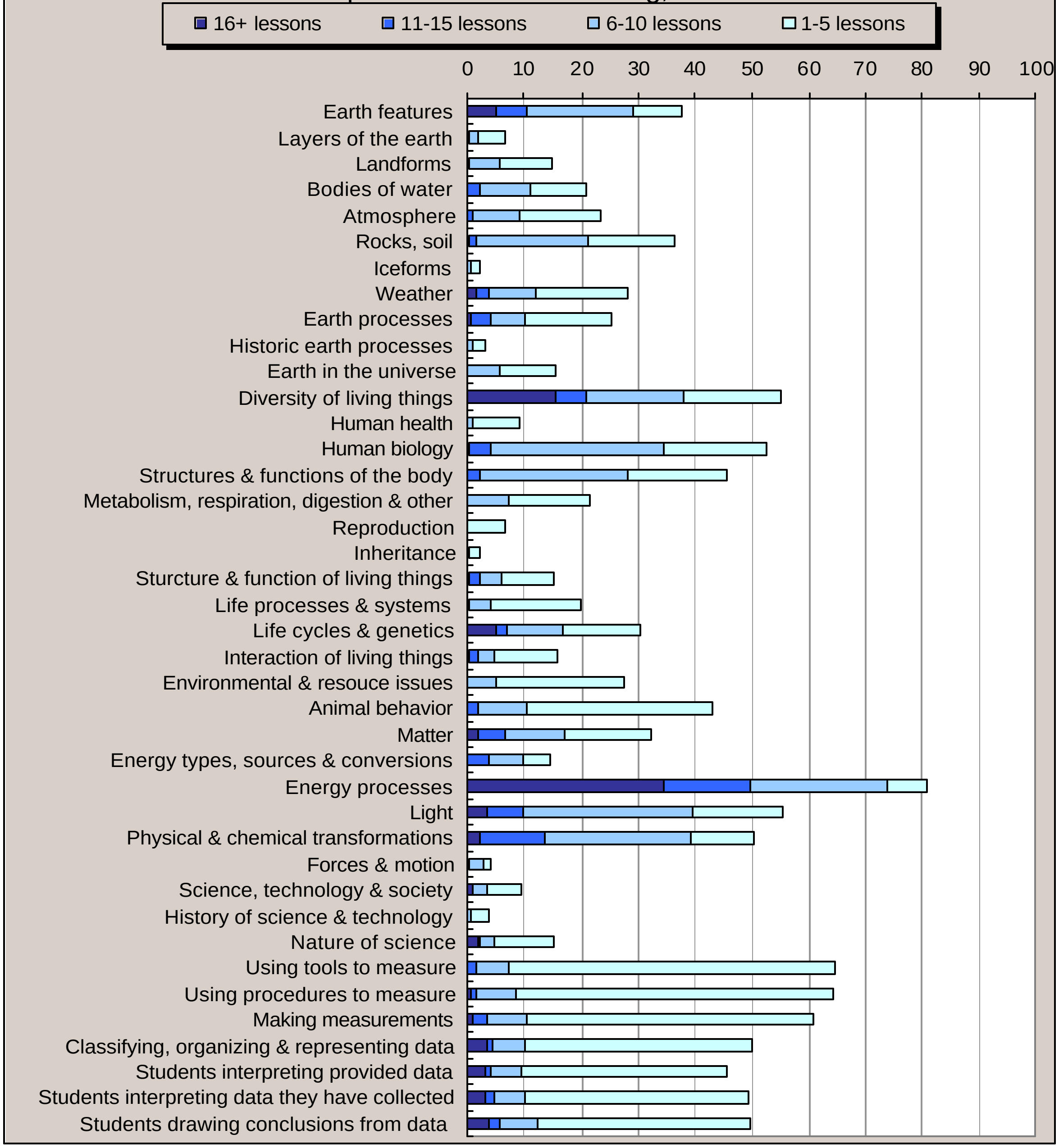


The U.S. profile is very similar to Ohio’s. However, a close look confirms that the proportions of teachers teaching individual topics for more than 15 lessons is even lower in the U.S. than in Ohio. Far greater proportions of teachers in the U.S. teach topics for less than one week. This suggest that Ohio’s primary school science instruction, despite the concerns just raised, may in fact be more focused and offer students more challenge and engagement than is typical elsewhere in the U.S.

However, what happens in other countries is worth a glimpse, if only to get a sense of alternatives. Figure 9 presents data for Japan’s third and fourth grades.

Figure 9. **Science Topics**

Percent of Japanese teachers teaching, Grades 3 and 4



Recall from Figure 2 that Japan's science curriculum does not call for any science instruction in grades three and four. Figure 9 confirms that some does indeed occur,[24] particularly energy processes and the diversity of living things. Significant numbers of Japan's teachers also focus on the topics of measurement and data (key aspects of Ohio's Inquiry strand), although they spend much less time there than do Ohio or U.S. teachers.

Nor is it clear that the extra time spent by U.S. teachers at this level pays off in higher student performance. According to the international TIMSS science results, both U.S. and Japanese third and fourth grade students performed well compared to other nations, well above the international mean (Martin et al., 1997). But Japanese students did achieve higher scores than U.S. students, if not statistically significantly higher. Whatever was being measured, despite much more science teaching in the early elementary grades in the U.S than in Japan, tested performance did not reflect this teaching difference.

Grades Seven and Eight

In Figure 10 on the next page, we display the results obtained when we asked Ohio's middle school science teachers what topics they taught and how often. Only nine topics are taught by 80 percent or more of the teachers. As in grades three and four, these consensus topics all relate to procedure, analysis, data, and the role of science, terms that link to Ohio's Inquiry strand. Another ten topics are taught by at least two-thirds of all the middle school teachers. These include:

- Earth features
- Earth processes
- Human biology and health
- Diversity and structure of living things
- Life processes and systems
- Types and properties of matter
- Structure of matter
- Energy types, sources, and conversions
- History of science and technology
- Environmental and resource issues

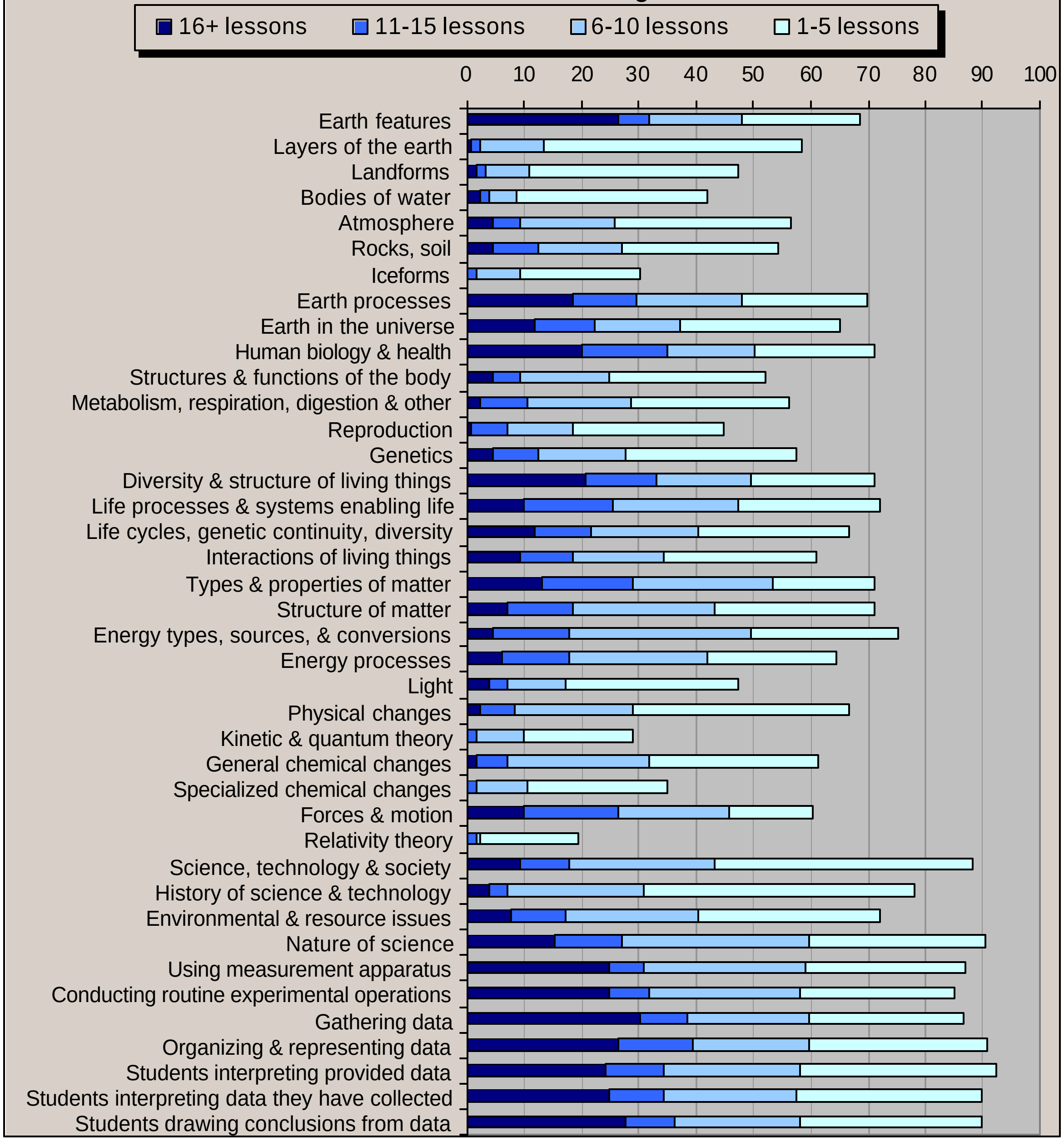
Again, this list is remarkably similar to the list of common topics for grades three and four, suggesting the possibility of repetition rather than deepening of instruction. Note also that while among these items are topics that more teachers devote multiple weeks to, large numbers do not teach them or teach them for less than a week.

The Inquiry and Application strands of the Model Curriculum seem well attended. The Knowledge strand may be less well served. The higher aspects of earth science, diversity in life forms, select topics in matter and energy get coverage.

However, most middle grade students can benefit from exposure to some deeper detail. There is little consensus among Ohio's middle school science teachers about how much work students need to begin to understand the core processes of biology, especially the topics of genetics and inheritance, keys to modern biological work. Most Ohio middle school students appear to be receiving some instruction in classical topics of physics like forces and motion. However, it is not clear that the kinds of issues that compel physical scientists today, such as light, energy, and kinetic theory, are being explored to any depth by Ohio's middle school students.

Figure 10. **Science Topics**

Percent of Ohio teachers teaching, Grades 7 & 8



Recall from Figure 1 (on page 5) that Ohio's districts expect over 30 TIMSS science framework items to be taught in seventh and in eighth grade. Topics that districts intended to be taught at this level but that apparently are taught for less than a week by most teachers in Ohio include:

- Earth's atmosphere
- The universe beyond the solar system
- Cells, tissues, organs
- Energy handling in biological systems
- Human biology and health
- Disease
- Energy types and conversions
- Light, magnetism, electricity

These are also key topics at this level in Ohio's model science curriculum. Certainly, the sheer number of topics intended and their complexity can be overwhelming. In the face of this, teachers need to make choices. These data suggest, however, that, as at third and fourth grade, different teachers make different choices. In the face of this, questions about the consistency of learning across Ohio and the articulation of learning between grades and buildings as students progress over time remain open.

Figures 11 and 12, on the next two pages, permit comparison of Ohio's seven and eighth grade science teachers' choices to the U.S. and Japan. Clearly, more of Ohio's middle school science teachers teach more topics more often that do other U.S. teachers. The primary foci of instruction appear similar, however. In terms of number of teachers teaching, the focus is on method and analysis, properties and structure of matter, and introductions to physical and chemical change. When the focus shifts to topics on which at least some teachers spend significant time, earth science, human biology and health, and diversity of living things join the list.

The Japanese pattern, however, is much different. Figure 12 shows a pattern of much more consistent concentration as well as consensus among teachers. Numerous subjects are not addressed. Most teachers focus on method and analysis, diversity of living things, life processes, matter and its structure and properties, energy, and general chemical changes. Nearly half also add material on human physiology and health. With this smaller set of topics, instruction can be made deeper. In addition, there is time for the extended exploration, discussion, and rehearsal necessary for efficient learning (Bransford, 2000, pp. 171-87) and so strongly advocated in Ohio's model science curriculum:

> School districts should emphasize the rigor of the science learning in each unit, not coverage of textbooks. The essence of the approach in this Model . . . is that a few units experienced in depth over time, using a variety of methodologies is the preferred strategy for optimal science learning (Ohio Department of Education, 1994, p. 15).

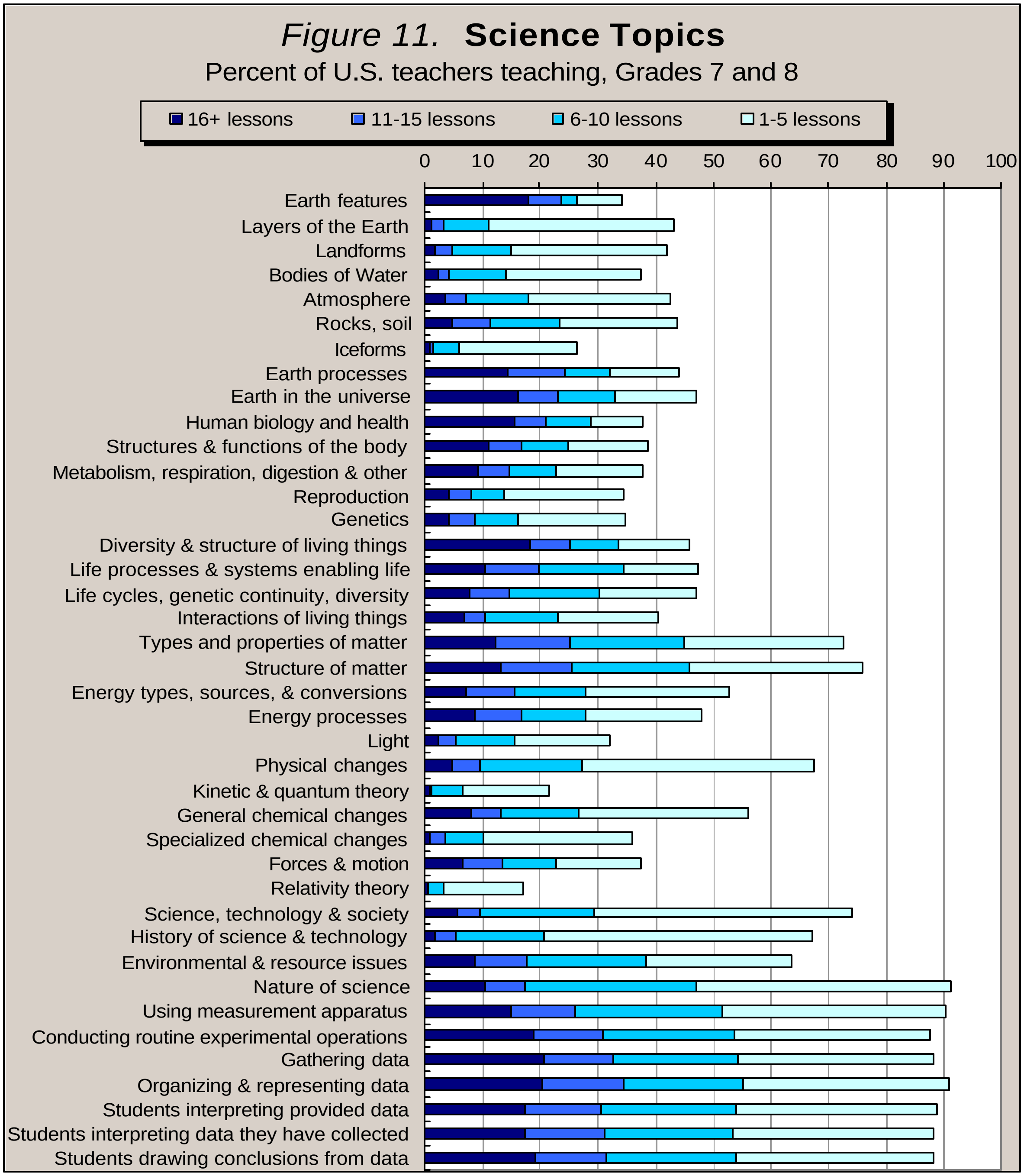


Figure 11. **Science Topics**

Percent of U.S. teachers teaching, Grades 7 and 8

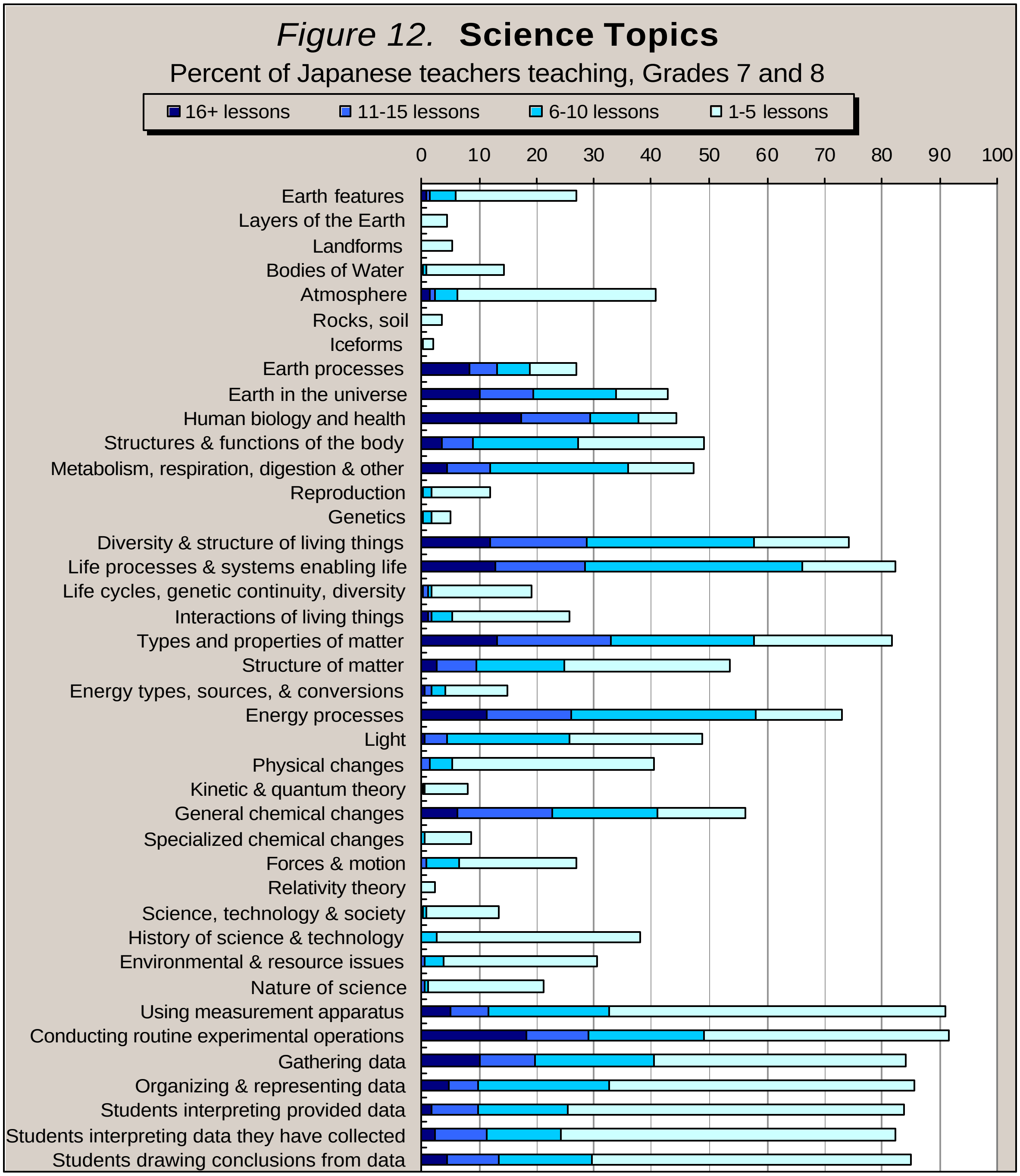


Figure 12. **Science Topics**

Percent of Japanese teachers teaching, Grades 7 and 8

Grade Twelve

Science is taught to all primary and middle school children in Ohio. That is not the case in high school. Ohio currently requires only one year of high school science, although many districts recommend more.[25] Consequently, many Ohio high school seniors do not enroll in any science course. A minority enrolls in college level or Advanced Placement courses. A few take remedial courses, or science electives.

Ohio and Illinois currently are the only states requiring just one Carnegie unit in science for high school graduation. Most states require two units. Twelve states require three units in science and one requires four (Snyder, 2000, pp. 166-160). However, Ohio's science requirements are changing. For the graduating class of 2006, two Carnegie units in science—one in biology and one in physical science—will be required.[26]

Exact data on high school course enrollments are difficult to obtain, in part because course titles are not consistent throughout the state. Historical course enrollment data[27] for Ohio's high schools, once definitional changes are accounted for, portray basically flat enrollment trends throughout the 1990s for the core high school science courses: biology, chemistry, and physics. Growth in enrollments in these courses matches (or slightly exceeds) the growth in the student population overall.

Table 1 presents one estimate of high school science course enrollments for the latest available reporting year, 1997-98.[28] Total high school enrollment was about 550,000 students. Of these, about 22 percent were seniors. We cannot tell from these data how many seniors were enrolled in science classes. We do know that most physics students in most high schools are seniors, implying that no more than a quarter of seniors would have been enrolled in that course. The best available evidence suggests that no more than a third, and probably considerably fewer, of Ohio's seniors are enrolled in science courses.

Table 1. **Science Enrollments in Ohio's High Schools**

Course	Enrollment
Biology	156,216
Chemistry	73,265
Physics	30,442
Earth science	28,257
Physical science	36,649
Environmental science	10,989
General science	69,379
Technology science	517

Figure 13, on page 26, reflects this variety. Given the above, it is necessary to remind that Figure 13 is not strictly comparable to the similar figures presented previously. Because so many seniors do not enroll in a science course, the percentages in Figure 13 do not speak to the entire grade; they speak only to that minority of seniors enrolled in science courses.

As in the lower grades, whatever the course, it is clear that methods of scientific inquiry and analysis take up a significant portion of class time. This focus is a hallmark of science instruction in Ohio's public schools at all levels. Figure 13 also

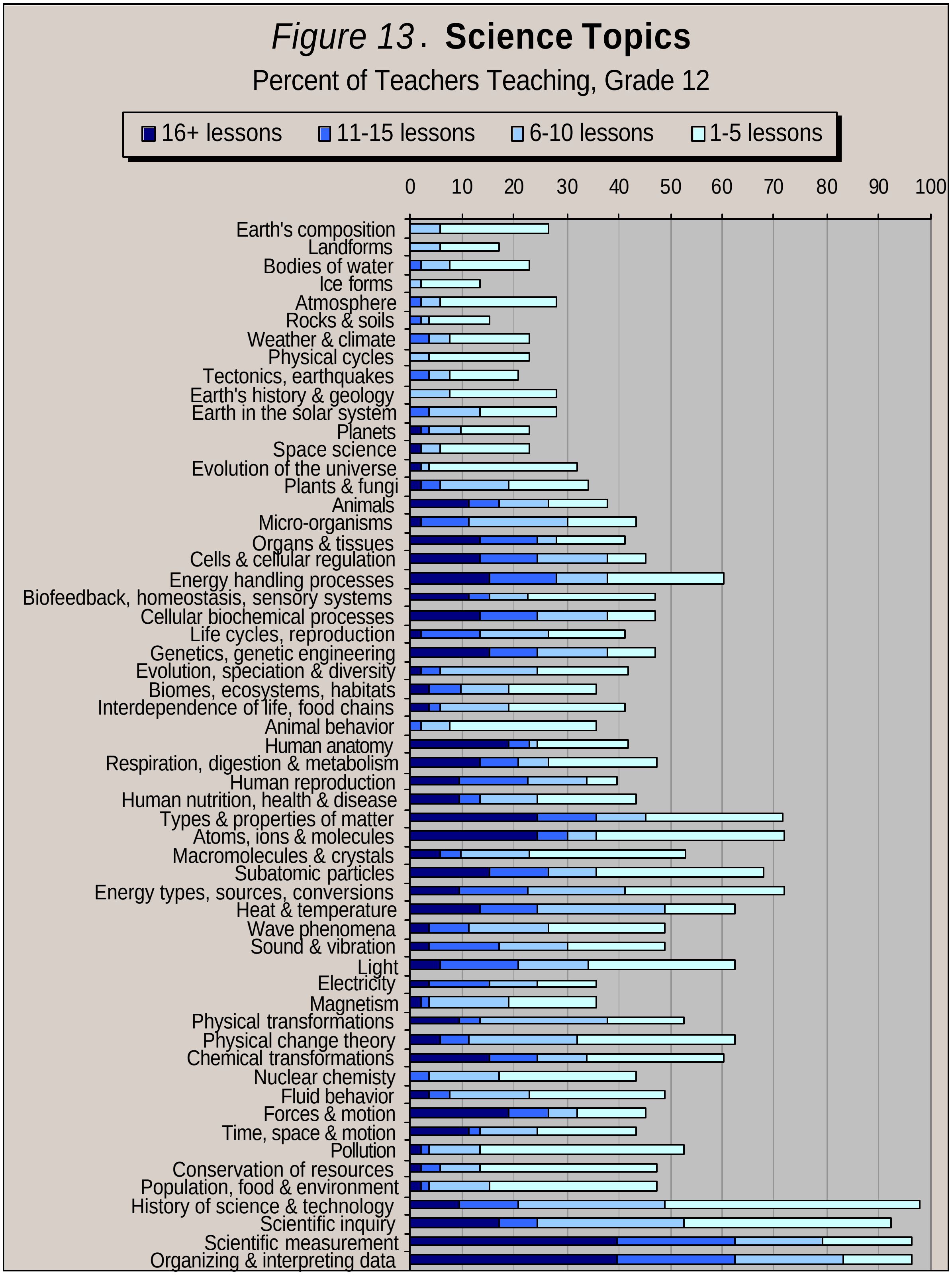


Figure 13. **Science Topics**

Percent of Teachers Teaching, Grade 12

confirms a point from the previous remarks in this section. Some students are doing remedial work: earth science courses are being given in grade twelve in some schools. Some students are taking biology or chemistry somewhat later than the norm. Physics gets its due. And Advanced Placement courses in human anatomy, advanced biology, and genetics are in evidence.

Still, it is difficult to determine from these data just how challenging this work is, that is, how well Ohio's students are being prepared in science. That Ohio's students are not being as well prepared in science as they could be is implied by the previous discussion, as well as other lines of evidence.

For instance, physics is a traditional, in the U.S., fourth year high school science course, for those students taking four years of science. During the 1990s the proportion of U.S. seniors enrolled in a physics course rose steadily, from about 20% of all seniors in 1990 to about 28 percent by 1998 (Neuschatz & McFarling, 1999, p. 3). While this is an improvement, it is necessary to observe that in many European and Asian nations virtually all secondary students take the equivalent of at least one full year of physics before graduation. Looked at another way, in the countries that performed best on the TIMSS physics exam in 1995, most of the advanced science students had taken the equivalent of two years of physics. The same could be said for only four percent of the U.S. advanced science students (Neuschatz & McFarling, 1999, p. 39).

Another instance may be drawn from data obtained in 1996 when some 14,000 Ohio seniors in 119 public high schools were tested using the *WorkKeys*® instrument developed by ACT, Inc.[29] This assessment links to a series of occupational profiles. It compares students' tested skills to seven skill levels, based on the requirements of real jobs. The skill set that is most closely related to science is Applied Technology, defined as solving job-related problems using principles of mechanics, electricity, and fluid dynamics as they occur in workplace equipment. The outcomes? Forty-six (46) percent of Ohio's graduating seniors performed at Level 3 in this area, the level of skill typical of such job titles as laborer, janitor, or administrative assistant. Twenty (20) percent reached Levels 4 or 5: secretary, shipping clerk, machine operator, industrial cleaner, or customer service representative; draftsman, machinist, industrial engineer. None reached a higher level. Fully one-third did not even reach Level 3.[30]

Seniors who go on to college will eventually acquire better skills. However, one-third of Ohio's graduating seniors do not go on to college. These are probably also the lowest scorers in the *WorkKeys* sample and those who took minimal science in high school. Their prospects for well-paying work in the technological sector are not good.

While jobs requiring science and technology skills are important to Ohio's economy—and obviously pose rewards for individuals, most good jobs in the current economy and that of the near future are in the office, not necessarily in science and technology (Carnevale and Rose, 1998).[31] These jobs require the skills and knowledge provided by a college education. Mastery of scientific habits and tools of inquiry is important for technical and for office work. But, substantive scientific content knowledge and application skills are necessary for college entry and subsequent success.

Another example may be observed in Ohio's treatment of evolution. Evolutionary concepts and approaches, whether personally agreed to or not, are central to a large sphere of scientific thought, not just to biology and ecology. Ohio is one of five states that avoids the use of the term in formal statements about what students should know and be able to do in science (Lerner, 2000). How individual districts and teachers treat the issue is unknown. That the state's model science curriculum, Learning Outcomes, and other statements provide no guidance on this critical (and volatile) issue hardly supports teachers' efforts to guide students' learning.[32]

The Capacity of Ohio's K-12 Science System:
What Resources Do Teachers Use?
What Do We Know about the Quality of those Resources?

A primary determinant of the capacity of Ohio's science system to deliver quality instruction is, of course, its teachers. We did not directly investigate the training, skills, capacity, capability, motivation, or other characteristics of Ohio's teaching force.[33] Nor did we investigate the quality of the formal support structures in place for teachers and teaching, such as the Regional Professional Development Centers, the Ohio Department of Education, and districts' and schools' efforts to hire skilled staff, train and motivate them. We also did not examine Ohio's teacher preparation institutions. Each of these deserves close scrutiny, and we know that there is considerable energy currently to improve them (American Council on Education, 1999; Belden, 1999; Darling-Hammond, 1999; National Commission on Teaching, 1996; National Science Board, 1999; National Research Council, 2000*a* & 2000*b*).

We focus here on where teachers seek support in their daily work and what resources they use to decide the details of the science they teach and how to teach it. One question in our survey asked "In planning science lessons, what is your main source of written information?" The teachers chose one of the following eight options: AAAS[34] or other national standards document, the Ohio Proficiency Test guidelines, Ohio's model science curriculum, the local district curriculum, a school curriculum document, the teacher edition of a textbook, the student edition of a textbook, or some other resource.
Table 2 presents the responses.

Table 2. **Main Source of Information Teachers Use to Decide What Science Topics to Teach** (in percent)	**Grade**		
	3 & **4**	**7** & **8**	**12**
AAAS standards	1	3	13
Ohio proficiency test guidelines	22	24	4
Ohio model curriculum	19	10	7
School district curriculum guide	40	37	37
School curriculum guide	9	16	17
Textbook, teacher edition	5	6	9
Textbook, student edition	1	2	9
Other resources	2	3	4

District and school curriculum guides dominate teachers' decisions about what to teach, accounting for about half of the teachers. This supports Ohio's vision of itself as a local control state. However, state-mandated accountability, e.g. the Proficiency Tests, is also engaging teachers' attention: the Learning Outcomes are a primary decision resource for just under a quarter of the teachers at the grade levels where these tests are given in science.

About one in five primary science teachers consults the model science curriculum prepared by the Ohio Department of Education in deciding what to teach. This drops to one in ten at middle school and one in 14 by the end of high school. However, the Model Curriculum document is not aimed at classroom teachers, but rather at district and school leadership for curriculum development. That 19 percent of the primary science teachers directly acknowledge this document shows its support at that level. This statistic may also suggest that local curricular materials need supplementation.

National science standards, such as those published by AAAS, play a direct role in very few Ohio K-8 teachers' decisions about what to teach. Textbooks too play only a small role. In high school, both of these become a little more influential, but local school syllabi play a larger role.

When these questions were asked in TIMSS, there was a clear distinction intended between national, state, and local standards. Since Ohio has not formally adopted statewide standards that set out in some detail what students should know and be able to do, it is problematic to compare Ohio's responses to this question to other nations'. Suffice it to say that internationally national and state standards play a much larger role than what was reported in Table 2 (Schmidt & Prawat, 1999).

Knowledge about the resources teachers use to choose *what* they teach may be less enlightening than the sources teachers use to choose *how* they teach. Individual teachers typically are more active in pedagogical than in curricular decision making (Cohen, 1990; Lortie, 1975). In most schools, the latter is an external charge or the result of group choice. In relatively few schools is the former consistently prescribed.

Table 3 presents data on teachers' choices about practice in Ohio. Textbooks dominate these decisions for about 40 percent of the primary and high school teachers. For middle school science teachers, "other resources" are more important than textbooks. These "other resources" are also important in primary and secondary school. Teachers do not appear to find the available resources provided by state, district, or school particularly helpful for these decisions. We need to know more about the other resources that science teachers do use. They provide a direct opening to influencing teacher decision making—and we do not know what this avenue is.[35]

Table 3. **Main Source of Information Teachers Use to Decide How to Present a Science Topic** (in percent)	**Grade**		
	3 & **4**	**7** & **8**	**12**
AAAS standards	2	3	6
Ohio proficiency test guidelines	10	7	2
Ohio model curriculum	5	15	4
School district curriculum guide	10	10	2
School curriculum guide	4	6	8
Textbook, teacher edition	35	21	25
Textbook, student edition	5	3	15
Other resources	28	35	38

Textbook Use

Teachers' ideas about science, science teaching, and science learning will directly influence what science they teach and how they teach it (Bransford, 2000, p. 155). If the teacher's knowledge of science is deep, if the teacher's pedagogical skills are broad and well-practiced, if the teacher's knowledge of how students—one by one and in groups—learn is well-founded, if the teacher remains at all times alert to the information flow in and around and through the class, then it is likely that learning will occur optimally and for all.[36] But, those are a lot of *if*s. In most science classes, instructional life will be somewhat less than optimal. Good instructional resources will be a necessity.

If how teachers present science is, for most, based on a textbook's selection and presentation of material and pedagogical suggestions, then we need to know how much time teachers devote to textbook-based instruction, and we need to know about the content and quality of the chosen textbooks, not to mention the "other resources" of Tables 2 and 3.

We asked teachers to tell us what textbooks they used and how often they used them. Table 4 confirms that science teaching in Ohio is heavily influenced by textbooks, particularly in high school. Half the twelfth grade teachers say they use textbooks over half the time. Almost one-quarter say they use them more than three-quarters of the time. (At the other end, one-quarter say they use them less than one-quarter of their teaching time.) At the primary and middle school levels, about 40 percent of the teachers base half or more of their science teaching time on textbooks.

Table 4. **What Percent of your Weekly Science Teaching Time Is Based on your Textbook?** (in percent)	**Grade**		
	3 & **4**	**7** & **8**	**12**
No text used	26	10	4
Less than 25% of the time	17	30	21
26-50% of the time	14	22	26
51-75% of the time	22	26	26
76-100% of the time	20	13	23

Fully one-fourth of Ohio's third and fourth grade teachers do not use a textbook at all when teaching science. In addition, it can be seen in Table 4 that in five or six of every ten science classrooms in Ohio more than half of instructional time is based on resources other than textbooks. These numbers suggest considerable variability in coverage and focus among districts, schools, even teachers. Textbooks are an important part of instruction for most of these science teachers; at the same time, it is clear they are not enough.

This pattern of textbook use (or lack of use) is, however, fairly similar to what occurs elsewhere in the U.S. According to data collected during TIMSS in 1995, one of every 20 U.S. middle school science teachers says (s)he does not use a textbook, compared to one in 10 in Ohio. Just over a quarter of these U.S. science teachers base half to three-quarters of their teaching time on a textbook, just as in Ohio. Just under a quarter of U.S. teachers base more than three-quarters of their teaching time on textbooks, a little more than is the case in Ohio.[37]

Given the mixed reputation of textbooks,[38] not using a textbook may be a sign of more enlightened teaching. Hence, it makes sense to ask, do Ohio's teachers who rely on textbooks less think differently about *what* they choose to teach? The answer appears to be “yes, somewhat.” At grades three and four, teachers who do not use science textbooks are more likely to depend on district curriculum guides to choose what to teach. They also depend much more on “other resource books” to decide how to teach. At middle school, the Ohio model science curriculum plays a somewhat greater role in topic choice for teachers who do not use textbooks. However, because there are not many teachers in our sample who do not use textbooks, these comparisons cannot be extended further.

Textbook Choice and Textbook Quality

Table 5 displays the science textbooks used in Ohio’s third and fourth grade classrooms. Sixteen books are listed, but two are somewhat more popular than the others. The Scott Foresman/Addison Wesley *Discover the Wonder* series is used in about a quarter of Ohio’s classrooms. One in six classrooms uses the MacMillan/ McGraw-Hill *Science Series*. Another 14 texts were used by the teachers we sampled. Clearly, no single text dominates at this level, although most appear to be fairly traditional textbooks for this level. One exception is the *Full Option Science System* developed at the University of California at Berkeley and distributed by Britannica. It is not possible to tell from this list that (or where) teachers focused their science instruction.

Table 5: **Science Textbooks in Use in Grades 3 and 4 in Ohio**

Publisher	Textbook	Percent of Teachers
Scott Foresman/Addison Wesley	Discover the Wonder	24.5
MacMillan/McGraw-Hill	Science Series	16.1
Silver Burdett Ginn	Science Horizons	7.7
Harcourt Brace	Science Anytime	7.0
Holt Rinehart & Winston	Holt Science	7.0
Scott Foresman/Addison Wesley	Destinations in Science	4.9
Silver Burdett Ginn	Discovery Works	4.9
Addison Wesley	Science	4.2
MacMillan/McGraw-Hill	Science in your World	4.2
Silver Burdett Ginn	Science	4.2
Scholastic	Scholastic Science Place	3.5
UC--Berkeley	Full Option Science System (FOSS)	3.5
McGraw-Hill	Gateways to Science	2.8
Merrill	Science	2.1
Heath	Science	0.7
Silver Burdett Ginn	Accent on Science	0.7

Recently, several appraisals of U.S. school science and mathematics textbooks have been published. Elementary science texts have so far not been evaluated while middle school mathematics texts have seen the most frequent scrutiny. Project 2061 of the American Association for the Advancement of Science (AAAS) has been at the forefront of this work. We include their findings in the next several tables.[39]

The AAAS evaluations were released in September 1999 and examined how well science textbooks help students learn key ideas in the sciences. The AAAS work is based on an emerging national consensus among educators and scientists on what all K-12 students need to know and be able to do in science, mathematics, and technology. In science, this consensus is well voiced in the National Research Council’s (1996) *National Science Education Standards.* The evaluation procedure was rigorous, involving independent teams of middle school teachers, curriculum specialists, and professors of science education. The process the teams used was developed and tested over three years, involving the collaboration of some 100 experts and funded by the National Science Foundation (cf. Roseman, Kesidou, & Stern, 1996).

Table 6 lists the science textbooks used by our sample of Ohio's seventh and eighth grade science teachers. There are 14 books listed. The earth, life, and physical sciences appear to form the core of these books' content. This supports the data from Figures 4 and 10 earlier, on Ohio's districts' intentions for the curriculum for this level and on the science topics these teachers said they focused on.

Four textbooks are more popular than others, in use in almost two-thirds of the middle school classrooms. Two of the four—Glencoe/McGraw-Hill's *Science Interactions* and Holt Rinehart and Winston's *SciencePlus*—are used in about 40 percent of Ohio's seventh and eighth grade classrooms. However, these two, as well as three of the next most popular four, all received *unsatisfactory* ratings from AAAS. None of the science textbooks used by our sample of teachers was judged *satisfactory* by the AAAS reviews.

Table 6. **Science Textbooks in Use in Grades 7 and 8 in Ohio**

Publisher	Textbook	Percent of Teachers	Project 2061 Rating[a]
Glencoe/McGraw-Hill	Science Interactions: Books 1, 2, & 3	21	U
Holt Rinehart & Winston	SciencePlus	18	U
Prentice Hall	Exploring Earth Science, Physical Science	13	
Glencoe/McGraw-Hill	Earth, Life, Physical Science	13	U
Prentice Hall	Science	9	U
Scott Foresman/Addison Wesley	Science Insights	6	U
Prentice Hall	Science Explorer	5	
Silver Burdett Ginn	General Science: Books 1 & 2	4	
Globe Fearon	Concepts & Challenges in Earth/Physical Science	2	
Heath	Life Science, Earth Science, Physical Science	2	
Silver Burdett Ginn	Focus on Life Science	2	
Merrill	Principles of Science: Books 1 & 2	1	
Science Curriculum	Introductory Physical Science	1	
Silver Burdett Ginn	Natural World	1	

[a] Project 2061 of the American Association for the Advancement of Science (AAAS) rated middle school science textbooks as *satisfactory* (S) or *unsatisfactory* (U). Not all available textbooks were evaluated.

Table 7, at the top of the next page, paints a much more diverse picture for the senior hear of high school. Twenty-nine textbooks are listed. These range across earth science, biology, chemistry, physics, anatomy, and astronomy. There are introductory high school science texts, advanced placement manuals, and collegiate texts. Clearly, there is considerable variability in what is taught at this level. However, science is not a required course for Ohio's seniors.

What we have in Table 7, then, is a display of textbooks for a broad mix of courses offered to some of Ohio's seniors. These include remedial or introductory science courses for a few, chemistry or physics courses in schools with traditional college preparatory tracks, as well as advanced placement work in anatomy and biology for students with a strong focus in the life sciences—and the good fortune to be enrolled in schools able to offer such advanced work. However, the fact remains that most of Ohio's seniors are not enrolled in any rigorous science course.

Table 7. **Science Textbooks in Use in Grade 12 in Ohio**

Publisher	Textbook	Percent of Teachers	Project 2061 Rating[a]
Glencoe/McGraw-Hill	Physics: Principles & Problems	10	
Prentice Hall	Biology: The Study of Life	10	P
Addison Wesley	Conceptual Physics	6	
Holt Rinehart & Winston	Modern Physics	6	
Addison Wesley	Chemistry	4	
Glencoe/McGraw-Hill	Biology: The Dynamics of Life	4	P
Glencoe/McGraw-Hill	Merrill Chemistry: A Modern Course	4	
Holt Rinehart & Winston	Modern Biology	4	P
McDougal Littell	Heath Chemistry	4	
Saunders	The Human Body: Concepts of Anatomy & Physiology	4	
Scott Foresman/Addison Wesley	Human Anatomy & Physiology	4	
Addison Wesley	Physics	2	
Benjamin Cummings	Biology	2	
CEEB	AP Biology Manual	2	
Glencoe/McGraw-Hill	Physics	2	
Harcourt Brace	The World of Biology	2	
Heath	Earth Science	2	
Heath	Fundamentals of Physics	2	
Holt Rinehart & Winston	Biology: Principles & Explorations	2	P
Holt Rinehart & Winston	Chemistry: Visualizing Matter	2	
Holt Rinehart & Winston	Modern Chemistry	2	
Holt Rinehart & Winston	Modern Human Physiology	2	
McGraw-Hill	Environmental Science: A Global Concern	2	
Prentice Hall	Chemistry: An Analytical Approach	2	
Prentice Hall	Exploring Physical Science	2	
Prentice Hall	Physics: Principles with Applications	2	
Scott Foresman/Addison Wesley	Essentials of Human Anatomy...	2	
Scott Foresman/Addison Wesley	Science Insights	2	
Wiley	Astronomy: The Evolving Universe	2	

[a] Project 2061 of the American Association for the Advancement of Science (AAAS) rated high school biology textbooks on a five-point scale: *excellent* (E), *good* (G), *satisfactory* (S), *fair* (F), or *poor* (P). Not all available biology textbooks were evaluated.

For those Ohio seniors who are enrolled in science courses, the quality of textbooks remains a concern. In its review of high school biology textbooks, for instance, Project 2061 found none acceptable. Ten biology textbooks were evaluated on 16 instructional categories in each of four key topics, 640 ratings in all. Across these 640 ratings, the Project 2061 teams gave only 3 excellent, 7 good, and 25 satisfactory ratings. From its perspective, the biology textbooks available to the U.S., and Ohio's, secondary schools are clearly inadequate. In the words of the project's director, George Nelson, these texts "provide only fragmentary treatment of fundamentally important concepts," focusing instead on vocabulary, isolated facts, and unnecessary detail (Project 2061, 2000). Ohio's high school teachers' choice of textbooks cannot be expected to do better than what is available to them.

The textbooks identified in Tables 5, 6, and 7 for Ohio are similar to the choices made elsewhere in the U.S. Additional confirmation for this similarity comes from reports by the American Institute of Physics. According to a survey of high school physics teachers nationally in 1997 (Neuschatz & McFarling, 1999, p. 5) the most popular regular first year physics textbook was *Physics: Principles and Problems*, published by Glencoe/McGraw-Hill. Table 7 confirms this is also Ohio's physics teachers' first choice. Nationally, the most popular secondary physics text for nonscience students was *Conceptual Physics* published by Addison Wesley. In Ohio, this is the second most used physics text.

Tables 5, 6, and 7 also suggest that the popular textbook choices typically are not those that the experts favor. However, it is also apparent that the experts have little positive to say about nearly all the science textbooks available for the middle and secondary school level. Expert knowledge and the science textbook industry seem particularly out of sync.[40]

The science standards advocated by the American Association for the Advancement of Science and the National Research Council began to appear in the late 1980s. The positions and beliefs underlying these reformist standards were highly influential in the state standards movement of the 1990s. Ohio’s model science curriculum was an early example among the states of this view. These changes have influenced the focus, format, and content of textbooks. Still, it takes multiple years for such changes to make it through the production process and appear in printed form.

From Table 8 we can see that well over half of the science textbooks that Ohio’s students opened in the fall of 1999 were printed before 1996 and therefore were little likely to have been influenced by the emerging reformist consensus. Within this context, Ohio’s middle school students were somewhat more likely to have had access to more recent textbooks, it would seem. The primary grade students used the oldest textbooks.

Table 8 . **Publication Dates of Ohio's Science Textbooks**
(in percent of teachers using)

Year	Grade 3 & 4	Grade 7 & 8	Grade 12
1999	0.0	10.1	2.1
1998	0.0	2.0	8.3
1997	6.0	29.3	8.3
1996	11.9	2.0	8.3
1995	31.3	23.2	31.3
1994	3.7	5.1	8.3
1993	4.5	17.2	6.3
1992	8.2	0.0	6.3
1991	4.5	3.0	4.2
Older	29.9	8.1	16.6

If the science texts Ohio’s teachers and students use are not informed by the best recent research about learning and the teaching of science, then it is likely that instruction will be inefficient and may align poorly with Ohio’s proficiency tests. In Ohio’s southeastern Appalachian region, for instance, this appears to be exactly what happened. An analysis of proficiency test data for six districts there confirmed that “the materials and instructional strategies used in most schools covered only three of the seven areas emphasized in the state assessment” (Dreher, 2000, p. 9).

Understanding the Evidence about Textbooks

We want to believe, and teachers want to believe, that textbooks make a difference. Still, the foregoing evidence and discussion raises a variety of doubts and concerns that need to be addressed.

- Is it possible that there are no substantive differences among textbooks? School staff may be selecting among textbooks that do not meaningfully differ. A critical question, of course, is whether the teachers who make up textbook adoption committees are aware that different, and possibly superior, science textbooks and science programs beginning to reach the market. Then again, it is possible that the science teachers who sit on adoption committees prefer middle-of-the-road textbooks.

- Is there no "hard" evidence to compare textbooks? Expert panels' opinions may be on the mark, but they are little help if they find no satisfactory science textbooks. Teachers' choices may be good ones. But how are we to know? Textbook publishing is a marketing-driven business. New, updated books by prestigious authors sell. States encourage textbooks to touch each standard they write. Clear omissions create failed sales. What is not available is unbiased, empirical evidence that shows how much and what learning a particular textbook produces.[41]
- Is it possible Ohio's teachers are not well qualified or too pressured to select science textbooks? Most school districts are small, often with fewer than 100 professional staff. Finding staff who have the time and the will to remain current with the literature and with new releases of textbooks is difficult for many districts.[42] Many staff members have taught for decades. Their focus has been on the classroom, not the profession. Their ties to professional associations, educational research, expert debate will have thinned. In addition, some claim that the professional training teachers receive is itself deficient (Gross, 1999).
- Is it possible that we have reached a point where the accumulated wisdom about learning in general and learning science in particular is no longer correct? The past century has seen startling developments in how we understand learning: from Freud's psychiatry to Watson's behavior therapy, to Skinner's free operant conditioning, to Piaget's stages—and somewhere in all that is the thought and influence of John Dewey. Over the past two decades that accumulated wisdom has seen dramatic and accelerating reshaping in the hands of cognitive scientists and constructivist educators (Bransford, 1999; Bruer, 1993).

  The average Ohio teacher is now in his or her forties. S/he obtained the teaching credential 15 or more years ago. Unless the teacher has been very diligent, s/he will be ignorant of the full scope and consequences of these changes in understanding for science instruction (Bailey, 1996). The teacher's accumulated repertoire of tools and practices—more precisely, the personal understandings about why, when, and how to employ these tools and practices—may not be consistent with the reasons now being offered to justify changed practice (Cohen, 1990). Under these conditions, they cannot make wise decisions about textbooks and other instructional supports.

  Other nations face this issue as well. And some have tools and practices to assure teachers remain stay well versed and motivated. In Japan, for instance, research lessons (Lewis & Tsuchida, 1998) bring teachers together around critical issues in applied pedagogy. These lessons focus the attention of groups of teachers over time as they engage in jointly designing and building effective lessons. The lesson must be justified both theoretically and practically, enforcing links to the research and what is known of best practice. Because this work focuses closely on teachers' own practical needs, because it brings the resources of teachers from different schools together, because it extends the work and the conversations about the work over time and across the daily boundaries of the single classroom, the research lesson concept bodes well for helping teachers generate new solutions, supported by applied and theoretical research, and empowered by the energy of a fellowship of peers (see Stigler & Hiebert, 1999).

- Is it possible that many U.S. science textbooks do not contain the right material? As part of TIMSS, samples of textbooks for all participating nations were analyzed. This confirmed that most American texts contain far more material covering far more topics per grade than is the case in most other nations (Schmidt et al, 1999). Moreover, American textbooks appeared disjointed and highly repetitive from grade to grade.

  U.S. teacher editions of textbooks typically add little more than correct answers for the student exercises. Textbooks in several other nations are much richer for teachers, providing numerous worked-out examples and illustrated processes. Materials for teachers focus more often on underlying principles and other materials suitable for self-study and guided lesson development.

What if these doubts are true? Then, in the effort to improve science education, are we not in fact asking teachers to do what they have not been trained to do? With limited tools? With the wrong tools? Under difficult conditions? With no time? And little support? Fortunately, the answer to each of these questions is not an unqualified negative. However, there is a lot of uncertainty. Textbooks and teachers, with students, are at the core of the learning enterprise (at least as we know it in schools). Textbooks need to be the best they can be. Teachers need the best support we can supply, especially if we are also asking that their teaching change.

Next, we examine some aspects of teaching and learning in Ohio today, aspects that are central to the changed teaching being urged.

The Culture of Teaching Science:
How Is Instruction Delivered?

We asked Ohio's science teachers how often they had their classes work as whole groups, as groups of students, or as individuals; how often they asked their students to do certain classroom tasks, such as putting events or objects in order and indicating their reasoning, using computers, writing scientific explanations, analyzing relationships using tables, charts, and graphs, and explaining the reasoning behind their ideas; and about how often they conducted various kinds of experiments inside and outside the classroom. Because these questions were also asked in TIMSS, they permit comparison of Ohio's teachers' classroom practices to other teachers in the U.S. as well as those from other nations. They also permit some sensing of where Ohio's teachers' practice stands with respect to the AAAS standards and other calls for reformed practice.

Authoritative reviews of research confirm that two factors are most influential in student learning: instructional quantity and metacognitive opportunities (Wang, 1990).[43] Hardly surprisingly, more opportunities to learn and to work at learning are predictive of greater learning. When these opportunities include such practices as children monitoring their own learning, planning to learn more effectively and testing alternative learning strategies for themselves, learning begins to accelerate. These factors tend to occur more frequently and to have greater impact when students are actively engaged in their work, when the challenge presented "grabs" them and focuses their attention and minds, and when they have opportunity to build their own solutions rather than simply regurgitating givens (cf. Brown & Campione, 1996). Classrooms that encourage such factors tend to be more collaborative in nature, less teacher-dominated than others.

The Organization of Instruction

The manner in which teachers organize classroom instruction and the relationships between teacher and student and among students are indirect estimates of the collaborative nature of the instruction that takes place there.[44] Inspection of the patterns observed in Ohio and comparing them to patterns elsewhere may help us understand the condition of science teaching and learning in Ohio.

Table 9 compares whether science instruction in Ohio is teacher-led, in three classroom work clusterings: whole class, individual student work, and small student groups. Teacher-led or assisted instructional patterns dominate. An exception occurs in grades seven and eight where teacher led whole class work runs just behind whole class work with students responding to each other. Moreover, at this level it also appears that individual and small group work are more common

Table 9. **Ohio Teachers' Reports of Class Organization for Science Instruction**[45]

	Grades 3 & 4			**Grades 7 & 8**			**Grade 12**		
(in percent)	*Rare*	*Some*	*Most*	*Rare*	*Some*	*Most*	*Rare*	*Some*	*Most*
Whole class, teacher led	1	57	42	9	73	18	6	58	36
Whole class, students responding to each other	5	65	30	6	71	23	2	70	28
Individual work, teacher assisted	5	74	21	2	68	30	6	72	22
Individual work, independent	25	67	8	17	75	9	13	64	23
Small groups, teacher assisted	0	70	29	0	59	40	4	62	34
Small groups, independent	17	68	16	14	66	19	11	64	25

classroom organizational forms than whole class instruction. In grade 12 the distribution is more balanced, although independent work is more important than at the lower levels. Overall, it is tempting to read Table 9 as supporting the common instructional patterns we all know well: teacher-led whole class work occurring most days, giving way most days to some individual teacher-supervised practice, with group work (experiments or laboratory sessions, possibly) as appropriate.

How does this compare to organizational patterns elsewhere? In Table 10 we compare Ohio to the U.S. overall and to Japan, as the questions were answered by teachers during the TIMSS surveys of 1995. No twelfth grade data are supplied since TIMSS did not ask high school teachers to complete surveys.

Table 10. **Teachers' Reports of Class Organization for Science Instruction**[46]

	Grades 3 & 4			**Grades 7 & 8**		
(Percent responding "most lessons" or "all lessons")	**Ohio**	**US**	**Japan**	**Ohio**	**US**	**Japan**
Whole class, teacher led	42	44	68	18	32	79
Whole class, students responding to each other	30	33	45	23	22	19
Individual work, teacher assisted	21	20	19	30	33	12
Individual work, independent	8	5	8	9	13	8
Small groups, teacher assisted	29	26	27	40	27	13
Small groups, independent	16	13	13	19	11	6

NOTE: Each cell of this table presents the combined percentages for two response categories—"most lessons" and "all lessons"—of the four available for the question asked each population. The percentages across the cells within the table should therefore not be expected to sum to 100 by row or by column.

The similarity in the elementary grades between the Ohio pattern and that in the U.S. typically is striking. At the middle grades, however, there are several divergences. Ohio's middle school science teachers are markedly less likely to engage in teacher-led whole class instruction, while they divide classes for small group work more frequently. It is tempting to link these differences to the emphasis Ohio gives to the Scientific Inquiry strand of the model science curriculum, since inquiry work can often be more effectively taught and practiced in small groups with significant student contribution and leadership.

In Japan, instructional patterns are much less varied in science. Two-thirds of the third and fourth grade teachers and well over three-quarters of the seventh and eighth grade teachers report teacher-led whole class instruction as the dominant mode. Still, in grades three and four, 45 percent of the Japanese teachers report that students respond directly to each other in whole class instruction in most or all classes, with the teacher taking a less dominant role. This pattern occurs quite a bit less frequently in U.S. elementary science. Small group work with teacher supervision also occurs fairly frequently in the Japanese elementary grades but is less common later. Individual work is quite rare at both levels. On the face of it, these numbers suggest that traditional, teacher-centric forms of organization dominate in Japanese science classrooms, more so at the middle grades.

Recall for a moment that U.S. schools' science performance in TIMSS in 1995 was above average internationally at grades three and four. It fell somewhat in middle school. A strong emphasis on whole class instruction was reported in most other countries with high achievement in TIMSS at the middle school level (Beaton, 1996). Is that pattern conducive to a more focused, and possibly more rigorous approach to science instruction? The answers are not yet clear, but we do know that they are not simplistic. For instance, the TIMSS video studies make clear that in Japanese classrooms the apparent organizational uniformity does not stifle student engagement (Stigler, Gonzales et al., 1999). In fact, Japanese instruction is often held up as an example of the instructional innovations that U.S. education reformers want to see (Peak, 1996).

What Students Do during Science Instruction

In addition to understanding how instructional time is organized, it is necessary to know what students do during instruction. The organizational pattern, after all, is only a vessel: what students learn is a function of the opportunities they receive during instruction and what they are enabled to do with those opportunities.

Several trends emerge in Table 11. Having students explain the reasoning behind scientific ideas occurs frequently in Ohio's science instruction, and occurs more

Table 11. **Ohio Teachers' Reports of How Frequently Students Are Asked to Do Certain Tasks During Science Instruction**

	Grades 3 & 4			**Grades 7 & 8**			**Grade 12**		
(in percent)	*Rare*	*Some*	*Most*	*Rare*	*Some*	*Most*	*Rare*	*Some*	*Most*
Explain reasoning behind ideas	1	32	67	0	28	72	0	21	79
Represent and analyze relationships using tables, charts, or graphs	7	72	21	0	60	40	0	43	57
Work on problems which have no immediately obvious solution	26	61	13	15	68	17	13	66	21
Use computers to solve exercises	69	30	1	54	42	3	38	51	11
Write explanations about what occurred or why it happened	1	48	50	2	39	59	2	47	51
Put events or objects in order and give reason for the order	6	71	23	9	64	28	11	62	26

frequently with increasing grade levels. Two of three elementary science teachers say this occurs in most or all science classes they teach. For classes for high school seniors this rises to four of five teachers. Striking increases over students' careers, almost 20 percentage points per level, also occur for the task, representing and analyzing relationships using tables, charts, or graphs. Computer use also increases with grade levels. Less obviously, but also increasing with level is working on problems with no immediately obvious solution.

These patterns are powerful ones. They confirm the widespread influence of the Scientific Inquiry and the Applications for Science Learning strands of the Ohio model curriculum, and the increasing power of these two strands as students become more adept and skilled. These differences fit well to the Project 2061 suggested standards and benchmarks for science instruction and other efforts to reform science education. However, what Table 11 cannot do is indicate the scientific content knowledge these skills are being applied to, or even if that content knowledge is distributed uniformly by level or geography. Nor, frankly, can they tell us whether students are learning to do science to deeper levels or are just being asked to demonstrate learned skills more often.

We turn to comparative data to help shed more light on these issues. Table 12 compares the reports for Ohio's middle grade science classrooms on these tasks to what was reported elsewhere in the U.S and in the First in the World Consortium.[47] The First in the World Consortium is a group 19 high-performing, high-SES school districts in Chicago's northwestern suburbs that participated in TIMSS as its own "mini-nation" in 1996. We include their data here because they raise some interesting issues for Ohio.

Table 12. **Teachers' Reports of How Frequently Seventh and Eighth Grade Students Are Asked to Do Certain Tasks During Science Instruction**[48]

	Ohio			**U.S.**			**FiW Consortium**		
(in percent)	*Rare*	*Some*	*Most*	*Rare*	*Some*	*Most*	*Rare*	*Some*	*Most*
Explain reasoning behind ideas	0	28	72	0	30	70	0	15	85
Represent and analyze relationships using tables, charts, or graphs	0	60	40	2	71	27	0	50	50
Work on problems which have no immediately obvious solution	15	68	17	29	60	11	26	52	22
Use computers to solve exercises	54	42	3	74	25	1	36	52	12
Write explanations about what occurred or why it happened	2	39	59	4	58	38	0	31	69
Put events or objects in order and give reason for the order	9	64	28	14	58	28	16	49	35

A first glimpse at Table 12 suggests that the reports for Ohio are similar to those for the U.S. overall. A closer looks finds some variance. The proportions of teachers stating they ask their science students to explain their reasoning during most or all lessons are identical. However, this response can mask considerable variation in meaning and practice. For instance, if students are consistently asked to explain their reasoning in class and if this practice increases over time, as it does in Ohio, then asking students to write explanations should by the middle grades be a fairly frequent occurrence. It is clear from Table 12 that writing explanations in science occurs much more frequently in Ohio than elsewhere in the U.S. Similarly, explaining reasoning should lead to more consistent use of tools for reasoning, including charts and graphs. Again, more Ohio science classrooms feature such activity than is typical in the U.S. The same logic can be applied to working on hard-to-solve scientific problems, and again the result is the same.

Next, inspect the data reported for the Consortium in the “Most” column of Table 12. In every case the Consortium’s numbers exceed those for Ohio. It is fair to ask: Why is this relevant here? The Consortium’s socio-economic advantages over Ohio are numerous: the Consortium’s community is better educated, its average income greatly exceeds Ohio’s, it teachers are paid much better, etc. The figures for computer use in science—which are correctly interpreted more as markers of computer availability than of different instruction—are another indicator, this one visible in Table 12. From the perspective of an average Ohio middle school, the Consortium’s schools operate in an altogether different world, one almost without constraint: they can implement the best practices from research in a supportive environment with carefully selected and highly trained staff.

Now, in Table 12, compare the differences between the Consortium and Ohio to the differences between Ohio and the U.S. Look at the hard ones first. The Consortium exceeds Ohio by 10 percentage points, 69 to 59 percent, with respect to students writing explanations most lessons. Ohio outpoints the U.S. by 21 percentage points, 59 to 38. With respect to using data, the Consortium is 10 points ahead of Ohio, 50 to 40 percent. But Ohio is ahead of the U.S. by 13 points, 40 to 27 percent. Obviously, comparisons of this sort are hardly conclusive, but they do suggest that Ohio’s science instruction differs considerably from the common U.S. pattern, and is closer to expectations about best practice than one might expect, given Ohio’s resource base.[49]

There is one more set of data that we can bring into play. Ohio’s elementary and middle school teachers provided more specific details about the content of their science lessons.[50] Table 13 sums up those data. Clearly, Ohio’s students frequently

Table 13. **Ohio Teachers’ Reports of Classroom Science Work**

	Grades 3 & 4			**Grades 7 & 8**		
(in percent)	*Rare*	*Some*	*Most*	*Rare*	*Some*	*Most*
Watch teacher do experiment in class	9	82	9	19	76	5
Conduct own experiments	3	64	33	4	56	40
Watch video of experiments	37	61	1	33	65	2
Go on science field trip	54	45	1	61	38	1
Design own experiments	49	49	2	28	68	4
Conduct weeklong (or longer) projects	27	65	8	23	69	8
Take part in other lab-related activities	48	46	6	14	55	30

conduct experiments themselves: one-third of the elementary teachers say they have their students do this most or all lessons; in middle schools this figure rises to 40 percent. In addition, 30 percent of the middle school science teachers say their students participate in other lab work during most or all lessons. Half to two-thirds of the teachers say they let students design their own experiments during some lessons each year, although about half the elementary teachers avoid this. About two-thirds of the teachers engage their students in week long or longer science projects. Clearly, most Ohio science classrooms are hands-on and directly experimental. Videos and field trips do not take the place of direct exposure and scientific involvement.

Reflecting back over all the Ohio data set out in Tables 9 through 13 engenders a picture that is similar in many ways to a coherent inquiry approach that one group of observers found in Japanese science lessons in grades four to six (Linn et al. 2000).[51] From observations of science lessons in seven schools in or near Tokyo, they isolated eight activity structures common to all the lessons:

1. Connecting lesson to student interest and prior knowledge
2. Eliciting student ideas or opinions
3. Planning investigations
4. Conducting investigations
5. Exchanging information from the investigations
6. Systematically analyzing or organizing the information
7. Reflecting or revisiting hypotheses or predictions
8. Connecting to subsequent lessons and/or identifying unanswered questions.

While it cannot be clear from the data we have reported that elementary and middle school science lessons in Ohio follow this Japanese pattern, it appears that the Inquiry and Application strands encourage Ohio's science students to focus on several of the structures found in Japan, particularly structures 4 and 6 and secondarily structures 3, 5, and 7. Moreover, they do so more than is common elsewhere in the U.S. In a number of ways, this 8-fold structure is consistent with what the current science reforms recommend. Maybe surprisingly, it is also highly consistent with long-standing models of instruction (e.g. Carroll, 1963).

Linn and colleagues also point to several features of the Japanese school system that supports these structures, including the presence of long-term group identification among students, strong teacher professionalism, teachers' collaborative self-improvement efforts, and strictly limited and sharply focused curriculum. In the case of Ohio, these same features are more often lacking than present, making it all the more striking that these structures appear able to perpetuate in Ohio.

Coming to Terms with the Evidence on What Science Is Taught in Ohio and How It Is Taught

These survey data by themselves cannot comprehensively nor conclusively describe and explain the state of Ohio's K-12 science education system. They do, however, provide new evidence and new perspective on what gets taught and how it gets taught in Ohio's public school science classrooms. Factored in with other information they will support better decision-making about the future directions of science education in Ohio.

The picture the data paint is of an education system that shares many of the faults and credits that accrue to the U.S. education system, within which it exists. These data, taken altogether, also suggest the Ohio system is no more focused with respect to scientific content and no less variable from school to school or teacher to teacher than the U.S. system. Good teaching and learning do occur. Reports from skilled teachers confirm numerous instances of excellent and creative teaching, representing a large but untapped reservoir of talent (Otto, 2000). One strength of Ohio's K-12 science education system rests on the Inquiry and Application strands of the state's model competency-based science curriculum program (Ohio Department of Education, 1999).

On the other hand, even in Ohio schools that work hard, teaching and learning are not always what they can be (Hewson & Kahle, 1999). Our survey data suggest that most Ohio school districts expect, and most science teachers try, to teach too many topics. Some of the science curriculum structures are reasonably well rationalized and articulated, but others could be improved. Consensus about what constitutes the core of science knowledge that students should acquire is lacking, certainly when compared to the apparent consensus on the scientific inquiry skills students should master.

Some of this uncertainty is, no doubt, caused by the daunting breadth and scope of modern scientific knowledge. Some of it is created by Ohio's strong, traditional respect for local control over education. Some of the uncertainty, it is probably fair to point out, is a consequence of a lack of will, particularly over politically and culturally sensitive topics within science. And, some of it is the lack of clear, consistent, and detailed academic standards, spelled out by the state Board of Education, supported by the General Assembly, and adopted by districts.

Without a consensus about the scientific content to be taught, Ohio's K-12 science education will remain somewhat adrift with respect to three of the four instructional strands that so well frame science education in Ohio. In terms of the Scientific Inquiry strand, Ohio's students appear to be receiving excellent preparation.

However, the Scientific Knowledge strand varies widely across the state in focus and consistency. Here, clear standards will be most beneficial. The Conditions for Learning Science strand is negatively affected by the weakness of the Knowledge strand. Determining and funding optimal conditions for learning is difficult if it is not clear what content is to be taught or how the emphases are to be drawn. With respect to the Applications for Science Learning strand, Ohio has made better progress. But here also the strong focus on Inquiry and the inconsistency about Knowledge creates a tension that has been difficult to resolve.

Ohio's teachers are expected to convert the plethora of topics in the local curricula into coherent instruction. The resources they can turn to for support in this are relatively few: each other, local curriculum specialists, textbooks, knowledge of the national standards movement. The time they have available to work with these resources is minimal. Moreover, some of these resources are often viewed by teachers as of limited assistance in focusing instruction, setting priorities for what to teach, supporting rigorous content, and selecting successful instructional strategy.

Of the available resources, only the Learning Outcomes for the Ohio Proficiency Tests are authoritative in the state and have begun to function to define the critical elements of the science curriculum (LOEO, 2000). The publication this year of district and school report cards has increased their prominence in focusing instruction. Still, the Learning Outcomes do not possess the detail, the rigor, nor the clarity that teachers need to convert curriculum to instruction. Nor is that a proper charge for what are essentially test specifications. That should be the consequence of state academic standards and districts' efforts to support teachers.

Undergirding the current and potential effectiveness of Ohio's science education system, of course, is the quality of its teachers. Hiring the best teachers is one aspect. Certainly, hiring more teachers with solid science credentials will improve science teaching.[52] More critical is the support provided to keep them and keep them the best (National Research Council, 2000*a*). Here, Ohio's districts often seem to fall short, despite some good efforts.[53] Certainly, in terms of classroom practice, the survey data suggest that Ohio's science teaching and achievement is open to the same charges leveled against U.S. science teaching and achievement.

Changing schooling is surprisingly difficult (Tyack & Cuban, 1995), but not impossible (Fullan, 1991). What and how teachers teach is at the core of schooling. What we know about learning has changed considerably (Bransford, 2000). This requires change in teaching. But, in schooling, change cannot be uniform: "the search for answers to improving school performance and student achievement will never yield just one value—that is, solutions that will work for all schools and students in all times and places" (Ladd & Hansen, 1999).

But, the conditions and culture of schooling make changing teaching practice difficult. Teachers typically spend 35-40 hours per week alone in a classroom with 25 or so students. Add to this the routine work of reporting, planning, and paperwork, and there is very little time left for the kind of intense involvement in the intellectual enterprise of teaching and learning required to engender and maintain fundamental change.

Many teachers believe that the key to changing science education is *collaboration*. As one Ohio teacher told us, “The need for a cooperative venture in education—teachers to administrators to the state—is paramount” (Otto, 2000). This theme permeates the relationships among teachers within the same school, districts, and subject areas. It extends to teachers across the state, as well as administrators, policymakers, business leaders, community members, and parents. No group alone will affect meaningful change in science education without cooperation, input, and collaboration from all others, Ohio’s teachers claim.

Ohio’s teachers, even the state’s best, convey an unsettling sense of isolation in their work. Many feel alone, not simply when standing in front of their classrooms, but in their desire to do what needs to be done for the student. They feel little meaningful support from their administrations or communities. They feel at times ignored and discounted, even though they serve closest to the students themselves. And, as discussed elsewhere in this report, the tools and resources they do have available are often lacking.

We know that the amount of science content a student is exposed to is predictive of his or her learning of science. We know that the quality with which instruction about that content is delivered is predictive of the student’s learning. What we do not know, and what teachers in schools do not know, is the details—what amounts matter and how to recognize critical decision points (cf. Wang, 1998; Wenglinsky, 2000). This implies several opportunities:

- We need to learn more about the resources teachers currently use to guide their work in classrooms, with an eye to understanding their strengths and weaknesses, building on the first and remedying the latter. Despite the remarkable strengths of the Ohio Department of Education, building a Model Curriculum and then expecting curriculum specialists to re-train teachers, for teachers to become familiar with it conceptually, and then to design and implement suitably revised practice is somewhat naïve. Teachers’ work is enmeshed in a web of local practice and belief and history and constraints. New concepts, new approaches may or may not fit that web. It will tend to shrug off what is different. Solutions that arise from within that web need to be identified and supported.
- We need to provide teachers with better knowledge of the consequences of the choices they make. This requires tools that measure student learning in

relation to teaching initiatives, and in real time. Annual, standardized tests are potentially useful systemic accountability tools. But, they are not particularly useful in helping teachers determine what works instructionally and what does not. What teachers need are measures that tell them whether this week's approach was more or less effective than last week's. Such measurement is not well supported in schools—and in fact is not likely unless schools and curricula become markedly more focused and rigorous about their work.

- Tools that help teachers to see daily what works in their professional lives are invaluable. But, these will generate only occasional, haphazard improvements unless they exist within an organizational culture that values reflection, and encourages the experimentation and risk-taking that improvement requires. Most schools today are not institutions that foster such attitudes.
- Schools must become more supportive of teacher initiative. Teachers need more time and more frequent opportunity to work together on instructional problems. Teachers need opportunity to see and hear about other ways of structuring teaching and learning. Opportunities for mentoring and sharing need to exist in the routine of work life in schools, not just in set aside moments.
- Teachers and administrators must learn to listen to students more. Learning often starts when perception contradicts belief. The opportunity to make this happen will not occur unless teachers know what students believe about science. Given better knowledge about students' scientific understandings, it is easier to structure class work so that students can meaningfully explore and invent, rather than memorize. Teachers and organizations that listen better to students will also listen better to adult staff. Here too the opportunities for perception to come into conflict with belief should be sought, and the motivation to change, to improve strengthened by the contradictions.
- Districts, schools, and staff must devote time to thinking hard about what is to be taught, when, to whom, and how. This will be hard and protracted work, but it will result in more focused curricula and enhanced opportunity for all students to be exposed to deep scientific thought. It is not wise to expect each district to do this independently. Nor is it wise for a state agency to do this work alone. Rather, multiple long-term collaborative efforts reaching across customary boundaries give great promise of building curricula that are focused, rigorous, and have sufficient scope and depth. Support for such work should come from a wide range of participants, including the state, business, advocacy groups, academia, and research institutes. Particularly in science, this work must accept from the beginning that scientific knowledge will change, that relative importance will shift with

time, and that the edifice being built must contain within it the means for its own constant regeneration. Standards ought not to be static.

As these solutions come on track, an opportunity structure must be built for teachers to engage continually in deep and meaningful professional dialog about the craft of teaching, content knowledge, and the science of learning. While the primary orientation for this dialog must be internal to the profession, it is critical to assure that it remains open to and seeks out external knowledge, opinion, and influence. To make this possible will require sharp modifications in how we structure schooling. A key will be to find or make time for teaching staff that is not spent supervising students. In addition, teachers will need significant support to learn to work together since, unlike other professionals, this is not something they have been trained for or have much experience in.

ENDNOTES

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[1] These four questions reword the core of the conceptual model that underpins the TIMSS perspective on teaching and learning science and mathematics. It was elaborated and refined over a multi-year period in the early 1990s by a group of senior researchers from six countries working together to build an internationally consistent conceptual framework (Schmidt, Jorde, et al., 1996). An overlapping group of international experts supplemented this work with the specification of a content model or curriculum framework for science and for mathematics (Robitaille et al.., 1993).

NCREL considers the TIMSS model and framework to be at the forefront of efforts to understand curriculum, instruction, and their consequences. We therefore adapted from these instruments for our study of Ohio's K-12 science system. However, NCREL fully accepts that survey instruments do not capture the full richness and variety that transpires in schools each day.

[2] A companion report (van der Ploeg, 2000) treats mathematics education.

[3] Because the survey questions are the same, the responses of Ohio's schools may be compared to those of the nations in the original TIMSS sample. In addition, other comparisons are becoming possible. Under the auspices of the National Center for Education Statistics (NCES), some of the TIMSS instruments have since 1996 been administered in a number of U.S. states and in the First in the World Consortium in Illinois (Kimmelman, Kroeze, Schmidt, et al., 1999). The IEA in 1999 sponsored TIMSS-R, re-administering TIMSS internationally; a larger number of U.S. states and consortia participated, including Project SMART in Ohio; these data are just now reaching publication (Gonzales et al. 2001).

[4] These grades were chosen to coincide with the three TIMSS populations. The 1995 TIMSS did not employ a teacher survey for Population 3, end-of-secondary school. A survey form for teachers at this level was drafted in preparation for TIMSS (Schmidt, Jorde, Cogan, et al., 1996). We administered an abbreviated version of this instrument.

[5] The number of Ohio public school districts is not fixed. For instance, in March 2000 a new district was formed, bringing the total to 612. Also, there are numerous schools in Ohio that are not public. About 50,000 high-school-age Ohio students, just less than 10 percent of all such students, attend them. Initially, we planned to include these in our sample. However, it became clear that we could not well identify the connections among these schools. That is to say, we could not expect to be able to talk about typical patterns of content exposure, because we could not tell from which school a student enrolled in a non-public high school came.

[6] Staff of the Ohio Department of Education provided us a list of schools in summer 1999 that was the most current available at that time.

[7] Such identification tends to depress response rates. However, generalization to typical patterns of curriculum delivery and student exposure required we link schools at various levels.

[8] Some districts returned only one GTTM, with the district's curriculum leader responding for all grades and buildings. Elsewhere, school curriculum leaders completed the GTTM. In a few cases, we received multiple GTTMs from a building, one from each teacher teaching science. These response patterns make it difficult to determine an exact, person-based response rate.

[9] Although we would prefer them to be higher, these return rates are, in fact, very respectable. Compare the following. A recent survey on the value and utility of Ohio's Ninth Grade Proficiency Tests conducted by Ohio's Legislative Office of Education Oversight and distributed to some 900 eighth grade teachers obtained a 63 percent teacher return rate (Legislative Office of Education Oversight, 2000). Compare also a national study recently published in a top refereed professional journal. This explored the relationships between school and staff characteristics and the fidelity with which school reform models are implemented. It was based on a sample of 184 schools, with a 68 percent teacher response rate (Berends, 2000).

[10] The TIMSS study used stratified random sampling of schools and classrooms. Several statistical weights are available to support analysis and appropriate generalization to students, teachers, or schools. Our Ohio sample had no explicit strata and we calculated no sampling weights. For consistency's sake, therefore, we report only unweighted TIMSS survey results in this report.

[11] What they do not have are statewide standards for the science curriculum. Ohio is one of the very few states which has not enacted such standards. In 1997, standards were approved in principle by the Ohio State Board of Education and submitted to the Ohio legislature for approval, but the legislature did not act on the proposal. Senate Bill 55, which was passed, incorporates some key elements of the proposed standards, including accountability and school improvement mandates, but does not describe the expectations the state has for its students and teachers.

[12] Although now approaching 10 years of age, these documents continue to receive support from a variety of independent perspectives (Finn & Petrilli, 2000; Glidden, Masur & Snowden, 1999). It is appropriate to point out that Ohio's leadership has been conscious that local control of education is highly valued in the state. Hence, standards and other efforts at educational direction have been general, intentionally leaving latitude for local filling in of the details (Minor, 1999). Still, the descriptions of the science that Ohio's students are expected to learn have been taken to task more, for being not specific enough, than have the descriptions for mathematics, English, or social studies (American Federation of Teachers, 1999).

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[13] The Learning Outcomes that the Proficiency Tests measure have faced external review less often than the Model Curricula. A recent review conducted by Achieve, Inc. (1999; TIMSS, 1999) concluded the Outcomes were generally too "vague," although less so in science and mathematics than in other subjects.

[14] The "whiskers" at the end of each bar indicate how much Ohio's districts vary around the average. The further apart the top and bottom whiskers are, the more the districts differ. The whiskers also indicate when two averages may be said to be meaningfully different. If the whiskers of two columns do not overlap, then the difference between the grades is unlikely to be caused by chance.

[15] Ohio currently requires only one Carnegie unit of science credit for graduation. (A Carnegie unit typically translates to one year of instruction.) Based on 1997's Amended Substitute Senate Bill 55, these requirements will soon rise: The graduating class of 2006 will need two units in science and the class of 2008 three units.

[16] For comparative purposes, the corresponding national figure was 78 percent, confirming how typical Ohio is educational system is in most respects when compared to the U.S. (Blank & Langesen, 1999, p. 22).

[17] Ohio's pattern vis-à-vis the U.S. is not dissimilar to that observed in Minnesota, where seventh and eighth grade students performed very well on the TIMSS science measures. Minnesota permitted a sample of its students to be tested with the TIMSS achievement batteries a year after the international TIMSS. The state's middle school mathematics performance was about average. The argument has been offered that the science results were remarkable because a confluence of events led to a focused science curriculum in Minnesota's middle schools, emphasizing the life sciences in seventh grade and the earth sciences in eighth grade. No such consistency was observed in mathematics instruction. For more information, see National Education Goals Panel (2000).

[18] A quick glance at Figures 3, 4, and 5 suggests that the Ohio data are considerably more complex than those for the U.S. and Japan. This is true in fact, as well as being an artifact of differences in how these data were obtained. The Ohio data represent averages of what many school and district staff told us. The Japanese data are derived directly from the single national science curriculum in place in that nation in 1995. No averaging process was necessary. The U.S. data represent a consensus agreement among a panel of experts engaged by the U.S. National TIMSS Center at Michigan State University (see Schmidt, McKnight, & Raizen, 1997, and Schmidt, McKnight, Cogan et al., 1999, for additional detail). The upshot of this is that the U.S. data in Figure 4 should be treated with circumspection: they almost certainly underestimate the variability in focus and challenge in the U.S. curriculum. On the other hand, it is not to be denied that they are indicative of the general pattern.

[19] See endnote 18.

[20] It is not possible to do exact calculations. A teacher responding to the survey could count one lesson toward just one of these topics or toward several, depending on the lesson content and plan. Summing these categories is obviously problematic. Our estimate is just that.

[21] While remaining a key element of the movement to reform science education, the focus on inquiry and "authentic" investigations by students has seen some critical revision recently. McGinn and Roth (1999) argue for inquiry as debate and negotiation, not as some well-defined notion of scientific process and procedure. Fradd and Lee (1999) point out that what is effective inquiry in one kind of classroom may not be optimal in another.

[22] This statement is made tentatively. Close reading of our respondents' answers support it; however, the sample was not large enough to support such statements statistically.

[23] The TIMSS framework is a classification primarily of scientific content, not application, method, or skills. This makes comparison with the Ohio model science curriculum somewhat difficult. Still, it also emphasizes the lack of a statewide science content focus in Ohio. That may explain the large variations across the state in the content teachers say they teach in these grades.

[24] This goes to show that even in carefully designed, centrally controlled educational systems, what is intended to be taught and what teachers teach are not usually in full agreement.

[25] In 1998, 93 percent of graduating high school seniors had taken a biology course. However, at most, only 60 percent had a second science course on their record, usually chemistry. Less than a third of the graduates had a third science course (Snyder, 2000, p. 156). Putting it another way, although the average U.S. high school student takes 3.1 years of science courses, (s)he studies only two areas (Finn, 1999).

[26] Three Carnegie units in science will be required for the graduating class of 2008.

[27] The Council of Chief State School Officers' (CCSSO) State Education Assessment Center maintains the most consistent set of indicators for the nation's K-12 mathematics and science education system. It has a long history of working closely with state education agencies to obtain the best possible data. Still, these indicators remain a mixed bag, so to speak, in terms of accuracy. Schools generate a lot of data; however, few schools are skilled—or much concerned—in data recording, archiving, or reporting. We used unedited numbers reported by the Ohio Department of Education to the CCSSO via the State Education Assessment Center's Electronic Survey Form (version 5) for its science and mathematics indicators collection system.

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[28] The data source for Table 1 is discussed in the previous note.

[29] This discussion is drawn from Ohio Business Roundtable (1998).

[30] For comparison, we note that *WorkKeys* exams were given in 1999 to high school seniors in the nine-county southwestern Pennsylvania region (Education Policy & Issues Center, 2000, p. 14). Only about one-sixth of the students—not one-third as in Ohio—scored below Level 3. Another sixth scored at Levels 6 and 7.

[31] In fact, pay in the technical and scientific fields has been relatively stagnant, rising less rapidly than in other fields (Carnivale & Rose, 1998, p. 18). In addition, much of the demand for information technology workers has really been for office work—office workers drive the information revolution, not programmers. Governor Taft in his State of the State address on January 19, 2000 alluded to the fact that Ohio ranks 10th among all states in the number of high-tech employees it supports. In the same address he alluded to Ohio employers traveling to India to find skilled information-technology workers. But, differences in pay scales and economic opportunities play a strong role, in the short run a much stronger one than education, in such decisions. Employment opportunity no longer respects regional, state or national boundaries.

[32] This may help explain the lack of consensus among Ohio's middle school science teachers about life science topics commented upon above (Figure10).

[33] However, we can be confident that Ohio's teachers' are quite similar in most basic respects to teachers nationally. The most recent data from the National Center for Education Statistics (Snyder, 2000) tells us that highest degree of 53 percent of Ohio's teachers is a bachelor's, one percentage point above the national average; 42 percent attained a master's, the same as the national average. Ohio's teachers are experienced with just over 31 percent having taught more than 20 years, compared to 30 percent nationally. The typical Ohio teacher was paid $38,977 in 1998, about $400 dollars less than the national average. These numbers, of course, cannot convey teachers' skills, motivation, or commitment (see Farkas et al., 2000).

[34] AAAS is the acronym for the American Association for the Advancement of Science, which through its Project 2061 and other activities has been instrumental in developing standards for science teaching. A set of *National Science Education Standards* were published by the National Research Council in 1996.

[35] Table 2 also provides an interesting perspective on Ohio's math teachers. These teachers depend on textbooks for guidance about how to teach markedly more than do the science teachers. The science teachers depend a little more on the state's model curriculum and the district curriculum and a lot more on "other resources," whatever these may be (van der Ploeg, 2000).

[36] To comprehend the richness of knowledge and skill and capacity required to support good teaching, it pays to review examples of good teaching. Chapter 7 of Bransford (2000) elucidates a number of cases. The sidebar to Gibbs (1999) provides others. The *Captured Wisdom* series of CD-ROMs provides numerous examples of rich and technologically sophisticated science lessons (at www.ncrel.org/cw/index.html)

[37] NCREL calculated these numbers from the U.S. TIMSS database.

[38] Commentary and debate on the quality and relevance of textbooks in the U.S. are voluminous, opinionated, often heated, and not remarkable for strength of proof or lack of proof of effectiveness. Internet newsgroups, such as AERA-L@asu.edu subscribed to by many educational researchers, retread these conversations with considerable regularity. Editorial writers too have at it periodically. See for instance the editorials in *USA Today* on October 14, 1999, shortly after the AAAS release of its review of science textbooks.

[39] In mathematics, several other groups have also published comparisons. These multiple comparisons have been especially helpful, since the groups present distinct viewpoints about what constitutes good schooling, good teaching practice, and good curriculum. This variety of viewpoints is not available to study science textbooks.

[40] While the experts also express wide-ranging doubts about the quality of most of the available mathematics textbooks, a few textbooks typically are identified as suitable for use (cf. van der Ploeg, 2000). That no science texts are found suitable suggests a more serious problem for this subject area.

[41] Updating a text, assuring it doesn't omit a critical need in one of the larger markets (i.e. California, Texas, New York) is expensive, but doable. Designing and conducting large-scale controlled experiments to determine a textbook's effect is expensive and requires time. State requirements change frequently and sales points occur annually. More critically, experimentation is risky: what if the results fail to confirm effectiveness? One member of a U.S. expert panel on mathematics texts insisted on such evidence of long-term impact on student achievement; the other panelists did not accept this as a criterion: the programs were "too new" to generate such data (Clayton, 2000). This lack of data is not uncommon in curricular decision making.

[42] The sheer size of today's textbooks makes it difficult to evaluate one, let alone keep up with many. A graphic comparison appears in a recent *Scientific American* article which contains a picture of the core textbooks for four years of science from three high schools, one each in Sweden, Canada, and the U.S (Gibbs & Fox, 1999, p. 88). The Swedish stack is four thin paperbacks. The North American stacks are each four fat hardbacks, larger in all dimensions. And, this does not include the student workbooks and ancillary texts used by most U.S. high schools.

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[43] The *quality* of the instructional experience appears not to be addressed here. However, quality is both a given—higher quality is better—and an intangible. While we can now begin to specify the kinds of learning opportunities that students need and some of the attributes a good teacher should possess, we still have difficulty objectively identifying instructional quality.

[44] We stress that the measure is indirect. Collaborative, interactive, engaging instruction is possible under many organizational regimes. Significant learning can occur in even very rigid structures, as any military recruit can attest after basic training. However, the purposes of schooling are at some remove from the purposes of the military.

[45] The responses reported in this table have been collapsed into three categories. Teachers were originally asked to respond to the choices "never or almost never," "some lessons," "most lessons," or "every lesson." For this table, the last two categories have been combined into "most."

[46] The data sources for this table include Beaton et al. (1996), Martin et al. (1997), and Mullis et al. (1998).

[47] While additional comparisons at the elementary and secondary levels would have been valuable, not to mention international comparisons, these questions did not appear on the TIMSS Population 1 science teacher surveys. There was no Population 3 science teacher survey. Japanese science teachers were not asked these questions at all.

[48] See endnote 46. The First in the World data are derived from NCREL analyses of primary data.

[49] Ohio, when compared to the other 49 states, recently ranked 21st in income per capita. In terms of per pupil expenditures the state ranked 20th. In terms of pupil:teacher ratio, it ranked 18th. In other words, Ohio's educational resources tend to place it in the middle of the pack of all states. Given that resource base, it usually ranks just a little higher on various measures of educational quality.

[50] We did not ask this question of the high school teachers.

[51] The findings of the Linn group are consensual with several other experts' viewpoints about good science teaching. A good, opinionated review is presented in McGinn and Roth (1999).

[52] The latest round of international assessment data from TIMSS-R (for "Repeat") in early 2000 provides some better data on teacher background. Among eighth grade science teachers internationally, most listed a subject area specialization as their primary credential. Only in the U.S. was an education credential the most common: 56 percent of U.S. eighth grade science teachers listed an education degree as their primary credential, compared to 30 percent internationally (Gonzales et al., 2001).

[53] For the past few years, in partnership with the National Commission on Teaching and America's Future (NCTAF), Ohio has built an infrastructure to support new procedures for preparing, licensing, and promoting teacher professional development. Still, more is needed. The recent decision to require *Praxis III* passage as a condition for new hires to teaching, beginning in 2002, is welcome. However, in reality, it will do little to assure Ohio receives the best teachers or supports its teachers well.

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