Before I plan a lesson, I use Curriculum Topic Study to study the research on students’ thinking and their possible misconceptions. I start with these student preconceptions in mind whenever I teach a new topic.

Curriculum Topic Study has helped me understand standards-based concepts I haven’t thought about or used since I was in college, like energy transformation. Now I know where to turn to refresh my knowledge of the concepts that make up the topics in my curriculum.

Curriculum Topic Study helped our committee look at the topics in our curriculum across grade spans to identify gaps, redundancy, new contexts, and make sure we are teaching important ideas at a level developmentally appropriate for each grade. Without this tool, we would have been shooting in the dark.

Our lesson study group uses Curriculum Topic Study to research the topic we chose for our lesson. Doing this step first has made a big difference in designing our research lesson so we don’t have to start from scratch. Our topic study results help us decide what goals to focus on in crafting the lesson and provide a filter for us to fine-tune our observations.

Curriculum Topic Study has given us a common set of understandings and neutral, third-party perspective to work from at our science department meetings. Our discussions have changed from “What I do” to “This is what the standards and research point out.”
I can’t imagine designing a workshop for our elementary science teachers without studying the science topic first. Yesterday, we examined a new FOSS kit on Electricity and Magnetism, and I felt much better prepared to explain how the lessons aligned with standards and research and how conceptual ideas flowed from one activity to the next.

**WHAT IS CURRICULUM TOPIC STUDY (CTS)?**

All of the above quotes came from science educators who use Curriculum Topic Study in their work as teachers, mentors, professional developers, and as members of collaborative learning communities. Curriculum Topic Study, referred to in this book by its acronym, CTS, is a methodical study process and a set of tools and strategies—organized around 147 curriculum topics—designed to help educators improve the teaching and learning of science.

Through the CTS process, educators can

- Improve their understanding of the science content they teach
- Identify K–12 “big ideas,” implications for effective instruction, and images of effective practice
- Clarify concepts and specific ideas and skills in a learning goal from their state or local standards
- Identify a cluster of related learning goals that make up a curricular topic
- Improve coherency of topic development within a grade as well as K–12 vertical articulation
- Identify potential learning difficulties, developmental considerations, and misconceptions associated with a topic
- Examine and apply effective strategies for teaching concepts and skills associated with a topic
- Improve their ability to identify relevant connections among concepts and skills within and across topics
- Increase opportunities for students of all levels and backgrounds to achieve learning goals articulated in district, state, and national standards

The CTS process guides individuals or groups through a systematic study of readings from a core set of professional science education resources. These readings are identified and screened in advance, then organized in “Curriculum Topic Study Guides” (see example in Figure 1.1). The specific features and uses of CTS guides are described in Chapter 2.

There are 147 CTS guides in Chapter 6, ranging from specific topics such as Density to broader topics such as Properties of Matter. The majority of the study guides address K–12 topics. Guides that address very sophisticated content, such as Nuclear Energy, are designed to be used only with upper grade levels.

For each topic, CTS guides list relevant professional readings from sources that include national standards documents, trade books written by scientists, research summaries, and K–12 conceptual strand maps (see Figure 1.2). Optional readings, videos, and Web-based material that are not part of the core set of science education resources can also be used to supplement the study of a topic. CTS users can use their own materials or search for supplementary material by topic on the CTS Web site at www.curriculumtopicstudy.org.
## Figure 1.1  Example of a CTS Guide

### Standards- and Research-Based Study of a Curricular Topic

**STATES OF MATTER**

<table>
<thead>
<tr>
<th>Section and Outcome</th>
<th>Selected Sources and Readings for Study and Reflection</th>
</tr>
</thead>
</table>
| I. Identify Adult Content Knowledge | **IA:** *Science for All Americans*  
  - Chapter 4, Structure of Matter, pages 46–49  
  **IB:** *Science Matters: Achieving Scientific Literacy*  
| II. Consider Instructional Implications | **IIA:** *Benchmarks for Science Literacy*  
  - 4D, *Structure of Matter*, general essay, page 75; grade span essays, pages 76–79  
  **IIB:** *National Science Education Standards*  
  - Grades K–4, Standard B essay, pages 123, 126  
  - Grades 5–8, Standard B essay, page 149  
  - Grades 9–12, Standard B essay, pages 177–178 |
| III. Identify Concepts and Specific Ideas | **IIIA:** *Benchmarks for Science Literacy*  
  **IIIB:** *National Science Education Standards*  
| IV. Examine Research on Student Learning | **IVA:** *Benchmarks for Science Literacy*  
  **IVB:** *Making Sense of Secondary Science: Research Into Children’s Ideas*  
  - Chapter 9, *Solids, Liquids, and Gases*, pages 79–84  
  - Chapter 12, *Water as a Liquid*, page 98; *Freezing Water and Melting Ice*, page 98; *Boiling Water*, pages 98–99; *Evaporation*, pages 99–100; *Condensation*, page 100  
  - Chapter 13, *Existence of Air*, pages 104–105 |
| V. Examine Coherency and Articulation | **V:** *Atlas of Science Literacy*  
  - *States of Matter*, pages 58–59 |
| VI. Clarify State Standards and District Curriculum | **VIA:** *State Standards*: Link Sections I–V to learning goals and information from your state standards or frameworks that are informed by the results of the topic study.  
  **VIB:** *District Curriculum Guide*: Link Sections I–V to learning goals and information from your district curriculum guide that are informed by the results of the topic study. |

Visit www.curriculumtopicstudy.org for updates or supplementary readings, Web sites, and videos,
CTS promotes effective and efficient use of science professional readings. While these readings are to some extent accessible, educators would typically have to sift through an enormous amount of unfamiliar, and often daunting, material from disparate sources. Indeed, teachers who have not used professional science education resources extensively may not even know where to look for the information they are seeking. CTS guides identify the purpose of different resources and explicitly link relevant parts to topics of study that are useful from the teachers’ perspective. CTS guides do the groundwork for the busy educator, providing a one-page study guide to relevant results from an enormous range of readings vetted in advance and organized for each topic.

The *National Science Education Standards* (National Research Council [NRC], 1996) and *Benchmarks for Science Literacy* (American Association for the Advancement of Science [AAAS], 1993) have provided a carefully crafted description of the ideas and skills all students should achieve by the time they graduate. *Atlas of Science Literacy* (AAAS, 2001) further clarified and supported those documents by detailing how those ideas and skills connect and develop from kindergarten to graduation. States and districts have modeled their own standards after these national documents, and stakeholders at every level are learning how to evaluate, modify, and develop assessments, curricula, and instructional materials to reflect this vision of science literacy. Many teachers have seen or own a copy of national standards or *Atlas*, and the research on student learning is growing and becoming increasingly accessible.

Yet for all of the thought that went into national standards and all of the research on how students learn, just having the documents is not enough to truly impact student learning. In particular, this means being able to relate them to state and local standards and their own curricular and instructional challenges. CTS provides

---

**Figure 1.2** Types of Readings and Their Sources

<table>
<thead>
<tr>
<th>Type of Resource</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adult science literacy description</td>
<td><em>Science for All Americans</em>, American Association for the Advancement of Science Project 2061</td>
</tr>
<tr>
<td>Adult science trade book</td>
<td><em>Science Matters</em>, by Robert Hazen and James Trefil</td>
</tr>
<tr>
<td>National, state, and local standards</td>
<td><em>Benchmarks for Science Literacy</em>, American Association for the Advancement of Science Project 2061</td>
</tr>
<tr>
<td></td>
<td><em>National Science Education Standards</em>, National Research Council</td>
</tr>
<tr>
<td></td>
<td>State Standards or Frameworks and/or local curriculum standards or frameworks</td>
</tr>
<tr>
<td>Research summaries</td>
<td><em>Benchmarks for Science Literacy</em>, Chapter 15, American Association for the Advancement of Science Project 2061</td>
</tr>
<tr>
<td>Conceptual strand maps</td>
<td><em>Atlas of Science Literacy</em>, American Association for the Advancement of Science Project 2061</td>
</tr>
</tbody>
</table>
this deliberate process, which uses a collective set of common resources (see Figure 1.3) to help users become well-informed science educators who can move beyond paying lip service to the label of “standards- and research-based.”

CTS is not a replacement for formal science coursework, but it can help teachers learn content at the same time that they are studying the pedagogical implications of teaching that content. This can be particularly helpful to elementary teachers, who are expected to teach all content areas and seldom have substantive coursework in all the sciences. CTS can also help teachers translate formal science course content into content that is appropriate for students at different grade levels, an essential step for teachers that content courses largely overlook.

Educators across all 50 states who use CTS will know how and understand why it is important to use the national standards and cognitive research to support implementation of their states’ standards and why one is not a replacement for the other. CTS provides the guidance, tools, and strategies educators need to be able to utilize professional resources and research in their practice. It moves standards off the shelf and into the hands and minds of teachers, leaders, and professional developers, who use them on a regular basis to improve teaching and learning of science topics.

**WHY STUDY A CURRICULUM TOPIC?**

While national, state, and local standards drive curriculum, instruction, and assessment, the content taught in schools is typically organized in the curriculum by topics. It is essential for educators to make a bridge between these topics and the specific, research-based ideas and skills laid out in national, state, and
local standards. To do this, they must understand the content and pedagogical implications of those specific ideas and skills. CTS provides a deliberate process to accomplish this. As the following quote by a former director of the National Science Foundation’s (NSF) Elementary, Secondary, and Informal Education Division indicates, teachers who are unfamiliar with the topics they teach tend to rely on textbooks, teach in a more didactic way, and often fail to make connections between important ideas in science:

[When] teachers cover topics about which they are well-prepared, they encourage student questions and discussions, spend less time on unrelated topics, permit discussions to move in new directions based on student interest, and generally present topics in a more coherent way, all strategies described as standards-based teaching. However, when teachers teach topics about which they are less well-informed, they often discourage active participation by students, keep any discussion under tight rein, rely more on presentation than on student discussions, and spend time on tangential issues. (Kahle, 1999)

A plethora of general professional resources for teachers are available in schools, districts, and professional development settings. Concept-Based Curriculum and Instruction (Erickson, 1998); Understanding by Design (Wiggins & McTighe, 1998); Enhancing Professional Practice: A Framework for Teaching (Danielson, 1996); Classroom Instruction That Works (Marzano, Pickering, & Pollock, 2001); Mapping the Big Picture (Jacobs, 1997); and Differentiated Instructional Strategies (Gregory & Chapman, 2002) are examples of the many tools schools and teachers are using. These “one-tool-fits-all disciplines” can be useful to teachers who know the content and structure of their disciplines well and are familiar with the cognitive research base on student learning in science. But they fall short for novice teachers, elementary teachers who teach all content areas, and others who may not have a sufficient knowledge base in the discipline they teach.

For example, in Understanding by Design, the authors encourage teachers to use misconceptions to construct questions or tasks for assessment purposes (Wiggins & McTighe, 1998). What if teachers do not know what misconceptions are likely? What if teachers hold similar misconceptions about the content? CTS provides content-specific tools to identify those misconceptions. CTS provides the content-specific knowledge needed to make the general tools embraced by school districts useful and effective.

In addition to adding content specificity to the general resources used in schools, teachers and professional developers who utilize CTS in a deliberate and systematic way will benefit by:

- Developing deeper understanding of the specific content that makes up student learning goals in a science topic area
- Clarifying the “big ideas,” central concepts and skills, and specific ideas associated with a topic
- Improving articulation and coherency of topic development within grade levels as well as K–12
- Effectively using the research base to identify potential learning difficulties, developmental considerations, and misconceptions associated with a topic
• Applying effective instructional strategies for teaching and assessing concepts and skills associated with a topic
• Improving ability to identify connections within and across topics
• Increasing opportunities for students of all levels and backgrounds to achieve science learning goals articulated in district, state, and national standards
• Using a common language and knowledge base about teaching and learning science topics regardless of geographic location or curriculum used
• Promoting collegiality among groups of colleagues engaged in intellectual discourse about science teaching and learning
• Providing a greater content focus to professional development activities

Such a study process is right in line with current thinking about designing learning experiences, such as “backwards design.” Backwards design, used in Wiggins and McTighe’s (1998) popular Understanding by Design, begins by identifying evidence of meeting desired standards before planning teaching and learning experiences. The backwards design model suggests four filters for determining what is worth teaching and understanding in a topic. Three of these filters include examining (1) the extent to which the “big ideas” in a topic are addressed, (2) the extent to which the ideas and processes in a topic reside at the heart of the discipline, and (3) the extent to which abstract and counterintuitive ideas need to be uncovered, including students’ misconceptions about ideas related to the topic.

Although they can be powerful, these filters assume that teachers are comfortable with the content, know what the “big ideas” are, can make the connections that reflect the knowledge structure of the discipline and support student learning, and are aware of the misconceptions students may have. Unfortunately, this is rarely the case. In reality, many teachers missed the “big ideas” in their own education. Many elementary teachers have limited science backgrounds, and middle and high school science teachers often specialize in particular disciplines. Teachers are often not aware of the misconceptions their students hold, and in many cases they harbor those very same misconceptions. The critical, and often overlooked, first step in any effective design involves having a clear understanding of the specific ideas and skills that students should learn and the pedagogical implications for how students learn them. A careful study of a topic, using standards and research, clarifies the “end in mind” and provides a framework for planning and instructional design that maintains content fidelity and takes student thinking and developmental levels into account. CTS combines the wisdom of teacher practice with the recommendations from standards and research and serves as the essential first step in effective planning and design.

All too often, teachers strike out on their own, when a wealth of information and resources, carefully thought through by distinguished scientists and educators, sits at their fingertips.
Even those teachers who understand the science behind the topics they teach can benefit from CTS. Knowing the content is distinct from knowing how to organize and represent it for student learning. Indeed, familiarity with the content of a topic can make it more difficult to identify difficulties a novice learner is likely to have. Designing learning experiences and facilitating learning requires pedagogical content knowledge. Teachers with this special knowledge of teaching and content understand what makes the learning of specific topics easy or difficult for learners, and they can develop strategies for representing and formulating content to make it accessible to learners (Shulman, 1986). Through CTS, teachers with strong content backgrounds can gain new insights about specific ideas that may have been overlooked, relevant connections within and across topics, relevant contexts for learning, developmental considerations for introducing new ideas, and effective instructional strategies. Thus CTS can help teachers deepen and extend their pedagogical content knowledge.

Outside of the work done by the AAAS Project 2061 to promote K–12 science literacy, to date there has been little systematic, widespread work in professional development to help teachers understand standards and research on student learning. Pre- and inservice efforts to support teachers’ content knowledge place little emphasis on helping teachers become aware of the intersections between the topics they teach, standards, research on learning and student misconceptions, and how ideas and skills connect as they develop over time. Teachers may have copies of standards or occasionally come across a research article, but a process for using them has been missing.

Now CTS brings this process to teachers at all levels of the science teaching professional continuum and engages them in classroom applications of standards and research. In today’s climate of accountability, teachers assume more personal responsibility for their own learning. Rather than waiting for the system to provide more effective professional development opportunities, science educators can use CTS to continue to grow and improve as teachers, enhancing student learning of the most important ideas in science.

WHY FOCUS ON TOPICS?

To understand why this book focuses on “topics,” it is important to clarify what is meant by the word. In the context of CTS, topics are the broad organizers for ideas and skills in a curriculum; they do not describe the end point of instruction. Learning goals provide the description of what students should know and be able to do after instruction, but they are sorted into topics within the curriculum (see Figure 1.4).

Making this distinction clear, and making the bridge between learning goals and topics, is one of the main goals of CTS. Rather than focusing on teaching a topic per se, CTS helps teachers think about the organization of curriculum, instruction, and assessment around a connected set of specific ideas and skills. CTS guides range in grain size from a specific idea, such
as Conservation of Matter, to a broader topic, such as Properties of Matter (which subsumes Conservation of Matter as a “subtopic”). For a topic to be included in a CTS guide, it must be considered critical content in science and be linked to specific learning goals articulated in national standards, National Science Education Standards (NSES) and Benchmarks.

CTS does not include contextual themes as topics for learning. Topics such as Ponds, Butterflies, Flight, Rain Forests, and Dinosaurs are common curricular themes. They can be used to develop, practice, and apply ideas and skills, but they are not by themselves critical content. A risk in teaching contextual themes is that teachers can fail to conscientiously develop the important ideas and skills and instead teach mostly facts associated with the context. For example, students doing a unit on “Dinosaurs” may end up learning little more than vocabulary and facts about dinosaurs. The CTS study guide on Fossil Evidence would help teachers focus on developing interrelated ideas and skills about changes in life forms and environments over time, even though they may use “Dinosaurs” as a context.

There are 147 topics included in this book (see Chapter 6). But this does not imply that all of these topics should be taught in the K–12 science curriculum. The Third International Mathematics and Science Study (TIMSS) shows that American teachers cover too many topics a “mile wide and an inch deep,” resulting in little conceptual understanding for students (Schmidt, McKnight, & Raizen, 1997). The list of CTS guides includes both traditional topics that might appear in textbooks or curriculum guides, and topics used to organize national and state standards and frameworks. Many of these topics have overlapping ideas and skills, and some are completely subsumed in others. The intent of CTS is to provide enough examples of common topics so that teachers can find CTS guides that address the topics they are currently teaching, consolidate topics for deeper understanding, and improve their understanding of how students best learn the ideas in the topics they teach. Furthermore, because CTS examines topics from a K–12 perspective, it allows teachers to eliminate unnecessary redundancy while planning purposeful reiteration for ideas that need to be revisited in different contexts at increasing levels of sophistication. This careful examination of a topic, in contrast to covering a “checklist of standards,” promotes the coherency that is lacking from current attempts at “standards-based” curriculum, instruction, and assessment.
THE UNDERLYING KNOWLEDGE AND RESEARCH BASE

The CTS approach was adapted from the Project 2061 study of a benchmark, a powerful approach to understanding single benchmarks as a learning goal for science literacy. In working with groups of teachers and science education leaders throughout New England, it became clear that although it is important to examine a single learning goal in certain cases, teachers often needed to examine learning goals more comprehensively rather than focusing on a single learning goal, as the Project 2061 process does. It was also clear that teachers benefited from working with a range of standards documents, including both Benchmarks and NSES together. In addition, teachers benefited from looking beyond standards documents to resources for learning content and research on how students learn specific ideas. Based on these experiences, CTS expanded the study process to include content resources, Benchmarks and NSES, state standards or local curriculum, Rosalind Driver’s research compendia, and Atlas to get a complete picture of a science curricular topic.

Clearly, translating standards into classroom practice is a challenge yet to be overcome. At the same time, there is a shift toward providing transformative professional development and supporting resources that reflect the current knowledge base on how teachers and students learn. In 2000, the NRC released *How People Learn* (Bransford, Brown, & Cocking), which is raising awareness among science educators of the need to understand the ideas students bring to their learning.

CTS—by virtue of its focus on the structure of scientific content, research into students’ conceptions, and pedagogical strategies linked to specific ideas and skills—can help address the findings from *How People Learn* that distinguish expert teachers from novices (see Figure 1.5). There is a strong link between teacher expertise, which involves both content and pedagogical content knowledge, and student achievement. Because teacher expertise has such a demonstrated impact on student learning, it stands to reason that processes that develop science teachers’ knowledge and skills, such as CTS, are a sound investment toward improving student achievement in science.

National, State, and Local Standards

The term *standards* (sometimes referred to as *benchmarks, learning results, performance indicators,* and so on) conveys different meanings to different people. CTS defines standards as a set of outcomes that define the ideas and skills that students should learn, and provide a vision for achieving science literacy for all students. A misperception by many educators is that the standards themselves are a curriculum. Curricular decisions at the state and local level are *informed* by standards, but there are a variety of ways to organize the ideas and skills in standards into a curriculum.

The national “content” standards used in CTS include Benchmarks and the NSES. Project 2061 led the national effort to define goals for science literacy in the late 1980s with the development of *Science for All Americans* (AAAS, 1990). Rather than a “list” of standards, *Science for All Americans* provides a narrative description of the
interconnected web of understanding that all adult Americans should possess after their K–12 education. This narrative account reflects a strong consensus among respected scientists and educators. Based on cognitive research and the expertise of teachers and teacher educators, *Benchmarks* was developed in 1993. Specific learning goals were developed for the K–2, 3–5, 6–8, and 9–12 grade spans—steps along the way to achieving the vision of science literacy laid out in *Science for All Americans*. *Benchmarks* also includes rich descriptions of the content, context, and instructional implications of those learning goals.

In 1991, the NRC agreed to coordinate the development of the NSES, which was released in 1996. The NRC took a collaborative and systemic approach to describe standards for all aspects of the science education system. The content standards in the NSES drew upon the previous work of Project 2061 to describe fundamental concepts, principles, and abilities at K–4, 5–8, and 9–12 grade spans. Since that time, states and local districts have been developing their own content standards.

Science educators face numerous challenges in the current standards-based teaching and learning environment, ranging from implementing new curricula to the high-stakes accountability requirements mandated by the “No Child Left Behind” legislation. Educators face the daunting task of applying local, state, or national standards in their own curricular, instructional, and assessment contexts. Local districts and states have spent considerable funds, time, and energy in developing their standards. There has been a flurry of activity in aligning curricula, instruction, and assessment to standards. But there is a missing link in the chain that connects standards to efforts to implement new policies, programs, and practices. Little time has been spent helping educators interpret the content, curricular, and instructional meaning of the standards. Interpretation has been left to individual teachers. As a result, consistency and coherency—and what counts as “alignment”—vary across classrooms, districts, and states. CTS provides a more reliable way to analyze and interpret standards. Using a science analogy, Copernicus did not change the motions of the earth and sun; he just provided a more accurate interpretation of those motions. CTS can provide a more accurate and consistent interpretation of standards, resulting in standards-based teaching that actually reflects the intent of the standards.

CTS will help educators recognize the role of standards, both national and state, as central pieces in their local science education system.

Figure 1.5  Characteristics of Expert Teachers

<table>
<thead>
<tr>
<th>Expert Teachers</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Know the structure of the knowledge in their disciplines.</td>
</tr>
<tr>
<td>• Know the conceptual barriers that are likely to hinder learning.</td>
</tr>
<tr>
<td>• Have a well-organized knowledge of concepts and inquiry procedures and problem-solving strategies (based on pedagogical content knowledge).</td>
</tr>
</tbody>
</table>

SOURCE: Bransford et al. (1999), *How People Learn*.
Cognitive Research

Research into student learning—both in general and with regard to specific ideas—is another fundamental feature of CTS. In Learning Science and the Science of Learning, Harold Pratt (2002) described the importance of using the research base on learning:

As science teachers and science educators, we approach teaching curriculum development, and assessment with our current conceptions about how the world of the classroom works, namely, how teachers should teach and how students learn. Our job as professionals is to find ways to take our current conceptions about learning and place them against new research, concepts, and information about learning as a way of examining and improving our practice. (p. xiii)

For teachers using CTS, awareness of the conceptions that students bring to the classroom and the developmental implications associated with the specific ideas they need to teach has proven a powerful learning experience.

The research literature on students’ science conceptions has been growing, even since the publication of Benchmarks and the NSES. However, much of it has been difficult for teachers to find and access. In fact, many teachers are not aware that there are resources readily available that summarize the research base. Each CTS guide links the topic to relevant research summaries. CTS uses two research compendia to provide concise, accessible summaries of the research that has been done around specific ideas in different curricular topics. In Chapter 15, Benchmarks contains research linked to the learning goals in other chapters. CTS also draws upon the work of notable researchers, such as Rosalind Driver, published after Benchmarks. In Making Sense of Secondary Science, research findings are arranged in three sections: life and living processes, materials and their properties, and physical processes (Driver, Squires, Rushworth, & Wood-Robinson 1994). New research articles, linked to the CTS guides, are also posted and updated on the CTS Web site.

CTS is also informed by research on adult learning. Engaging teachers in CTS by surfacing their initial ideas related to a topic, followed by a systematic study and discussion of standards and research, reflects the constructivist theory of learning. In constructivism, learners construct knowledge by modifying or rejecting existing ideas (Bransford et al., 2000). In CTS, teachers interact with the information in the standards and research tools, and filter them through their everyday experiences with students. Furthermore, the collaborative learning environment created when teachers engage together in CTS reflects how people learn through interaction with one another, so that they can make sense of new concepts and ideas (Jonassen, 1994). Another important aspect of learning is personal reflection. Effective teacher-learners use metacognitive strategies during a topic study to monitor their own ideas and thought processes, compare and contrast them with those of others, and provide reasons why they accept them (Loucks-Horsley, Love, Stiles, Mundry, & Hewson, 2003). CTS is designed to take account of all these insights into adult learning.
Changes in Professional Development

The seminal publication for professional development in science and mathematics, *Designing Professional Development for Teachers of Science and Mathematics*, has informed the work of CTS as a tool for transformative teacher learning (Loucks-Horsley et al., 2003). The changes in science education and professional development described in this book create an urgent need for new teacher learning tools and materials focused on content. Some of these changes described by Loucks-Horsley et al. and the connection to CTS are as follows:

1. **The knowledge base about learning, teaching, the nature of science, and professional development is growing.** Our current knowledge base about teachers and teaching and learners and learning has expanded exponentially since the rise of standards. The findings from *How People Learn* and recent papers in professional journals have increased our knowledge of how students learn specific ideas, the misconceptions they are likely to hold, and the developmental implications for introducing ideas in different grades. This literature reveals more about what constitutes and supports transformative learning for teachers and helps educators recognize the importance of developing not only content knowledge, but pedagogical content knowledge as well. Consequently, teachers need tools, such as CTS, to move beyond personal and management concerns in order to successfully implement new practices.

2. **Standards are more widely consulted as school districts shape their visions of teaching and learning.** Standards are now commonplace in most schools, but implementation is still a struggle. Most state standards were developed through a process that consulted and rewrote the learning goals in national standards using performance verbs and broader descriptions of content. Like a childhood game of telephone, by the time these standards reached the teachers, their clarity and specificity were lost, leaving enough ambiguity for most teachers to continue doing what they were doing before, while being able to claim that they were meeting the standards. There is growing recognition that national science standards are essential to understanding the specific intent of state standards. Through CTS, teachers can clarify the meaning and intent of their state standards, recognize the authentic changes they demand, and increase the coherency and consistency of their implementation.

3. **Content and pedagogical content knowledge are playing a greater role in professional development programs.** Professional development for science teachers has shifted from a schoolwide focus on generic opportunities to learn with all the other disciplines to opportunities that are directly connected to the content they teach. CTS reflects this shift by helping individuals and groups of teachers focus on the specific science content they teach and gain knowledge about how students interact with the content.

4. **“Job-embedded,” “practice-based,” and “collegial” forms of professional development are more widely accepted, researched, and practiced.** Teachers can embed CTS into their daily practice and preparation for instruction. Furthermore, CTS is well suited to collegial structures such as study groups, lesson study, and looking at student work. By using CTS up front, teachers will be grounded in a common understanding. Teachers who experience CTS together draw upon the same knowledge base and use common language in their professional conversations about teaching and learning science.
**Reading Research**

The CTS process involves a substantial amount of reading and analysis, producing an apparent contradiction to the principle of “active learning” in professional development. An NSF *Foundations Series* research monograph examined ways in which a constructivist paradigm can facilitate teachers’ learning from and with text material as part of a strategy called “Gathering and Making Sense of Information” (NSF, 2002). The theoretical rationale and empirical support for this strategy supports the CTS process as an effective strategy for both individual learning and learning within a community.

Selected readings from science trade books, standards, and research source materials can be an integral part of constructing a personal understanding of content, standards-based reform, and the use of cognitive research findings. Recent research on reading, in particular, helps us understand how the CTS process can become an active and socially constructed process:

Reading researchers have argued that reading does not need to occur as an isolated, or even individual activity. First, reading should be purposeful. In other words, teachers should read either to address questions that they feel the need to know more about or because their concerns could not be resolved through discussion. Reading can also be a catalyst for other experiences. Indeed, reading can fulfill many functions while teachers inquire into any topic (Siegel, Borasi, & Fonzi, 1998). Readings can provide background information, raise questions for further inquiry about a topic, synthesize different points of view, and offer models for teachers’ own practice. Reading is not a passive or straightforward matter of decoding or extracting information from text (e.g., Pearson & Fielding, 1991; Rosenblatt, 1994). Rather, readers construct meaning in interaction with the text, their own background and interests, and their purposes for reading the text. Furthermore, such construction of meaning can be even more productive when it is augmented by interactions with other learners so that different interpretations can be shared and discussed. (NSF, 2002)

Reading and analyzing text in a social context led by a skilled facilitator is preferred, but CTS can also be useful as a stand-alone process for individual teachers, particularly teachers in isolated areas or those constrained by limited release time for workshops. Through CTS, those teachers can still take charge of their own professional development.

**Science Teachers and Teaching**

Standards and research provide a sound, theoretical foundation and vision for student and teacher learning, but the rubber meets the road in the classroom. What does it take to be effective in this new vision of science teaching? What do teachers need to know and be able to do to be effective?
Research studies that examined the relationship between teacher qualifications and background and student achievement in science found high school science teachers with standard certifications in their fields of instruction (usually indicating coursework in both subject matter and education methods) had higher-achieving students than teachers teaching without certification in their subject areas (Darling-Hammond, 2000; Monk, 1994).

However, the current reality is that many classrooms lack a “highly qualified” teacher. Most preservice education students do not have basic knowledge of science disciplines as they begin their teacher preparation programs (Zembal-Saul, Blumenfeld, & Krajcik, 2000). Unfortunately, many students, especially students in high-poverty and high-minority settings, do not have teachers with a major or minor in their subject matters. Most elementary teachers did not major or minor in science. Even at the secondary level, where teachers are more likely to have majored in science, it is hard for teachers to keep up with recent developments in the biological, space, earth, and physical sciences that have expanded our horizons and influenced the school curriculum. In addition, a secondary teacher with background in one science discipline (e.g., chemistry) is often called upon to teach other sciences (e.g., physics, earth, or life). Furthermore, it is clear that requiring more content courses alone does not necessarily translate into better understanding of the discipline and how to represent it effectively for learners (Zembal-Saul et al., 2000). Ongoing professional development—especially programs that focus on content and how to teach it—coupled with tools like CTS, can close the gap between what teachers know and what they need to know (Loucks-Horsley et al., 2003).

Effective teaching reflects an understanding not only of the content but also the structure of the content—how ideas interconnect and build on one another. For example, to understand how the eye works, students need to understand that “something can be seen when light waves emitted or reflected by it enter the eye,” yet they may struggle with the idea of light traveling if they do not already understand the precursor idea that “light travels and can be absorbed, redirected, bounced back or allowed to pass through objects” (AAAS, 2001, p. 65). Teachers who know the content and how the content builds from understanding of many topics are better able to diagnose and address confusions. They know the next best question to ask when students are engaged in inquiry.

CTS is designed to help teachers identify the content they need to understand in order to teach ideas at a level appropriate for their students. Two resources used in CTS for the purpose of improving teachers’ content knowledge are Science for All Americans (AAAS, 1990) and Science Matters (Hazen & Trefil, 1991). The former describes the specific ideas and skills that a scientifically literate adult should have. Science literacy is important for every adult who will encounter science in his or her daily life, including teachers of every subject area and grade level. Reading Science for All Americans is also helpful for teachers who already have a background in a science discipline, as it describes how ideas come together in an integrated picture of science. Science Matters is a science adult trade book, written by two credible,
respected scientists. Often when teachers do not understand a topic they need to teach, they turn to a textbook. But textbook language is stilted and technical. Trade books such as *Science Matters* explain science in vivid and comprehensible ways. Together, these resources are used in CTS to help teachers (both with and without a content background) to improve their understanding of the ideas and skills in the topics they teach. Teacher content knowledge is also linked to the research base on students’ ideas. Providing opportunities for teachers to examine their own conceptions of the content can help teachers change instructional strategies that may unintentionally convey inaccurate ideas about the topics they teach.

**Pedagogical Content Knowledge**

Teaching for understanding requires more than content knowledge:

[Teachers] also must be skilled in helping students develop an understanding of the content, meaning that they need to know how students typically think about particular concepts, how to determine what a particular student or group of students thinks about those ideas, and how to help students deepen their understanding. (Weiss, Pasley, Smith, Banilower, & Heck, 2003, p. 28)

These skills constitute a teacher’s specialized professional knowledge, called *pedagogical content knowledge* (PCK). PCK is an understanding of what makes the learning of specific topics easy or difficult for learners and knowledge of ways of representing and formulating subject matter to make it comprehensible to learners (Cochran, DeRuiter, & King, 1993; Fernández-Balboa & Stiehl, 1995; Shulman, 1986; Van Driel, Verloop, & DeVos, 1998). Developing this special knowledge of teaching PCK is contingent on a teacher’s subject matter knowledge (Clermont, Krajcik, & Borko, 1993). What is the important content, and what should children at the different grade or age levels know with respect to the content? What common misunderstandings do students have with respect to the content? Knowing the answers to these questions sets the course for making important pedagogical choices in the classroom to guide learning. The *NSES* emphasizes the importance of this type of knowledge:

Effective teaching requires that teachers know what students of certain ages are likely to know, understand, and be able to do; what they will learn quickly; and what will be a struggle. Teachers of science need to anticipate typical misunderstandings and to judge the appropriateness of concepts for the developmental level of their students. In addition, teachers of science must develop understanding of how students with different learning styles, abilities, and interests learn science. Teachers use all of that knowledge to make effective decisions about learning objectives, teaching strategies, assessment tasks, and curriculum materials. (NRC, 1996)

This is where CTS comes in and why it is called the “missing link.” It provides the process to help teachers think about how to create meaningful and appropriate learning opportunities for students. Examining the essays in *Benchmarks* and *NSES* and utilizing the research summaries helps teachers identify topic-specific strategies.
that support student learning in science. These strategies can include use of particular representations, phenomena, and inquiry-based activities that directly challenge students’ misconceptions. Such strategies also include knowing how to sequence those experiences in such a way as to scaffold students’ developing understanding. In a similar vein, Atlas provides a graphic representation for teachers to examine students’ growth of understanding as ideas begin in K–2 and become increasingly sophisticated by the end of high school. It also provides a way for teachers to think about the interconnections among and across the various topics they teach.

**Beliefs About Teaching and Learning**

CTS draws out teachers’ knowledge and beliefs about a topic and how students learn it, and it helps them connect new ideas gained through CTS with their previous ideas and beliefs. One way teachers change or reinforce their beliefs is through discourse in a social setting. Having an opportunity to present one’s own ideas after studying a topic, as well as hearing and reflecting on the ideas of others, is an empowering experience. This kind of learning is highly personal. Perhaps most important, it can resolve the dissonance between long-held beliefs and new thinking, resulting in changed practice (Mezirow, 1997).

Cognitive research on how people learn has begun to influence beliefs about teaching and learning. A significant shift seen among science teachers who have used CTS is in how they see their own role as teachers. More and more, the teachers are moving away from seeing teaching as telling to seeing it as facilitating learning. They are moving away from the idea that only some children can learn to embracing the belief that all children can learn challenging content. Driver (1989) noted children’s prior knowledge of phenomena is an important part of how they come to understand science. Children often interpret phenomena from a “commonsense” point of view that can lead to misconceptions. Effective teaching involves changing beliefs that knowledge is passed on from the teacher to recognizing that engaging students in rethinking their ideas results in increased learning.

**Having a Professional Knowledge Base**

A teacher’s role as a facilitator of learning of all students is complex and demanding (Loucks-Horsley et al., 2003). It is enhanced when teachers operate from a body of specialized professional knowledge that is based on research on how to teach and how people learn (Stigler & Hiebert, 1999). CTS provides such a professional knowledge base. Teachers who use it can describe or defend their choices of instructional strategies in the context of the research. One notable observation made while working with teachers who have used CTS is hearing how their conversations became more grounded in the research. For example, teachers are frequently heard to say, “According to the research, it is common for students to have trouble with this concept. What can we do differently to help them?” As they engaged in conversations about what is important to teach, they would say, “Let’s look at the standards.”

With regard to learning, the national standards and research on cognition point to the importance of learning environments that draw upon learners’ prior knowledge and help them make connections between what they know and what they are
learning. This sometimes involves helping the learner to discard old ideas that no longer work and accept new ones in order to move to deeper understanding of the knowledge base of science teaching. Furthermore, knowledge is socially constructed, requiring learners to interact actively with others and with the ideas and phenomena they are learning (Bransford et al., 2000).

**The Teacher Professional Continuum**

Learning to teach can be regarded as a continuum of professional experiences (Bransford et al., 2000). And research on professional development is linked to this concept of a professional continuum (see Figure 1.6). This continuum begins with teachers’ experiences as they progress through their K–12 education, and it builds to include preservice programs, induction, professional development, and other life and professional activities. Studies show that teachers develop differently and have different attitudes, knowledge, skills, and behaviors at various points during their careers. Characteristics that change include the nature of their concerns about teaching, their instructional behaviors, their understanding of how students learn science, and their perceptions of themselves, their work, and their profession. As teacher characteristics change, their needs change accordingly.

NSF’s Teacher Professional Continuum Program, which provided funding for the development of CTS, is designed to provide support for a comprehensive, coherent, and integrated sequence of lifelong learning for teachers (NSF, 2003). In response, CTS advocates personalized support that addresses the unique needs of an individual teacher as well as a learning community and moves them along a path of learning. “Becoming an effective science teacher is a continuous process that stretches from pre-service experiences in undergraduate years to the end of a professional career” (NRC, 1996). CTS is a tool designed to address this continuous learning by helping educators at all career stages evolve in the science teaching profession.

**Figure 1.6** The Teacher Professional Continuum Program