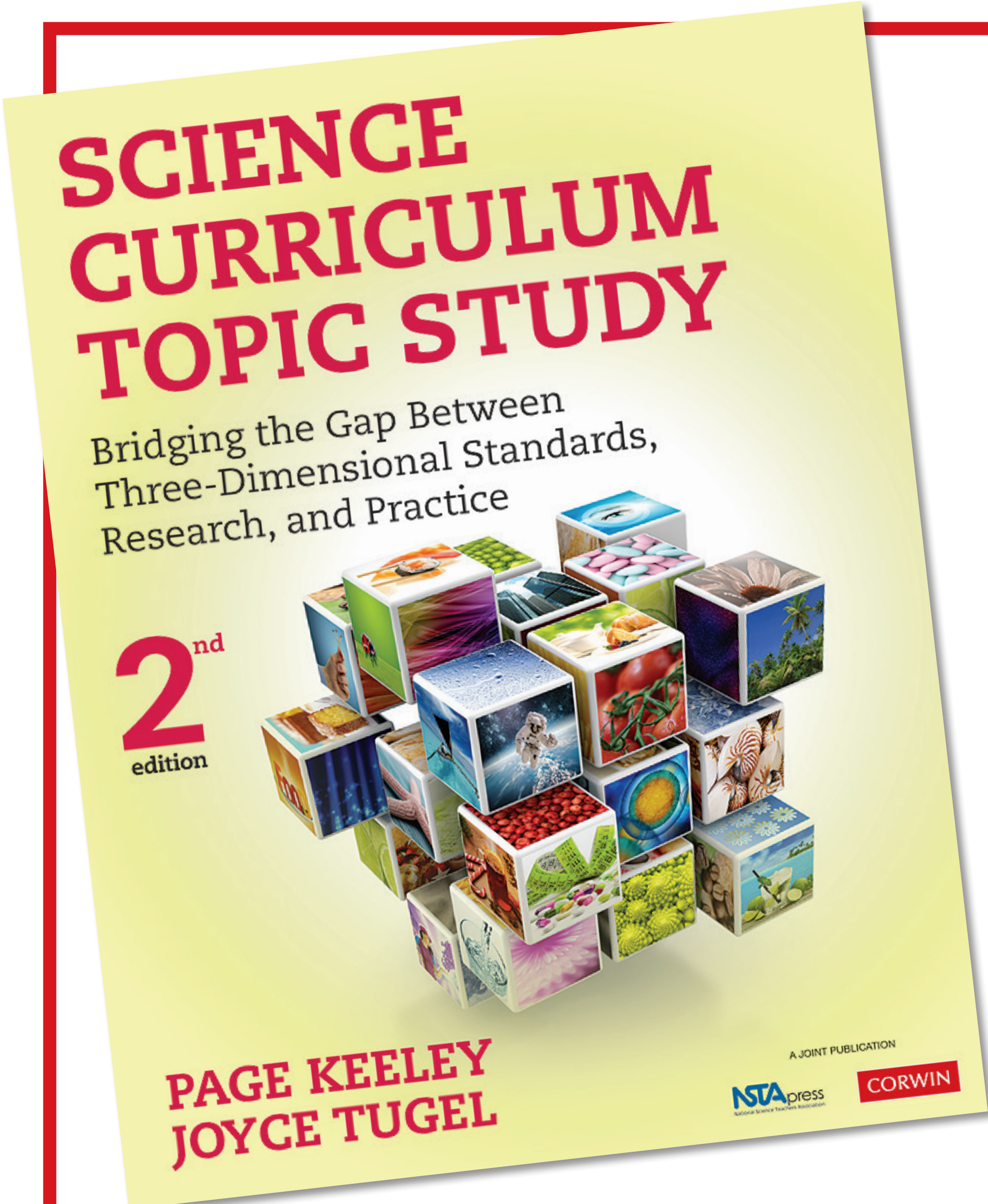


Thank you

FOR YOUR INTEREST IN CORWIN

Please enjoy this complimentary excerpt from *Science Curriculum Topic Study, 2nd Edition,* by Page Keeley and Joyce Tugel. In this chapter, the authors make clear the appropriate uses and applications of Curriculum Topic Study (CTS) and help the reader to identify the sections that apply to their own circumstances.

LEARN MORE about this title, including Features, Table of Contents and Reviews.

CORWIN

CHAPTER 4

Using and Applying Curriculum Topic Study

WHAT CTS IS NOT

The previous chapters helped you understand what CTS is and the resources used for CTS. In this chapter you will examine different ways CTS is used in both individual professional learning situations as well as in various group professional learning contexts. Before you consider ways you might use CTS in your work, keep in mind that CTS helps you seek answers to questions of practice related to content, curriculum, instruction, or assessment. CTS provides the analytic lens and process to help you think through questions and issues related to your work in science teaching and learning and analyze the information you gather through the process. It does not provide the specific answers or solutions you may be seeking. The answers or solutions come from you as you synthesize the information you gather through the CTS process and relate it to the purpose of your study. The following describes what CTS is **not** intended to do:

- CTS is **not** a remedy for weak science content knowledge. It can be used to enhance and support content knowledge but it is not a replacement for a serious lack of content knowledge.
- CTS is **not** a curriculum or collection of lesson plans and activities. It will help you make better decisions about curriculum and instructional materials, including teacher-designed lessons.
- CTS is **not** an instructional how to. It does not prescribe a particular instructional model or set of instructional strategies. It can help you think through ways to make your instruction more coherent and effective, including embedding formative assessment to help you understand students' thinking prior to or throughout an instructional sequence.
- CTS is **not** a source of performance assessments. It does identify performance expectations that can be used to inform assessment development.

- CTS is **not** a quick fix. It takes serious, dedicated time to read, analyze, and reflect on the findings from CTS.
- CTS is **not** a stand-alone or end-all for professional or preservice learning. It is used with other types of professional or preservice learning, such as backwards planning for curriculum. Additionally, CTS often reveals additional learning needs.
- CTS is **not** solely a *Next Generation Science Standards* (*NGSS*) resource nor does it replace other *NGSS* resources. CTS can be used with any set of standards. Furthermore, when used to support *NGSS*, CTS is just one of a set of processes and tools developed to support *NGSS*. Besides CTS, there are many other resources developed by Achieve and others that are not included in this book but are valuable tools to consider.

INDIVIDUAL USE OF CTS

Individual teachers can use CTS on their own to strengthen their content knowledge, clarify their learning goals, inform curriculum and assessment planning, design or modify lessons, examine ideas students are likely to bring to their learning, anticipate difficulties students may have, understand what comes before and after their grade level, and answer specific questions related to their practice. CTS increases teachers' knowledge of what is important to teach and how to effectively organize and teach their curriculum (pedagogical content knowledge). Perhaps you are switching to a new grade level, teaching new subject matter, or shifting from a focus on teaching to a focus on learning. CTS can help you make that transition by grounding your practice in the important ideas from the standards, deepening your knowledge about coherent and effective curriculum and instruction, utilizing research on learning, and understanding how the three dimensions intertwine and support each other.

When using CTS as an individual, remember you can start with any of the sections I–VI on a CTS guide. You might use only one section to ask a specific question about your practice or you might do a full topic study to have a deep understanding of the topic you teach. Keep notes as you study each section, recording the information from the resources that will be used as "evidence" when you make curricular or instructional decisions. Figure 4.1 provides short snapshots that you can use to practice first steps of CTS by identifying a topic study guide and the section you can use to answer a specific question of practice. Try out two or three of these snapshots if you are new to CTS. Figure 4.2 provides an answer key to the guide and section(s) that can be used for the snapshots.

FIGURE 4.1 Snapshots for practicing CTS Guide and sections (I–VI) selection

A. I am planning a lesson in which students will investigate how matter is conserved during a chemical reaction. What alternative ideas and potential difficulties should I be aware of?	B. Our seventh graders will be developing models to explain what causes the phases of the moon. What important aspects of this practice should I focus on and how can it support learning about moon phases?	C. I am not sure about the depth or breadth I should go into when including ideas about atoms and molecules in my lessons. What is the current thinking about what is important at my grade level?
D. My students are designing and testing different types of parachutes to safely land a fragile object. How can I ensure this activity is addressing the engineering practice of designing solutions?	E. Our elementary students have a difficult time understanding what happens to matter when one organism eats another. What instructional considerations should I take into account as I plan my lessons?	F. The concept of waves is embedded in several of our secondary physical science units. How do ideas about wave properties develop from the middle grades through high school?
G. I notice my students have problems interpreting graphs. Are there certain types of graphs students have problems interpreting? What common difficulties related to analyzing graphs should I be aware of?	H. The concept of systems cuts across many of our instructional units. How can I build my understanding of what systems are and how they can help us understand phenomena?	I. We are writing assessments for our geology unit. I'm wondering how a performance expectation about movement of earth's plates could inform our learning targets for a three-dimensional performance task?
J. Our elementary teachers are planning a lesson on the water cycle. How can I use a formative assessment probe to elicit their initial ideas about the water cycle and find instructional suggestions to inform the planning of our lessons?	K. I'm teaching a course on astronomy for the first time. Our standards ask students to construct an explanation of the Big Bang Theory. I need to refresh my knowledge about the Big Bang. What basic introduction to this theory could help me?	L. When we ask students to construct explanations, do they know what that means? How can I help them distinguish everyday explanations from scientific explanations?
M. We are working on revising our approach to energy in our K–12 curriculum. When do students encounter the concept of energy, and how does this concept progress from one grade span to another?	N. Our district is revising our K–12 curriculum to include crosscutting concepts. How are concepts and procedures in mathematics used with the crosscutting concept of scale, proportion, and quantity?	O. How some organisms in a population may have traits that allow them to survive changes in their environment is a major idea in our life science curriculum. What commonly held ideas should I anticipate that students may have about this idea?

FIGURE 4.2 Snapshots answer key

Snapshot	Guide(s)	Sections(s)
A	Conservation of Matter, or Chemical Reactions	IV
B	Developing and Using Models and Phases of the Moon	II and III
C	Atoms and Molecules	II or V
D	Designing Solutions	II and III
E	Cycling of Matter in Ecosystems, or Food Chains and Food Webs	III
F	Waves and Wave Properties	II or V
G	Analyzing and Interpreting Data	IV
H	Systems and System Models	I
I	Plate Tectonics	VI
J	Water Cycle and Distribution	III
K	Formation of the Earth, Solar System, and the Universe	I
L	Constructing Scientific Explanations	III
M	Concept of Energy	V
N	Scale, Proportion, and Quantity	II or V
O	Adaptation	IV

GROUP USE OF CTS

Group use of CTS can be as simple as two colleagues studying a topic together, an instructional coach and a new teacher clarifying learning goals, several people on a committee using CTS to inform their curriculum work, an after-school professional learning community (PLC) deepening their understanding of crosscutting concepts, a preservice methods course using CTS before planning a lesson, or a large workshop setting in which groups combine their studies to examine three-dimensional learning. Whatever the format, topic, or audience is, professional learning and collaboration is enhanced when colleagues have opportunities work together to analyze, discuss, and apply findings from a curriculum topic study.

In addition to managing the resources used for CTS, as described in Chapter 2, leaders of small- or large-group use of CTS must consider ways to organize, discuss, and share results of CTS, especially when a group is doing a full CTS of all the sections (I–VI). A commonly used method for dividing a task among a group is the jigsaw strategy. A jigsaw builds on the idea that we learn best when we have to teach others. It is also a way to reduce the amount of reading an individual would have to do by distributing the readings among a group, with each reading summarized and shared by the group member assigned to that CTS section. Below are some suggested ways to jigsaw a CTS:

Large Group Jigsaw with Expert Groups. In this option, CTS readings are assigned to "table groups." Each table group becomes the expert for their assigned reading. After the participants in each expert group have read their assigned section, they discuss the reading within their group. For example, one table group might be assigned to read CTS sections IA and IC for the CTS study of Natural Selection. After participants have discussed that reading, they prepare a summary of sections IA and IC to share with the other groups that were assigned other readings from the Natural Selection CTS guide. When all groups have finished their summaries, a member of each group meets with others to form a group that includes all the readings. In this new group, participants share out each of their summaries, completing a full topic study. For example, a member of the group that summarized sections IA and IC meets with a member of the group that summarized the section II reading, a member of the group that summarized the section III reading and so on forming a new group of six, with each person sharing their summary of the reading that was assigned to them.

Small Group Jigsaw. In this option, each person in a small group is assigned to be the "expert" for a specific reading or section of a CTS guide. Everyone in the group has a different assignment in which they read their section and prepare a summary for their group. Each person takes a turn sharing the summary of their section with their whole small group.

Assigning Jigsaw Readings

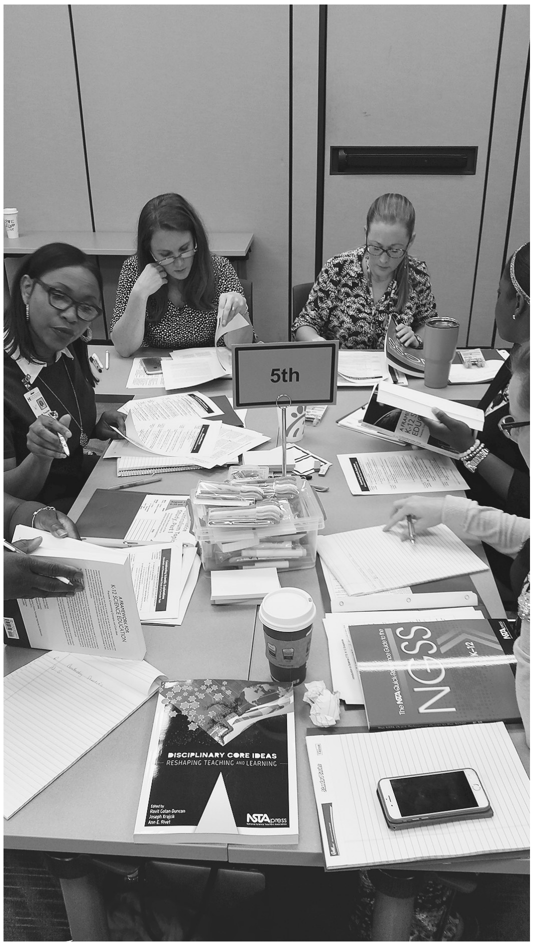
There are a variety of ways to assign jigsaw readings. The breakdown you choose depends on the resources you have available, the grade spans you want to focus on, and the sections of the CTS guide that fit the purpose of your study in case you choose not to do all six sections. Individuals can be assigned a reading or it can be done in pairs. The following are options for assigning readings:

Assign by CTS sections. I, II, III, IV, V, VI, deciding within each section which subsections to include, for example: IA, IC, IIC, IIIA, IVC, VC, VIA and VIC. If you are the facilitator, review the readings first and combine short ones so that everyone is reading for about the same amount of time.

Assign by Book. Assign readings from different sections using the same book or a combination of books. For example, one person might do all the readings from the *Framework*, whereas another does all the readings from the *Atlas*.

Assign by Grade Span. If you are doing a full K–12 topic study, consider dividing the readings for sections II, III, and VI by grade span (as seen in Figures 4.3 and 4.5).

FIGURE 4.3 Teachers engaged in CTS



Other Group Strategies

Some professional learning groups prefer jigsaws and others prefer not to be restricted in their readings and discussions. Whether you choose to jigsaw or not depends on your audience, the topic(s) chosen, and the time frame available for doing the study. Some other group strategies are

> ***Large Group Discussion, All Readings.*** This option works best when each participant has access to at least one CTS resource for each section and readings can be done in advance or in a longer time frame. Each participant reads all the sections selected by the facilitator, makes notes, and shares findings and insights during a whole group discussion. While some participants may not have had time to read all sections, it is likely that someone has read one of the sections assigned and can share with the whole group.
>
> ***Small Group Discussion, Assigned Expert.*** This option is the same as the small group jigsaw but instead of reading only the section that is assigned to you, you may read any or all the sections. However, you are assigned one reading you have the responsibility to be the expert for, in case others don't get to that reading. Once you complete that section, you can read any of the other sections, as well as participate in the discussion of any sections you read. This option ensures that all the readings are covered but provides flexibility for everyone to read sections they are most interested in.

These are just some of the ways you can organize and structure a group CTS. As you become familiar with CTS, you will find ways to facilitate the process that works best in your professional setting.

UTILIZING CURRICULUM TOPIC STUDY FOR DIFFERENT PURPOSES

CTS is a versatile process that can be tailored to fit your purpose and the context you are working in. Think of it as the Swiss Army knife of content, curriculum, instruction, and assessment. Like a Swiss Army knife, it is a versatile tool that serves several different purposes. You can use a single part of the tool or several in combination.

CTS can be used by preservice and classroom teachers, curriculum and assessment developers, science specialists, instructional coaches, professional developers, preservice instructors, informal educators, and anyone interested in improving science teaching and learning. It can be used to build understanding of science content; clarify learning goals; inform curricular, instructional, and assessment decisions; and understand how students think about science concepts, ideas, and practices. It can be used to examine a single grade level, a grade span (e.g., grades 3–5), or a vertical progression K–12. The remainder of this chapter presents examples of how CTS is used in different ways educators encounter in their work. As you become familiar with CTS, you may find other ways to utilize the process and resources that are not listed here.

Using CTS to Enhance Content Knowledge

A science-literate adult is one who has a basic understanding of the science needed to be a productive and informed participant in today's world. A science-literate person is not necessarily one who has majored in one of the sciences in college or works in a science-related career. Science literacy applies to all adults, regardless of their post-secondary education or career choice. It applies to all teachers of science including those who have a college degree in science as well as education generalists who teach all subject areas, including science. When using CTS with teachers, it is important to explain what science literacy means in the context of CTS.

A strategy teachers frequently use to gain or refresh their own adult content knowledge before teaching a new topic is to look in their textbooks, teacher guides, or the internet to get the information they need. While instructional materials may include the same content encountered by students, they often only superficially cover the content with an emphasis on terminology and facts. Furthermore, they often do not provide rich explanations, relevant phenomena, interesting examples, or explanatory models that support adult understanding of the content.

CTS provides a different alternative to developing or enhancing one's science (and engineering) content knowledge. CTS does not replace formal content coursework or content-focused professional development. Instead it provides a systematic way to engage with the content a science-literate adult should understand and be able to use, through selected readings that can be used on a "need-to-know" basis or embedded within a variety of professional learning formats.

In addition to disciplinary content, section I of CTS also clarifies the content that makes up the understandings for engaging in scientific or engineering practices and using crosscutting concepts. For example, crosscutting concepts are new to some teachers. Section I readings can build teachers' own understanding of a crosscutting concept, such as Patterns, in which the reading from the *Framework* explains the relationship between the way data are represented, pattern recognition, and the development of mathematical expressions.

Most new standards and curricula include scientific and engineering practices, such as developing and using models to understand and explain phenomena or make predictions. A teacher might decide to learn more about models before designing learning experiences in which students develop or use models. Section I of the *Developing and Using Models* CTS guide describes what models are and how they are used in science or engineering. An excerpt from IA *Science for All Americans* can be used to understand what a model is and the different types of models. The reading goes on to describe each of the different types of models and considerations for selecting a model.

> A model of something is a simplified imitation of it that we hope can help us understand it better. A model may be a device, a plan, a drawing, an equation, a computer program, or even just a mental image. Whether models are physical, mathematical, or conceptual, their value lies in suggesting how things either do work or might work. For example, once the heart has been likened to a pump to explain what it does, the inference may be made that the engineering principles used in designing pumps could be helpful in understanding heart disease. When a model does not mimic the phenomenon well, the nature of the discrepancy is a clue to how the model can be improved. Models may also mislead, however, suggesting characteristics that are not really shared with what is being modeled. Fire was long taken as a model of energy transformation in the sun, for example,

> but nothing in the sun turned out to be burning. (American Association for the Advancement of Science, 1989, p. 168)

The section IA reading from *Science for All Americans* can be combined with the section IB narrative in the *Framework for Science Education*, which focuses more on conceptual models. Additional descriptions of ways models are used in science and engineering are provided in the *Framework* reading. Taken together, the two readings provide background information about models that can help teachers build their own understanding of models to effectively incorporate the practice of developing and using models in their curriculum, instruction, and assessment.

When teachers have a strong understanding of the content they teach, they are able to be more versatile in quickly and effectively responding to students' questions, ideas, and learning needs. A teacher with a working knowledge of the content they teach knows the best question to ask to push student thinking and is better able to steer and guide students' learning down the most appropriate path.

Whether you are using CTS individually to examine what every science-literate adult should know about a topic or you are using it in a professional learning format such as a workshop, science methods class, summer institute, or an online professional learning community, the following are suggestions for using CTS to build content knowledge:

- Identify and discuss the big ideas or components of practices that are the culmination of a K–12 science education.
- Identify and discuss examples that illustrate and explain key ideas or practices.
- Look for relevant terminology all adults should be familiar with and clarify definitions.
- Find examples of ways the content integrates across the sciences, mathematics, technology, or engineering.
- Look for vivid descriptions, real-life examples, phenomena, and analogies that help make the content comprehensible.
- Look for and explain theories, laws, scientific principles, or generalizations.
- Make connections between the content from the CTS reading and what you are doing in a professional development setting (e.g., content immersion with a scientist).

Using CTS to Inform Curriculum

Curriculum is the way content is organized and generally consists of a scope and sequence of learning goals and activities for learning. It refers to the knowledge and practices in topic areas that teachers teach and that students are expected to learn (NRC, 2012). Standards by themselves are not a curriculum. They outline the learning goals, which inform the selection of materials, activities, tasks, discussions, and so on, that make up the curriculum.

Backwards Design. Backwards design, a process and framework developed by Grant Wiggins and Jay McTighe (2005), is a method used to develop curriculum by first establishing the goals for learning and being clear about what an understanding of those goals looks like, before selecting instructional methods, activities, and assessments. It is a focus on the output before selecting the input. CTS can be thought of as the "upfront part of backwards design." By first doing CTS, learning goals that support the performance expectation can be clarified, boundaries for assessment can be established, relevant phenomena can be selected, and suggestions for effective instruction can inform the development of activities and tasks.

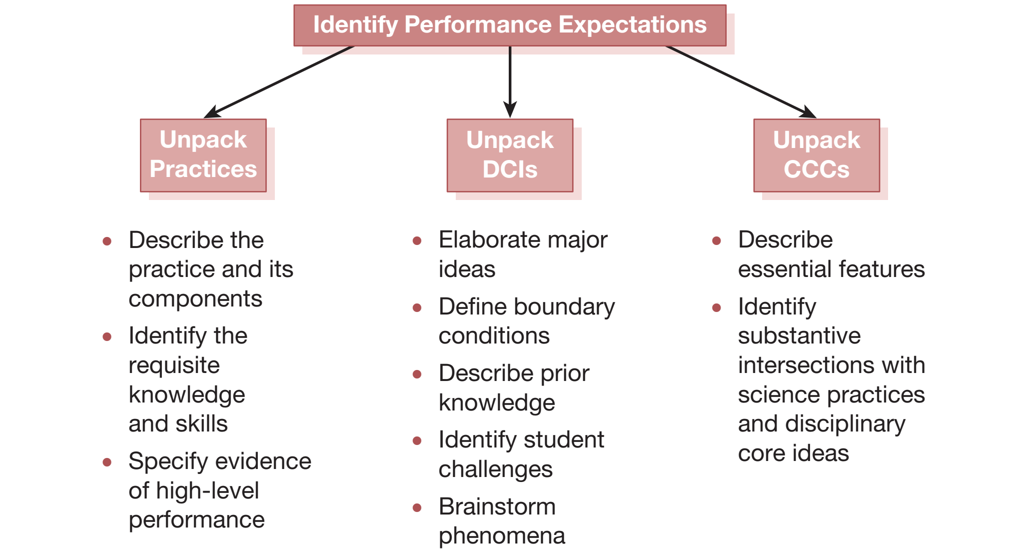
Unpacking Learning Goals or Standards into Subcomponents. Unpacking refers to the practice of breaking down a broad learning goal or standard into its component parts to more precisely identify what students should know and be able to do. It involves a process of clarifying what the true meaning and intent of a learning goal or standard is. Section VI of CTS describes the performance expectation(s) for a particular topic. It is the expectation of what students should be able to do by the end of a given grade, not by the end of the unit. It is used for assessment purposes but curriculum and instruction involve more than the performance expectation. To achieve the performance expectation, unpacking the disciplinary core idea(s), practice, and crosscutting concept that contribute to a performance expectation using CTS section II or section V is crucial. In designing curriculum and instruction, the elements that make up the disciplinary core ideas, practices, and crosscutting concepts are unpacked. Examining the elements of the three dimensions in section II (for example, the bullets in the foundation boxes of the *NGSS*) and discussing them with colleagues provide insight and clarification into what is to be learned by students and are used to inform the curriculum. The *Atlas* in section V helps educators visualize how one idea builds off another and the connections between ideas. The progressions of elements in section V are also used to unpack learning goals. Examining the clarification statements and boundaries for the performance expectation that includes the dimension(s) being unpacked helps pinpoint what is and what is not important to know. Furthermore, unpacking the practices allows educators to make decisions about multiple contexts in the curriculum in which a practice is used to figure out phenomena or solve a problem.

A single dimension, whether it is a disciplinary core idea, a scientific or engineering practice, or a crosscutting concept can be unpacked into the specific subideas or subpractices that make up that dimension. For example, after a middle school study of plate tectonics, the disciplinary core idea from NGSS ESS2.B, "Maps of ancient land and water patterns, based on investigations of rocks and fossils, make clear how Earth's plates have moved great distances, collided, and spread apart," can be broken down into the following subideas using CTS sections I, II, V, and VI:

- Rock formations and the fossil record help scientists reconstruct where land and oceans once were located.
- The rock layer beneath earth's surface is made up of huge sections of thick, solid rock called plates.
- Continents and ocean basins are part of these plates.
- These plates have moved great distances, collided, and spread apart.
- The movement of plates results in most continental (continental shelves, mountains) and ocean floor features (ridges, fracture zones, trenches).

These subideas come from the readings of the narrative sections as well as the ideas described in the *Framework's* grade band endpoints, NGSS disciplinary core ideas, and elements in the *Atlas*. For unpacking the three dimensions in more detail, including identifying student learning challenges (CTS section IV), brainstorming phenomena, and looking at intersections of crosscutting concepts with the other two dimensions, NSTA provides some very good tools on their NGSS Hub website at https://ngss.nsta.org/ngss-tools.aspx. Figure 4.4 summarizes a three-dimensional unpacking process.

FIGURE 4.4 Unpacking the three dimensions of a performance expectation



SOURCE: Graphic by Ted Willard based on procedures described in Creating and Using Instructionally Supportive Assessments in NGSS classrooms (NSTA Press, in press) by Harris, C. J., Krajcik, J. S., & Pellegrino, J. W.

Three-Dimensional Curriculum. While earlier science standards and frameworks communicated the importance of inquiry, most publications placed these expectations at the front of the standards document—as a separate section. When teachers were running short on time, they typically focused on what they perceived to be the highest priority—the content, attempting to efficiently "cover it all," often with an emphasis on facts and terminology.

The *Framework for K–12 Science Education* articulates a vision where students, over multiple years of school, actively engage in scientific and engineering practices and apply crosscutting concepts to deepen their understanding of the core ideas in science and engineering. The *NGSS* and most state standards now expect students to be learning science by "being scientists." It is no longer sufficient to know facts and terminology; students are expected to make sense of the world around them through developing explanations of concepts and phenomena and designing solutions supported by evidence-based arguments and reasoning.

The term *three-dimensional learning* refers to the three pillars that support each standard in the *NGSS* or other similar standards. These three dimensions are the Science and Engineering Practices, Crosscutting Concepts, and Disciplinary Core Ideas. As teachers shift toward a three-dimensional learning approach, students are making sense of phenomena by building models, designing investigations, sharing ideas, analyzing data, making claims based on evidence, engaging in scientific argumentation, and applying new knowledge to other situations. They use crosscutting concepts such as cause and effect or systems to develop a coherent and usable understanding of science. The nature of science and engineering is also naturally embedded in the classroom environment, strengthening important 21st-century skills such as communication, collaboration, and critical thinking.

This three-dimensional approach to teaching and learning is exciting but complex. CTS guides can help teachers clarify the intent of each of the three dimensions, as well as what is intended by "Nature of Science." We recommend that before a teacher, school, or district interweave these dimensions into a unit of study, a curriculum, or an instructional approach, they take the time to examine each of the specific dimensions of interest using a CTS guide.

For example, a PLC group decides to select a topic from the life science CTS guides, a scientific practice guide, and a crosscutting concept guide. They decide to focus on CTS sections II, III, V, and VI for their grade level. They also study section I to ground their own knowledge of the topic and section IV to be aware of difficulties students might have in understanding the key ideas in their unit of instruction. They conduct a study of each of the three guides and merge the results to discuss the implications for organizing their curricular unit topic using a three-dimensional approach.

Another approach to developing curricular units is to use *bundles*. Bundling is when related performance expectations are combined to create the endpoints for a unit of study. Bundles allow for more efficient use of instructional time by teaching ideas that were traditionally taught in separate units, to be taught together as a coherent unit of interconnected ideas. Sample bundles and tools for bundling can be viewed on the NGSS website at https://www.nextgenscience.org/resources/bundling-ngss. After conducting a CTS, the results from the study can be used to create your own bundles or examine existing bundles through the lens of CTS.

Curriculum Coherence and Articulation Across Multiple Grades. Putting together a multigrade science curriculum (e.g., K–5; 6–12, K–12) aligned with standards is not an easy task. It is even more difficult when committee members lack the necessary tools and resources to undertake this arduous work. A curriculum scope and sequence can be compared to a jigsaw puzzle:

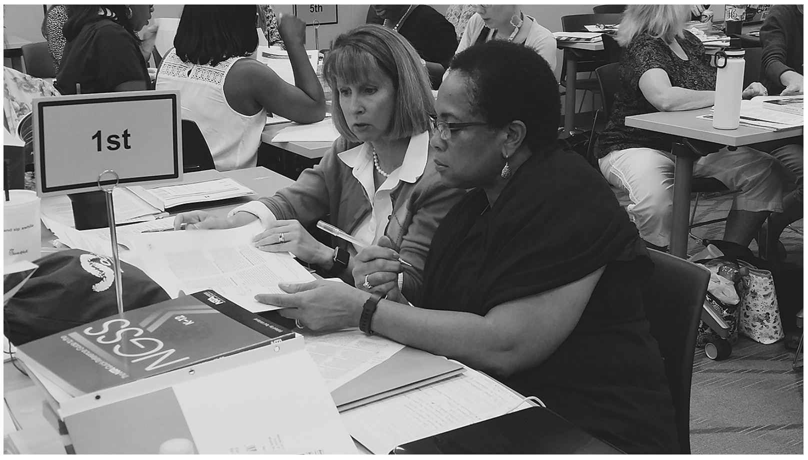
> Imagine that we are faced with a pile of jigsaw puzzle pieces and told to put them together. Our first reaction might be to ask for the picture. When we put together a jigsaw puzzle, we usually have a picture to guide us. None of the pieces means anything taken alone; only when the pieces are put together do they mean something. (Beane, 1995, p. 1)

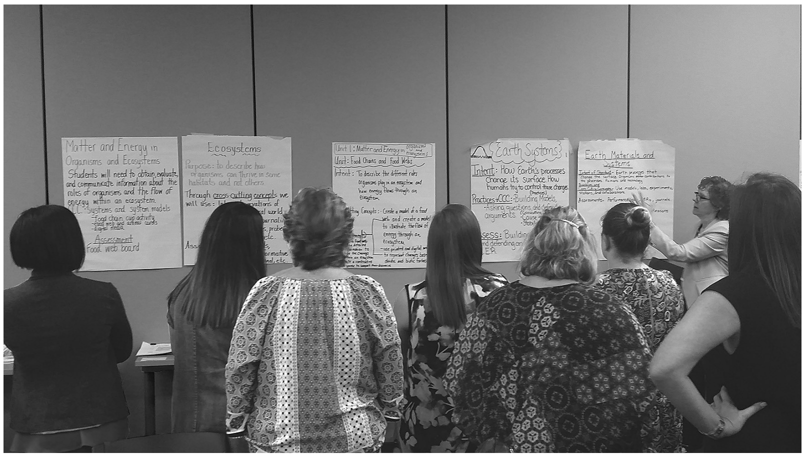
CTS provides the picture needed to put the necessary pieces together in a way that they make sense for students (coherence). Examining a curricular topic (section II) is like holding a jigsaw puzzle piece up to see roughly what area of the puzzle you should put it in. After getting some of the initial pieces laid out, the interconnections between concepts, ideas, and practices in CTS section V help connect groups of puzzle pieces and the progression links groups of pieces together. The CTS results are the *picture* you keep looking at to make sure the pieces fit together and are not disconnected, such as a K–12 or other grade span curriculum. Figure 4.6 shows elementary teachers sharing results of a CTS as a lens to examine their curriculum.

A coherent curriculum is one that holds together, that makes sense as a whole; and whether you use two dimensions or three dimensions, the dimensions are unified and connected by that sense of the whole. This involves thinking through the flow of ideas and practices in the three dimensions and across grades to determine

- The important set of concepts, ideas, and practices students should learn
- Which crosscutting concepts and practices will support a disciplinary core idea, and across the curriculum, how to ensure they all receive sufficient attention
- The connections among the concepts, ideas, and practices that support three-dimensional learning
- Which concepts, ideas, and practices need to recur frequently and in varied contexts across disciplines and grades
- Important prerequisites leading to increasing sophistication of concepts, ideas, and use of practices
- Connections to the nature and enterprises of science, engineering, and technology

FIGURES 4.5 (TOP) AND 4.6 (BOTTOM) **Elementary teachers using CTS for curriculum decisions**





Selecting Curriculum. The choice of instructional materials can have as much of an impact on student learning as improvements in pedagogy (Chingos & Whitehurst, 2012). CTS is helpful for reviewing and selecting curriculum materials. Beware of instructional materials that claim to be standards or *NGSS* "aligned." Regardless of whether you adopt the *NGSS* or other standards, CTS is used as a lens to examine instructional materials with an eye for determining whether they are informed by standards and research. CTS is not a replacement for a rigorous and thorough curriculum analysis procedure. There are several very good processes for reviewing curriculum materials. CTS can help you use these processes with increased validity and reliability by first studying the curricular topic. For example, the EQuIP rubric (Educators Evaluating the Quality of Instructional Products) provides criteria used to evaluate the extent to which lessons and units are designed to meet the *NGSS*. The *NGSS* Lesson Screener includes fewer criteria and is less rigorous than the EQuIP rubric yet provides a quick screen to see if a sequence of lessons is on track. These resources can be used with CTS and are found at https://www.nextgenscience.org/resources/equip-rubric-lessons-units-science.

Implementing Curriculum. Curriculum implementation involves the classroom use of new instructional materials. As schools and districts adopt new instructional materials that reflect the current vision of standards, teachers will need to understand their part in a multiyear scope and sequence and how to support students in building on their prior knowledge and use of the three dimensions (NRC, 2015). They may have to learn the major concepts and ideas of new disciplinary content they have not taught before or even deepen their understanding of familiar disciplinary content and how it is interwoven with practices and crosscutting concepts. To do this teachers need opportunities to communicate and collaborate with other teachers teaching with the same materials as well as across grade levels. CTS provides a process to help teachers do this. It helps them improve their understanding of the content of the curricular topic(s) they are teaching (CTS section I); understand the meaning and intent of the curricular objectives (CTS section II); be aware of the research on learning that may have informed the development of the materials or that they should be aware of as they use the materials (CTS section IV); and understand how one concept, idea, or practice contributes to or connects with another (CTS section V); as well as examine the assessment expectation, and link back to section III by examining the curricular unit's lessons and other support material.

If you are leading curriculum implementation for a grade level, consider creating a customized CTS guide to match the curricular unit teachers will be implementing. There is a template for creating a customized guide on the CTS website at www.curriculumtopicstudy2.org. Include only readings that relate to the curriculum unit being implemented. For example, fifth-grade teachers using the FOSS Mixtures and Solutions kit may combine the CTS guide Mixtures and Solutions with the Developing and Using Models CTS guide, focusing on readings for grade 5 using the CTS resources available to teachers. For section III, they look at the module after completing the other sections of CTS and discuss how the lessons support what they learned through the CTS, including supplemental suggestions that might strengthen the unit. Figure 4.7 shows an example of a customized guide for curriculum implementation. For this guide, the teachers are using the online resources and the *NSTA Quick Reference Guide to the NGSS*. Since there are not enough copies of the Section IV resource, the facilitator shares results from that section using her copy of *Making Sense of Secondary Science*. After completing the CTS, teachers have a lens through which to view their materials and focus their instruction.

FIGURE 4.7 Grade 4 FOSS Mixtures and Solutions Module

<table>
<tr><th colspan="2">FOSS Mixtures and Solutions Module
Grade 4 Standards- and Research-Based Study of a Curricular Topic</th></tr>
<tr><th>Section and Outcome</th><th>Selected Sources and Readings for Study and Reflection
Read and examine related parts of</th></tr>
<tr><td>I.
Content Knowledge</td><td>IA: Science for All Americans
• Ch. 11: Models, pp. 168–172

IB: Framework for K–12 Science Education: Narrative Section
• Ch. 5: PS1.A: Structure and Properties of Matter, pp. 106–107</td></tr>
<tr><td>II.
Concepts, Core Ideas, or Practices</td><td>IIA: Framework for K–12 Science Education: Grade Band Endpoints
• Ch. 5: PS1.A: Structure and Properties of Matter, p. 108 (focus on grades 3–5)
• Ch. 3: Developing and Using Models, p. 58

IIB: NSTA Quick Reference Guide to the NGSS K–12: Disciplinary Core Ideas Column
• Grade 5: PS1.A: Structure and Properties of Matter, pp. 112–113; PS1.B: Chemical Reactions, pp. 112–113
• 3–5: Developing and Using Models, p. 100</td></tr>
<tr><td>III.
Curriculum, Instruction, and Formative Assessment</td><td>IIIA: FOSS Mixtures and Solutions Module
• Examine the lessons and the teacher support material after completing the other sections of CTS</td></tr>
<tr><td>IV.
Research on Commonly Held Ideas</td><td>IVA: Benchmarks for Science Literacy: Chapter 15 Research
• 11B: Models, p. 357

IVB: Making Sense of Secondary Science: Research Into Children's Ideas
• Ch. 8: Mixtures and Substances, pp. 74–75
• Ch. 9: Dissolving, pp. 83–84
• Ch. 10: Mixtures of Substances, p. 85
• Ch. 11: Particle Ideas About Solutions, p. 95
• Ch. 12: Dissolving Substances in Water, pp. 100–101</td></tr>
<tr><td>V.
K–12 Articulation and Connections</td><td>VB: NSTA Quick Reference Guide to the NGSS K–12: Progression
• PS1.A: Structure and Properties of Matter, p. 61
• PS1.B: Chemical Reactions, p. 62
• Developing and Using Models, Condensed Practices, p. 51</td></tr>
<tr><td>VI.
Assessment Expectation</td><td>VIA: State Standards
• Examine your state's standards

VIB: NSTA Quick Reference Guide to the NGSS K–12: Performance Expectations
• Grade 5: 5-PS1-1, 5-PS1-2, 5-PS1-3, 5-PS1-4, pp. 112–113</td></tr>
</table>

Integration and Interdisciplinary Connections. Many schools, districts, and afterschool programs are striving to bring "the real world" into their curriculum through interdisciplinary learning. We applaud these efforts and appreciate their value in supporting the 21st century skills of collaboration, creativity, critical thinking, and problem solving. The challenge lies in ensuring that the interdisciplinary connection goes beyond providing an engaging, fun activity to one that possesses academic rigor and content integrity. We have worked with several projects and initiatives where CTS has been used to ensure that students learn science by applying important ideas through use of scientific and engineering practices.

Project Based Learning (PBL). PBL is a teaching method in which students gain knowledge and skills by investigating an authentic question, problem, or challenge. In-school and after-school educators who embark on a PBL approach benefit from conducting a CTS study of the science topic that will be investigated, asking: What should we as the facilitators of learning know? What are the concepts, ideas, and practices we can incorporate as we design and facilitate our PBL curriculum? What are appropriate expectations for our age group of students? "Gold standard" project-based learning has design elements that include focusing on key knowledge, understanding, and success skills. CTS can clarify these elements so that students' opportunity to learn the science is not lost in the project.

Service Learning. The National Youth Leadership Council defines *service learning* as an approach to teaching and learning in which students use academic knowledge and skills to address genuine community needs. We have collaborated extensively with in-school and after-school programs that are working with the KIDS (Kids Involved Doing Service learning) model, which is based on three key principles: Academic Integrity, Apprentice Citizenship, and Student Ownership. When our service-learning partner first experienced a CTS study of Ecosystems, she exclaimed, "This is the best thing since sliced bread!" She finds that CTS helps her participants, who often do not have a science background, understand how science learning goals can be supported through service-learning projects. For an example of a free downloadable resource that uses CTS in service learning projects, go to http://harkinsconsultingllc.com/products/integrating-scientific-practices-and-service-learning-engaging-students-in-stem/. (Note: This resource uses the first edition of Curriculum Topic Study.)

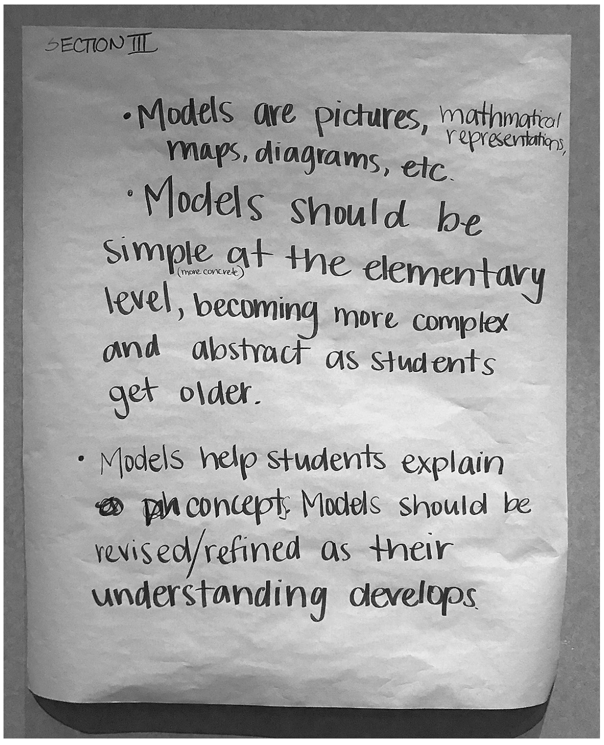
Stem Integration. Engineering has become a component of many science programs, as well as a stand-alone course, with the expectation that all students have an opportunity to experience the engineering design process across the K–12 continuum. Many schools struggle with how they can fit engineering into an already overburdened curriculum. Groups who conduct a CTS study of the Science and Engineering Practices or Engineering Design see the relatedness of engineering with science concepts they teach and are able to combine the two—either applying their understanding of a science concept to generate creative solutions to a problem, or arriving at a "need to know" moment during their engineering design lesson, where a science concept is then explored. For section III, a useful resource can be added that will be available in 2020: *Uncovering Student Ideas About Engineering and Technology* (Keeley, Sneider, & Ravel, in press). This resource can be used with the category D and F guides.

The Committee on STEM Integration (National Academy of Engineering and National Research Council, 2014) advocates a more integrated approach to K–12 STEM education, particularly in the context of real-world issues. While many teachers, schools, or districts want to bring STEM into the classroom, it is frequently implemented in a disjointed manner, resulting in S, T, E, and M as separate disciplines. CTS can help STEM educators understand what is meant by science, technology, engineering, and mathematics integration, so groups can move beyond the superficial STEM integration to a deeper, cohesive instructional design that interweaves but does not force-fit the disciplinary fields. The category D guides can be used to study the engineering practices as well as the science and engineering practice of using mathematics and computational thinking. The category F contains the STEM Connections guides. These guides are divided into two sections. The engineering, science, and technology guides focus on understanding the engineering design process, including how science is utilized in the process and how new technologies result. It includes both the distinctions of and the relationships between engineering, science, and technology and their impacts on society and the natural world we live in. The Nature of Science guides focus on understanding the nature of scientific knowledge. It is distinct from engaging in the scientific practices because the focus is more on understanding the enterprise of science. Together all twelve guides in category F can strengthen teachers' understanding of how STEM is represented in the classroom.

Using CTS to Inform Instruction

Instruction refers to methods of teaching and the sequencing of learning activities used to help students achieve the learning objectives specified in their curriculum (NRC, 2012). It includes both the active involvement of the teacher and the student in carrying out activities, investigations, discussions, and other learning opportunities that help them learn and use science concepts, ideas, and scientific and engineering practices. For example, a group of elementary teachers summarize their findings from section III of the Developing and Using Models CTS guide (Figure 4.8). They will use the summary to inform their instruction when they have their students develop models.

FIGURE 4.8 Charting CTS results from a study of Developing and Using Models



Modifying Lessons. The vision of the *Framework for K–12 Science Education* calls for coherent investigation of core ideas across multiple years of school, with a seamless blending of the Science and Engineering Practices, Crosscutting Concepts, and Disciplinary Core Ideas. It is imperative that educators acknowledge the implications this shift has for planning lessons.

It is unrealistic to expect that districts will start from scratch, and experienced teachers often have lessons that have been shown to engage students and stimulate their curiosity. CTS can be used to examine such lessons to determine how they might fit into the current vision and goals for science teaching and learning. By studying a curricular topic, teachers can examine their lessons through the lens of CTS, asking

- Does my lesson provide an opportunity for students to use a scientific or engineering practice and crosscutting concept?
- Does my lesson uncover preconceptions and connect to prior experiences my students have had?
- Is my lesson based on an anchoring phenomenon that will generate interest, stimulate curiosity, and raise questions related to a scientific concept? Or is my lesson based on an interesting problem to solve?
- Does my lesson take the time to examine, investigate, and puzzle through ideas and phenomena and construct initial concepts and explanations or solve a problem using the engineering design process?
- How will students develop conceptual and procedural understanding? How will I introduce formal concepts and vocabulary linked to students' experiences so they can engage in sense making and construction of scientific explanations or solutions to problems?
- How will students apply concepts, skills, and explanations to new contexts, and transfer learning to new, related situations?
- If I am going to deepen understanding by incorporating a 5E approach of Engage, Explore, Explain, Elaborate, Elaborate, then this will take more time. How can my lesson fit within this instructional model?
- Does my lesson provide an opportunity for students to learn the concepts and ideas and use the practices that will later be assessed?

Teachers are encouraged to make these shifts one step at a time. Take one lesson or unit of study that relates to an important topic in science such as Cycling of Matter in Ecosystems, Properties of Matter, or Forces Between Objects. Combine the topic with the study of a scientific or engineering practice and a crosscutting concept that can be part of a lesson. Examine your existing lesson, and use the results from CTS sections II, III, IV, V, and VI to modify your lesson based on your study's findings. After you implement the modified lesson in the classroom, take a moment to reflect on how your lesson has changed. How did these shifts impact your students? How can you incorporate these insights into other lessons?

From Inquiry-Based Teaching to Scientific and Engineering Practices. Teachers have worked hard to make inquiry the centerpiece of their science teaching for several decades. While inquiry is still very much a part of doing science, the focus has shifted to scientific and engineering practices where the role of inquiry has been enhanced and involves simultaneously building new knowledge while using the range of intellectual and social processes required to participate in science and engineering. There are ten category D CTS guides that address a scientific practice, an engineering practice, or a practice that is used in both science and engineering. To design instruction that combines learning content with use of a practice, a CTS guide from categories A, B, or C can be combined with a category D guide. Each topic is studied together, and the results are merged to understand how students will use the practice to learn important concepts and ideas.

For example, a study of the Earth, Moon, and Sun System, focusing on middle school, is combined with a study of Developing and Using Models. Questions that guide the study might include

- **CTS section II:** What are the specific ideas students learn about the Earth, Moon, and Sun System? What are the ways students are expected to develop and use models? How can I merge these ideas with these elements of the practice?
- **CTS section III**: What are some effective ways students learn about the Earth, Moon, and Sun System? What are some ways students are supported in using this practice? What instructional experiences can students have that combine learning about the Earth, Moon, and Sun system with developing and using a model to explain phenomena associated with this system? Is there a formative assessment probe I could use to uncover their initial ideas about Earth, Moon, and Sun phenomena that could also reveal how students use a model?
- **CTS section IV**: What does the research say about commonly held ideas and difficulties I need to be aware of when students are trying to make sense of Earth, moon, and sun phenomena? What can the research tell me about difficulties students might have using models that I should be aware of when using Earth, moon, and sun models?
- **CTS section V**: In looking at the progression and prerequisite ideas for both topics, how will I be building on prior ideas and use of the practice? Are there prerequisites I should first check on to make sure my students understand and can use prior ideas and elements of the practice?
- **CTS section VI**: How will my instruction prepare students for the assessment? Will they be able to demonstrate how the practice is used with Earth, Moon, Sun system phenomena? What boundaries for the assessment should I be aware of?

Selecting Phenomena. One of the major shifts in instructional practices today involves phenomenon-based teaching and learning. Natural phenomena are observable events or processes that occur in the natural world that are explanatory or predictive. To develop knowledge of the core concepts and ideas in science, students build ideas by gathering and using evidence that can be used to explain or predict phenomena. Phenomena are also used in engineering. Problems may arise from phenomena (such as how to prevent erosion of a section of a riverbank) that can be solved using the engineering design process. By centering instruction on phenomena, the teaching and learning phase shifts from learning about a topic to figuring out why or how something happens related to the topic. A good resource for learning more about phenomena is on the Next Generation Science Standards website at https://www.nextgenscience.org/resources/phenomena.

The challenge for educators is to select phenomena that are relevant and can be used to drive instruction. CTS can help with this process. CTS section I provides an overview of the content to be learned and may give insight into contexts that include phenomena. Sometimes a phenomenon is described in CTS section I. For example, in section IA of the CTS guide Visible Light and Electromagnetic Radiation there is an explanation for why the sky looks blue. This phenomenon could be used with middle or high school students to explain how the scattering of different wavelengths of light affects the color we see. CTS section III describes instructional contexts and may offer suggestions for relevant phenomena, including how the phenomenon is used to drive instruction. For example, in section IIIA of the Inherited Traits CTS guide, a third-grade teacher might be looking for phenomena that can be used to explain how some traits are inherited, some are influenced by the environment, and some are both. Examples of phenomena such as how a flamingo's pink color is influenced by its diet and how burrowing and nesting behaviors can be both instinctive (inherited) and learned provide explanatory evidence that traits can be inherited and/or influenced by the environment.

A collection of phenomena is archived at https://www.ngssphenomena.com. After studying a disciplinary topic, phenomena on this site can be analyzed through the lens of the CTS study to determine its usefulness in a phenomenon-based lesson. Questions to ask about a phenomenon after doing CTS include

1. What is the phenomenon and how do you explain it?
2. What key idea(s) can be used to explain the phenomenon?
3. Where, when, and how can the phenomenon be used in the lesson?
4. What are some difficulties to anticipate or commonly held ideas students might have about the phenomenon?
5. What prerequisite ideas are needed for students to use the phenomenon?
6. How can the phenomenon be used for assessment?
7. Overall reflection: How does the phenomenon support students' learning?

Using CTS to Inform Classroom Assessment

The new vision of teaching and learning presents not only considerable challenges but also a unique and valuable opportunity for assessment (NRC, 2014). *Classroom assessment* refers to assessments designed or selected by the teacher that can be used to inform instruction, provide feedback to the learner, monitor changes in students' thinking and learning, or measure and document the extent to which students' have achieved learning goals after they have had an opportunity to learn following a lesson, activity, or curriculum unit. The first step in using CTS to inform assessment is to define the purpose and stage in the assessment process:

Diagnostic Assessment. What preconceptions and existing ideas do my students have about the scientific concepts and ideas in the topic? CTS sections II (or V) and IV can be used to examine the specific concepts and ideas in the topic that students will need to know and understand as well as the research on how students think about concepts and ideas. Section III provides examples of questions that reveal students' thinking. All this information can be used before and during classroom instruction to elicit ideas and ways of thinking that students bring to their learning.

Formative Assessment. When teachers use diagnostic assessment data to inform their instruction, it becomes formative assessment. Formative assessment also includes a feedback loop between student(s) and the teacher and the teacher and student(s). During formative assessment the teacher gathers evidence of how students are building their understanding of concepts and ideas as well as how they use scientific and engineering practices. It is used as a checkpoint at any point during an instructional cycle. The information feeds back into the teachers' instructional plan to make modifications that will move students toward the learning goal(s). CTS section II helps teachers identify clear goals students are moving toward. CTS section IV helps teachers anticipate the commonly held ideas students may bring to or develop during their learning. Together these two sections can be used to develop formative assessment probes. Section III helps inform the questions, representations, contexts, phenomena, and other instructional strategies and experiences that may be effective in building a bridge between students' existing ideas and use of practices to the scientific or engineering understandings and use of practices that make up the goals for learning. Section V indicates possible gaps or steps along the way that may need to be revisited or assessed.

Summative Assessment. Summative assessments are given after students have had the opportunity to learn and use the concepts, ideas, and practices. CTS sections II and V clarify the specific learning goals that make up a disciplinary core idea, practice, or crosscutting concept. Section VI clarifies how these three elements come together in the form of a performance expectation. CTS can be used as a lens to determine if the assessment fairly targets the learning goals. It can also be used to determine other contexts that may be used to gather evidence of whether students can transfer their learning to other situations, phenomena, or problems.

CTS provides information teachers can use to help teachers develop classroom assessments or be better consumers of assessment and assessment data. Some specific assessment applications of CTS include the following.

Developing Learning Intentions and Success Criteria. Many districts mandate that for each lesson or period of instruction, the teacher must post the learning objective and share it with students. Often this becomes what has been referred to as the "wallpaper objective" (Wiliam, 2011). In other words, it is posted and shared with the students at the beginning of the lesson but then ignored for the rest of the lesson. This token approach is not what is meant by sharing, clarifying, and using learning goals so that students can monitor their own progress toward meeting a learning goal, a key component of formative assessment that provides feedback to the learner.

Learning intentions (sometimes called learning targets) are used to determine the goal for a lesson and make the purpose of the lesson explicit to students so they know what they are expected to learn and do during the lesson (Keeley, 2015). Learning intentions are accompanied by success indicators that gauge the extent to which a learning goal has been met. They are sometimes referred to as "I can" statements. Taken together they do the following:

- Give students a clear idea of what will be learned and why
- Transfer the responsibility for learning to the student (no teacher can do the learning for the student)
- Provide students with a way to monitor their learning
- Help students focus on the purpose of the lesson and what they should be learning rather than merely on the completion of the activity
- Help teachers review progress and provide a clearer focus for instructional next steps
- Help break down broad standards or goals

To develop learning intentions and success criteria, teachers can use CTS section VI to first determine what students will be expected to know and perform on a final assessment. CTS sections II and V describe the specific elements and the progression or "steps along the way." Teachers examine their lessons and develop learning intentions and success criteria that are specific to a lesson or lesson sequence.

For example, in a fourth-grade unit on light, the teacher used the CTS guide Visible Light and Electromagnetic Radiation. Using CTS section VI, the teacher examines the performance expectation that will be required as part of their district end-of-year testing program. The performance expectation states: "Develop a model to describe that light reflecting from objects and entering the eye allows objects to be seen" (NGSS Lead States, 2013). As she unpacks this performance indicator she notes that one of the things students will need to know to achieve this performance expectation is how light reflects off objects. She then uses CTS section II to examine the disciplinary core idea that states, "An object can be seen when light reflected off its surface enters the eye." Using CTS section V, she looks at what students learned about light and reflection prior to grade 4. In grades K–2 they learned that some objects give off their own light and that mirrors can redirect beams of light. Examining CTS section IV she finds that students have a commonly held idea that only shiny things like mirrors reflect light.

She uses this information to develop a lesson that all objects we see can reflect light and that they do not have to be shiny like mirrors to reflect light. She has students design an investigation to collect evidence that ordinary objects, both dull and shiny, can reflect light. She develops her learning intention and success criteria for the lesson, which she will use to make the purpose of their learning explicit and allow students to self-monitor how well they are meeting the goal of the lesson. Her learning intention and success criteria, informed by CTS sections VI, II, IV, and IV, are:

Learning Intention #1: Understand how light is reflected from objects.

- I can design an investigation to test whether an object reflects light.
- I can show what happens when light strikes a mirror or other type of smooth, shiny object.
- I can show what happens when light strikes an object that is not smooth or shiny.

Following the lesson on reflection, she designs a lesson that will involve students in developing models to explain how they see the light from a reflected object. Using the same sections of CTS, she develops another learning intention:

Learning Intention #2: Understand the role of light in how we see objects.

- I can draw a diagram that shows the path of light to and from an object.
- I can use my model (the diagram) to explain how we see objects.
- I can use my model to describe what happens when you look at an object in a totally dark room.

Because learning is not in the materials or tasks themselves, CTS helps teachers develop learning intentions and success criteria that help students make conceptual connections and use the practices of science and engineering as they manipulate materials and complete activities and investigations. Thus they become active participants in their learning rather than passive recipients (Heritage, 2010).

Formative Assessment Probes. Assessment probes are used diagnostically to elicit students' ideas. When the data are used to inform instruction, and monitor changes in students' thinking, they become formative assessment probes. Formative assessment probes are two-tiered. The first tier includes a prompt with selected answer choices, and the second tier has students construct an explanation to support their answer choice. Formative assessment probes are designed to uncover how students are thinking about a phenomenon or concept. The use of formative assessment probes helps make students' thinking visible to themselves, their peers, and the teacher. Figure 4.9 is an example of a formative assessment probe that utilized the CTS guide Weathering and Erosion.

FIGURE 4.9 Example of a formative assessment probe: Grand Canyon

Six friends were standing along the rim of the Grand Canyon. Looking down, they could see layers of rock and the Colorado River at the bottom. They wondered how the Grand Canyon formed. They each had a different idea. This is what they said:

Natara: I think the Grand Canyon was formed when Earth formed. It has just gotten bigger over time.

Cecil: I think the Grand Canyon formed from earthquakes that cracked open the land and pulled it apart.

Garth: I think the Colorado River and streams slowly carved out the Grand Canyon.

Robert: I think a huge flood rushed through the land and formed the Grand Canyon.

Kumiyo: I think the river got so heavy that it sunk down through the rock and formed the walls of the Grand Canyon.

Luna: I don't agree with any of your ideas. I think the Grand Canyon was formed in some other way.

Who do you think has the best idea? ___________________ Explain your thinking.

CTS has been used to develop assessment probes for the *Uncovering Student Ideas in Science* series as well as with teachers to develop their own formative assessment probes. Steps in using CTS to design formative assessment probes are:

1. Identify the CTS guide for the unit topic you are teaching. For the example in Figure 4.9, the guide Weathering and Erosion was selected.
2. Examine section II or V to identify the specific concepts and ideas in your curricular unit. For the example in Figure 4.9, the disciplinary core idea, the role of water in Earth's surface processes, was identified. One of the elements that make up this disciplinary core idea describes how water's movement causes weathering and erosion and can change land's surface features. This idea will be the focus of the formative assessment probe.
3. Examine CTS section IV to learn more about commonly held ideas students might have related to weathering and erosion.
4. Select a phenomenon that can be the focus of the prompt that will elicit students' ideas about the role of water in the weathering and erosion of surface features. For the example in Figure 4.9, the formation of the Grand Canyon was selected as the phenomenon.
5. Develop the prompt and answer choices. Distracters should mirror the commonly held ideas from the study of the research in CTS section IV. Include a best answer, which for the example in Figure 4.9 is answer choice Garth.
6. Add a second part to the probe in which the student provides an explanation for the answer choice.

For the example in Figure 4.9, the teacher uses the formative assessment as an initial elicitation to uncover ideas students bring to their learning that they use to explain a long-term weathering and erosion phenomenon such as the Grand Canyon. The teacher then uses the information about students' thinking to design instructional experiences. During instruction students will revisit their initial ideas, modifying them as they gather evidence from investigations and other instructional opportunities. The formative assessment probe can be used again after students have had the opportunity to figure out the phenomenon and use their ideas about how moving water, which carried small pieces of rock over a very long period of time, carved out the Grand Canyon. The assessment probe can now be used to provide evidence of the extent to which students are able to use the specific ideas about weathering and erosion.

The sections in teacher notes that accompany each of the probes in the *Uncovering Student Ideas in Science* series mirror the results of a CTS. For example, CTS section I informs the explanation. CTS section II and VI informs the section that lists related disciplinary core ideas and performance expectations. The summaries of related research in the teacher notes are informed by CTS section IV. The suggestions for further assessment and instruction are informed by CTS section III. These teacher notes are a good example of how CTS can be used in a variety of ways, including developing support materials for teachers.

Summative Three-Dimensional Classroom Assessment Tasks. To measure the three-dimensional science learning described in the *Framework* and the *NGSS* requires assessment tasks that examine students' performance of scientific or engineering practices in the context of crosscutting concepts and disciplinary core ideas (NRC, 2014). To develop such assessments that are aligned with three-dimensional performance expectations requires careful thought and development. CTS can be used to develop rich, culminating performance tasks. After selecting a performance expectation or bundle of performance expectations from CTS section VI, the appropriate CTS topic guides are selected for each dimension. CTS section II is used to unpack the ideas and practices that will be assessed in a multipart performance task. CTS section V is examined to determine if students have the necessary prerequisites to complete the task and if multiple related and connected ideas can be combined in a task. CTS section III can be used to determine if students had appropriate instructional opportunities to learn the ideas and practices leading up to the task. All this information feeds into the development of a complex task and is further supported by using assessment tools and resources available on the *NGSS* website at https://www.nextgenscience.org/assessment-resources/assessment-resources and guidance from the resource, *Developing Assessments for the Next Generation Science Standards* (NRC, 2014).

OTHER APPLICATIONS OF CTS

There are more applications of CTS other than the ones described above. There are also other existing tools and resources that can be used with CTS such as the *NGSS* Storylines, the *NGSS* course descriptions, curated *NGSS* lessons, and more. Many of these tools and resources that complement CTS can be accessed on the NSTA *NGSS* Hub at ngss.nsta.org. As you become familiar with CTS, you may find there are additional tools and resources that can be used with CTS or you might develop your own tools and templates to use for various CTS applications. Consider sharing tools you have developed that can be used with CTS. With your permission and citation, these tools can be shared on our *Curriculum Topic Study Second Edition* website. Contact either of the authors of this book (see bios for contact information) if you would like to share your CTS tools and applications.