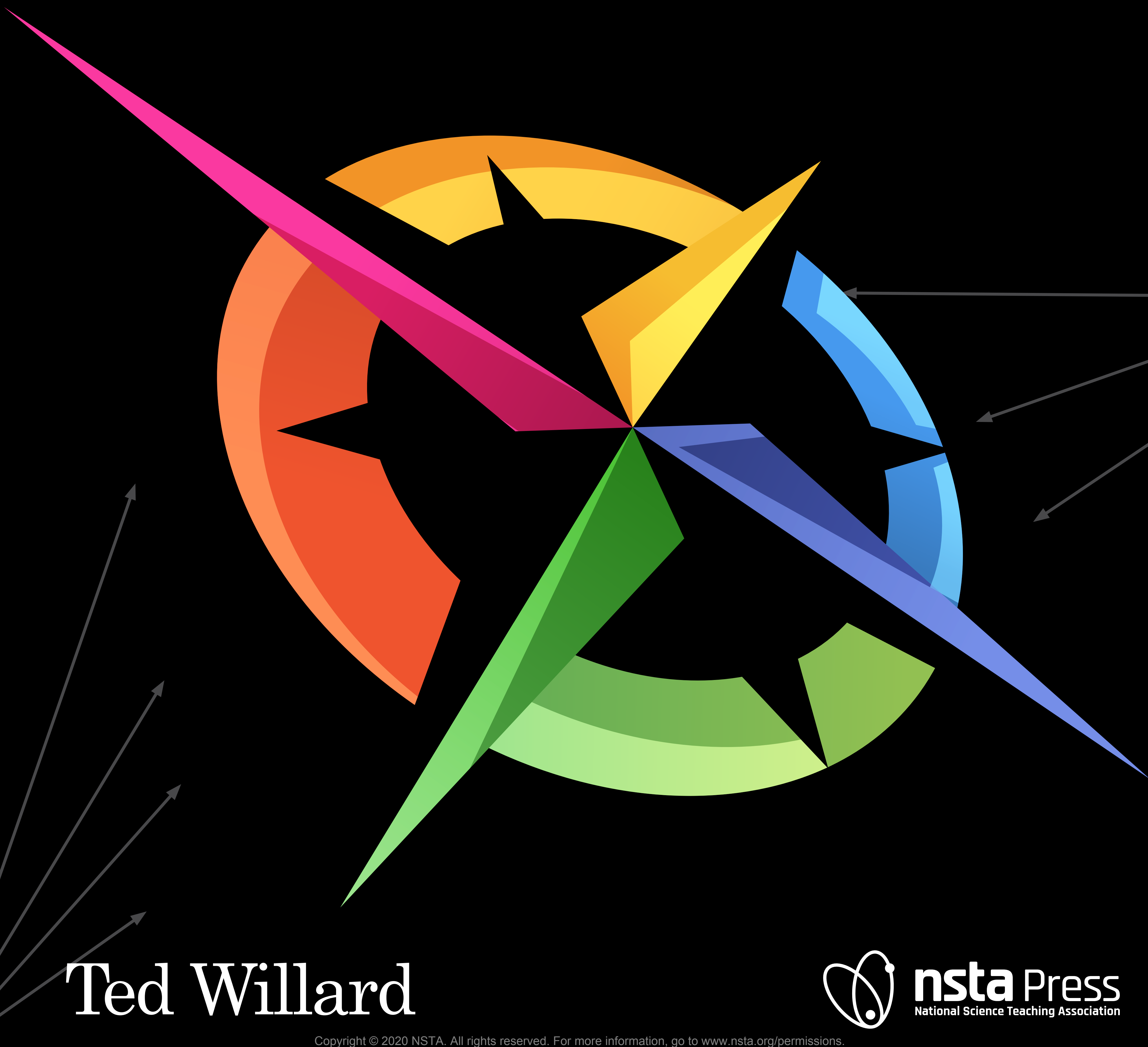
The NSTA Atlas of the THREE DIMENSIONS



Ted Willard

nsta Press
National Science Teaching Association

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Arlington, VA

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FOREWORD

The *Next Generation Science Standards* (*NGSS*; National Academies Press, 2013) have marked a significant change in how we approach science education in the United States. The foundational publications of *Science for All Americans* (Oxford University Press, 1990), *Benchmarks for Science Literacy* (Oxford University Press, 1993), and the *National Science Education Standards* (National Academies Press, 1996) set us on the path for high-quality science instruction. Now, the *NGSS* have brought us an important shift in how we think about and plan for instruction and how we design assessment in science class. This simple (yet not so simple to implement) idea to integrate science and engineering practices, crosscutting concepts, and disciplinary core ideas in order to properly reflect thinking and problem solving is taking hold across the country, and I believe it will change how our students engage in science.

But one thing continues to be a challenge—figuring out how these dimensions connect. How do concepts relate to one another? One premise of *A Framework for K–12 Science Education* (the *Framework;* National Academies Press, 2012) and the resulting *NGSS* was that connections need to be leveraged. The *Framework* and *NGSS* creators sought to provide students with a full perspective of phenomena. We continue to live with the Committee of Ten decision to separate our sciences. Although there is some good reason for that, this division can unfortunately put student thinking in a "black box" and perpetuate the misconception that phenomena live in only one discipline. I cannot tell you how many times I have heard teachers say that the chemistry in the *NGSS* is slim or the biology is too vague because it does not discuss the chemistry of life. Comments like those usually result from people reading only one section of the standards, thus missing important connections.

Standards are really an artificial construct of the world. When categorizing them, the experts decide what the "best" place for each standard is. Some categorization decisions in the *NGSS* were specifically made to show the connections across disciplines. For example, chemistry is not limited to just PS1: Matter and Its Interactions. In fact, to fully grasp concepts such as bonding, one must also look at PS2: Motion and Stability: Forces and Interactions and PS3: Energy to *understand* bonding as opposed to merely *reciting* what bonding means. The chemistry connections even extend beyond the disciplinary core ideas in physical science to Earth and space science. Understanding that all elements came from the Big Bang is ESS1: Earth's Place in the Universe, not PS1. Clearly, this incredible world we live in is not bound by discipline; it is bound by our own knowledge and bias.

The NSTA Atlas of the Three Dimensions, by Ted Willard, gives teachers valuable insight into how to put these standards together in a way that can eliminate the black box. Of course, creative and innovative teachers will find their own connections as well, but Ted has put forward a way of thinking about the *NGSS* that will foster great discussion and guide teachers as they plan individually and in teams. This book, like the *Framework* and *NGSS*, supports a growth mindset rooted in developing knowledge over time. It underscores that the progressions of learning are critical to developing a scientifically literate citizen. Teachers will be able to see how concepts develop over the course of students' K–12 education. I think seeing that progression alongside the connections will give teachers a new perspective and approach to implementing the *NGSS* and three-dimensional instruction in general.

In closing, I would like to thank Ted for his hard work on this book. I know it has been a labor of love for him, and he has been dying to do it since the *NGSS* were released. I thank him for his time and effort on behalf of our science teachers.

I hope you enjoy *The NSTA Atlas of the Three Dimensions* and the journey going forward as we continue to improve science education for each student.

Stephen L. Pruitt, PhD
President of the Southern Regional Education Board
formerly, coordinator of the development of the *NGSS*
as Senior Vice President of Achieve

ABOUT THE AUTHOR

Ted Willard is assistant executive director of science standards for the National Science Teaching Association (NSTA). In this role, he supports implementation of the *Next Generation Science Standards* (*NGSS*), other standards based on *A Framework for K–12 Science Education*, and three-dimensional learning, more broadly, by creating resources such as web seminars, conference sessions, workshops, books, and journal articles. In addition to developing *The NSTA Atlas of the Three Dimensions,* Ted edited *The NSTA Quick-Reference Guide to the* NGSS (NSTA Press, 2014). He currently oversees the content of the NGSS@NSTA Hub, which is a website that offers dynamic browsing and searching of the *NGSS,* tools to support curriculum planning and professional learning, and classroom resources focused on the standards.

Before joining NSTA, Ted spent 12 years at Project 2061 for the American Association for the Advancement of Science (AAAS), where he was responsible for the development of the *Atlas of Science Literacy, Volume 2* (AAAS, 2007). He was also involved in many of Project 2061's efforts in standards-based education reform, including teacher professional learning, curriculum resources development, assessment development, and science education research. Earlier in his career, Ted spent five years editing science textbooks for commercial publishers and was a high school physics teacher. He has a bachelor's degree in Earth, atmospheric, and planetary science from the Massachusetts Institute of Technology.

ACKNOWLEDGMENTS

I need to thank many people for their help in making this book possible. But for so many reasons, my acknowledgments must begin with a thank-you to Andrew "Chick" Ahlgren. Chick worked closely with Jim Rutherford in the development and writing of *Science for All Americans* (Oxford University Press, 1990), which many science educators, including myself, consider to be the seminal work in science education standards. The ideas in *Benchmarks for Science Literacy* (Oxford University Press, 1993), the *National Science Education Standards* (National Academies Press, 1996), *A Framework for K–12 Science Education* (National Academies Press, 2012), the *Next Generation Science Standards* (National Academies Press, 2013), and the science standards in all 50 states can be traced directly back to *Science for All Americans*. So I thank Jim for founding AAAS (American Association for the Advancement of Science) Project 2061 with the idea of describing what everyone needs to know to be scientifically literate. And I thank Chick, whose voice I can still hear every time I read the beautiful prose in *Science for All Americans*.

Chick also came up with the idea of mapping standards—putting goals into small boxes and then connecting them with arrows on a page. The making of such maps was essential to the development of *Benchmarks for Science Literacy*, but even after the goals had been printed as lists, Chick pushed for printing a coffee-table book with these maps. Oxford University Press, the publisher of *Science for All Americans* and *Benchmarks for Science Literacy* declined to publish the *Atlas of Science Literacy* (AAAS, 2001 and 2007), feeling that there wasn't a market for such a book. Chick persevered, and AAAS and the National Science Teaching Association (NSTA) agreed to copublish the *Atlas*. Soren Wheeler, under the tutelage of Chick, developed the maps in volume 1 of the *Atlas*, which turned out to be quite popular. So I must thank both Chick and Soren for all their work developing the techniques I used to make the maps in this book.

But most of all, I must thank Chick for seeing some potential in a high school physics teacher who wrote to him out of the blue one day with an interest in moving to Washington, D.C., and a dream of working for Project 2061. Chick was aware that Soren would soon be leaving Project 2061 and was on the lookout for a good replacement. As that physics teacher, I had the good luck of having Chick decide to hire me and the great fortune of working with him closely until he retired. Daily conversations with Chick during that time were tremendously enjoyable and influential in my understanding of standards-based education reform. To this day, I consider the opportunity to have those conversations one of the highlights of my professional career. In remembrance of Chick, I have tried to carry on the traditions that he taught me.

After Chick retired, I continued to work broadly on standards-based education reform and specifically on volume 2 of the *Atlas of Science Literacy*. That work was greatly aided and improved by the expertise and oversight of Sofia Kesidou, George Deboer, and Jo Ellen Roseman as well as the involvement of my many Project 2061 colleagues, including Cari Herrmann Abell, Mary Koppal, Francis Molina, and Jill Wertheim.

Obviously, *The NSTA Atlas of the Three Dimensions* would not have been possible without *A Framework for K–12 Science Education* (the *Framework*) and the *Next Generation Science Standards* (*NGSS*), so I owe a debt of gratitude to everyone who was involved in the development of those two works. In particular, I want to acknowledge Heidi Schweingruber from the National Academy of Sciences for shepherding the writing of the *Framework* and Stephen Pruitt for his work overseeing the development of the *NGSS* while at Achieve.

I also want to acknowledge the two educators who have been so influential in developing my own understanding of three-dimensional teaching and learning that I have given them both *NGSS* nicknames. I thank Brian Reiser (aka "The Godfather of *NGSS*") and Joe Krajcik (aka "Captain *NGSS*") for their efforts to promote teaching and learning that has students developing and using practices, core ideas, and crosscutting concepts for the purpose of making sense of phenomena and designing solutions to problems.

Text from the *Framework* is used heavily (with permission) throughout the *NSTA Atlas* to provide greater context on various topics, but more text was needed regarding the nature of science in Chapter 7. I am therefore indebted to Norman G. Lederman, Fouad Abd-El-Khalick, Ryan Summers, and Dawnne LePretre for crafting some discussion on the nature of science for inclusion in the *NSTA Atlas*.

The challenges of successful implementation of the *Framework* and *NGSS* created a need at NSTA and the opportunity for me to move there in 2012 to become their in-house standards expert (or NSTA's standards geek, as I often say on Twitter). I greatly appreciate Francis Eberle for making this move possible, and I also thank Gerry Wheeler and David Evans for letting me continue in this role that I love. In addition, while there are many talented people at NSTA, I am extremely fortunate to work closely with some of the best. I thank Jennifer Horak, Tricia Shelton, and Cindy Workosky for the many talents they possess, for the extra effort they put into all that they do, and—perhaps most of all—for the kindness and patience they exhibit every day while working with me.

It is fairly unusual, if not unprecedented, for an NSTA staff member to write a book for NSTA Press, so I want to extend my gratitude to David Evans, David Beacom, and Claire Reinburg for the special arrangements they made to allow me to develop the *NSTA Atlas*. I also want to thank NSTA Press and NSTA's art and production team—in particular, Rachel Ledbetter, Catherine Lorrain, and Will Thomas—for turning the various files on my computer into the finished product you now have. I also want to thank Joe Butera and Eléonore Dixon-Roche for giving me design advice.

I also wish to thank Meridith Bruozas of Argonne National Laboratory for helping me find photos, including the opening image for Chapter 1.

Although I individually crafted each map, I must profusely thank the many people who took time to review maps and provide extremely useful feedback. The list of reviewers can be found on page 183.

A special thank-you to my daughter, Laura, for compiling the index for the *NSTA Atlas* and to my wife, Jennifer, for her patience as I spent many nights and weekends either at the office or on the computer in our dining room working on this book.

Finally, I thank the many educators who have expressed interest in the *NSTA Atlas* on Twitter and in person. Your desire for this resource and your words of encouragement motivated me to get this done and to do it right. Ultimately, this book is for you. As I like to note when leading workshops, none of this work matters without the work you do in your districts and in your classrooms to help students become scientifically literate. If the *NSTA Atlas* helps you in that mission, then I will consider my efforts a success.

INTRODUCTION

Progressions

A key aspect of learning in K–12 education is the idea that what students know and are able to do grows and evolves over time. Simple ideas learned in the early elementary grades gain levels of detail and complexity as students progress in their education. Connections between different topics and disciplines are made. This process happens not just in what students know but also in their ability to engage in science practices.

Therefore, a key feature of setting standards for students is to describe learning progressions. Simply put, a *learning progression* is an articulation of the "steps along the way" that a student might go through as he or she works toward mastery of a concept or core idea.

A Framework for K–12 Science Education (the *Framework*; NRC 2012) emphasizes the importance of progressions by noting the following:

> *To develop a thorough understanding of scientific explanations of the world, students need sustained opportunities to work with and develop the underlying ideas and to appreciate those ideas' interconnections over a period of years rather than weeks or months. This sense of development has been conceptualized in the idea of learning progressions. If mastery of a core idea in a science discipline is the ultimate educational destination, then well-designed learning progressions provide a map of the routes that can be taken to reach that destination. Such progressions describe both how students' understanding of the idea matures over time and the instructional supports and experiences that are needed for them to make progress. (p. 26)*

Appendix A of the *Next Generation Science Standards* (*NGSS*; NGSS Lead States 2013) goes on to note this:

> *First, focus and coherence must be a priority. What this means to teachers and curriculum developers is that the same ideas or details are not covered each year. Rather, a progression of knowledge occurs from grade band to grade band that gives students the opportunity to learn more complex material, leading to an overall understanding of science by the end of high school. Historically, science education was taught as a set of disjointed and isolated facts. The* Framework *and the NGSS provide a more coherent progression aimed at overall scientific literacy with instruction focused on a smaller set of ideas and an eye on what the student should have already learned and what they will learn at the next level.*
>
> *Second, the progressions in the NGSS automatically assume that previous material has been learned by students. Choosing to omit content at any grade level or band will impact the success of students in understanding the core ideas and put additional responsibilities on teachers later in the process. (p. 2)*

While there is no one path that applies to all students, some paths are more common than others. Some paths are also more efficient and effective than others. In some topics, there is ample evidence from research to chart the progressions. In other topics, charting the progressions depends much more on the logic of the discipline, the general principles of cognitive development, and the experiences of educators.

The *Framework* provides specific grade-band endpoints for the disciplinary core ideas (DCIs) and describes progressions for the science and engineering practices and the crosscutting concepts. In the *NGSS,* there are tables of progressions for all three dimensions (as well as for the connections to the nature of science and connections to engineering). Many other state standards based on the *Framework* have similar tables. *The NSTA Quick-Reference Guide to the* NGSS, *K–12* (Willard 2014) has these tables all together in an easy-to-use form. The connections box at the bottom of each standards page in the *NGSS* has cross-references between the DCIs listed on that page and the DCIs at other grade levels and in other topics. Thus, the connections boxes provide some guidance on how topics relate to one another.

But none of these documents is particularly user-friendly in conveying how ideas build on each other and relate to one another. The tables in the *NGSS* appendixes and the *Quick-Reference Guide* are linear and do not provide any sense of how topics can branch out or converge or how ideas from different disciplines connect. The information in the connections boxes is not focused at the element level and can be hard to interpret. A better way of illustrating connections is needed for these new standards. One of the most successful methods of conveying those relationships—perhaps *the* most successful method—has been through a particular kind of mapping.

A Brief History of Mapping Standards

In the early 1990s, AAAS (American Association for the Advancement of Science) Project 2061 gathered teams of educators together to write *Benchmarks for Science Literacy* (AAAS 1993). This book was a set of learning goals that would lead students to have the knowledge and skills described in *Science for All Americans* (AAAS 1990) by the time they graduated from high school. The developers often wrote science ideas (that were eventually called *benchmarks*) in little boxes and connected them with arrows as shown in Figure 1 (p. xii).

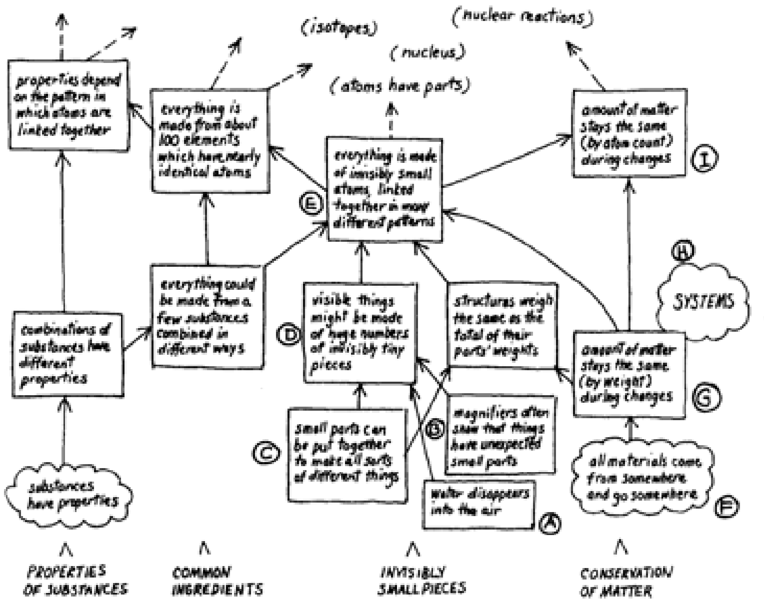


Figure 1. Sample Map Made During the Development of Benchmarks for Science Literacy

In a chapter describing the development of *Benchmarks*, the authors explain the following:

> *The team members had to imagine what progress students could make toward each SFAA [Science for All Americans] goal, a process that came to be called mapping because it required groups to link more sophisticated ideas in later grades to the more primitive ones suitable for the early years. (AAAS 1993, p. 305)*

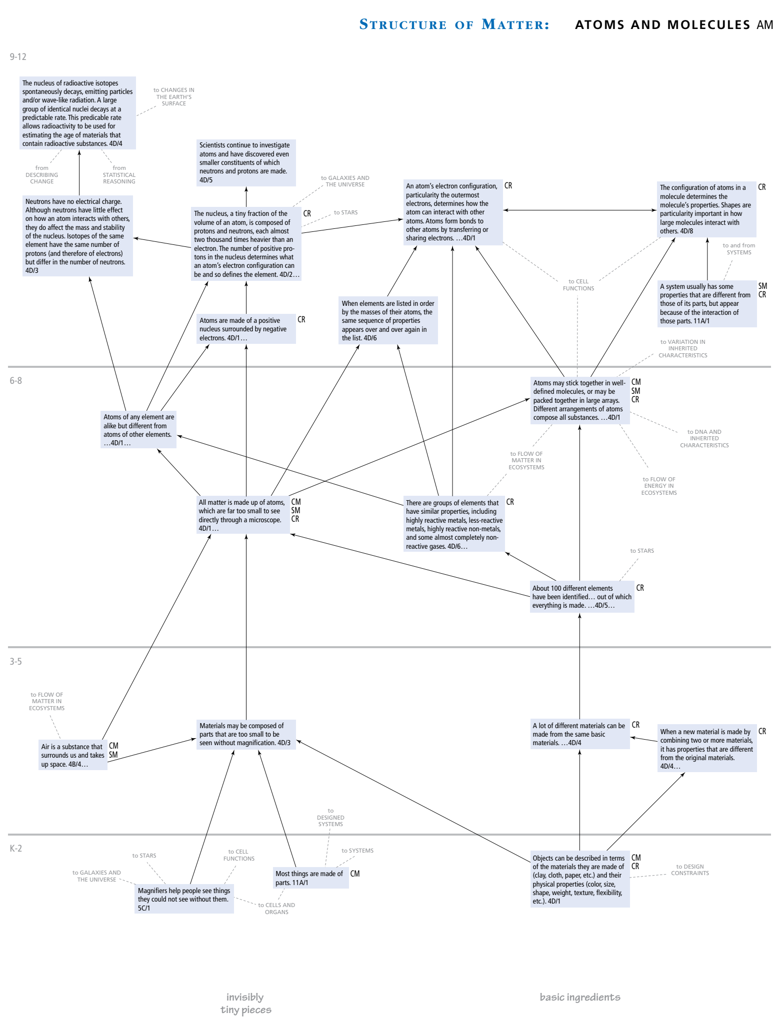


Figure 2. Atoms and Molecules Map From the Atlas of Science Literacy, Volume 1

When *Benchmarks* was published, it had lists of benchmarks rather than maps, but work soon got underway to produce maps of the benchmarks. In 2001, Project 2061 published the first volume of the *Atlas of Science Literacy*. It included 49 maps of different topics in *Benchmarks*. I joined the staff of Project 2061 that year and developed 43 maps for volume 2 of the *Atlas,* which was published in 2007. Figure 2 shows an example of one of these maps.

Many educators found the maps extremely helpful in their work in developing and improving curriculum, instruction, and assessment. After the release of the *Framework* and *NGSS*, teachers and curriculum specialists desired a similar tool to assist with work involving the new standards.

How to Read a Map

(*Note:* The information in this section is summarized in the Map Key on p. xxii and on the inside back cover.)

Maps organize all of the elements from the standards on a particular topic (e.g., models, patterns, or definitions of energy) on a single page. The elements come from bulleted statements in the foundation boxes of the standards (as shown in Figure 3) and the progressions in the appendixes of the *NGSS.* In turn, these statements are drawn from the progressions and grade-band endpoints in the *Framework*. Chapter 9 (p. 114) has maps of performance expectations (PEs) rather than elements.

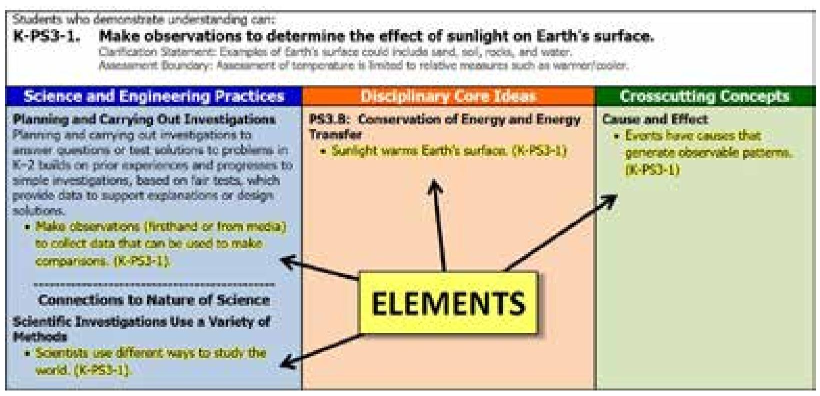


Figure 3. Elements Highlighted in the Foundation Box

Each element appears in an **element box** that is color coded to indicate what type of element it is (see also Figure 4).

- Blue = Science and Engineering Practices
- Green = Crosscutting Concepts
- Orange = Disciplinary Core Ideas
- Purple = Connections to the Nature of Science
- Teal = Connections to Engineering
- Gray = Performance Expectations

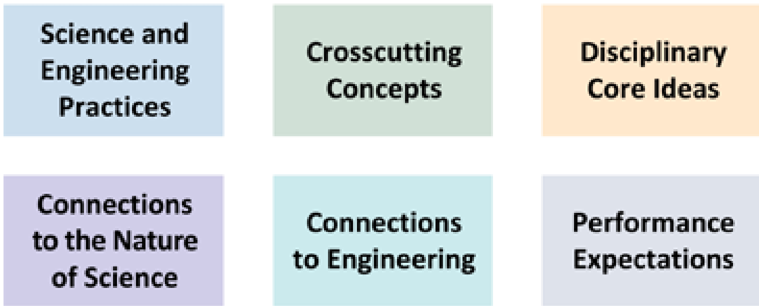


Figure 4. Background Colors for the Element Boxes

Arrows connect elements to indicate how competency in one element can be useful in learning another element. An arrow can connect two elements in the same grade band or in two separate grade bands.

Connections have many possible meanings, more than can be easily categorized. However, here are several examples of what an arrow from A to B (A → B) could imply:

- A is an essential prerequisite to B.
- A defines a term or concept that is useful in learning B.
- B is a more complex version of A.
- B encompasses A along with an additional expectation.
- Being able to do A is useful in learning to do B.
- Doing A helps understand B.
- B is a generalization, and A is a specific example of that generalization.
- A is a generalization, and B is an exception or special case of that generalization.

At the same time, the arrows are not used to address some kinds of connections between elements. For example, two core idea elements might be needed to make sense of one particular phenomenon, but this type of connection would not be represented on the maps. The maps also do not indicate how practices, core ideas, and crosscutting concepts can be integrated to describe student performance.

There is also a practical limit to how many connections can be shown between crosscutting concepts and core ideas. For example, some of the elements dealing with the crosscutting concept of systems and system models could arguably be connected to a great number of core idea elements—many more than can be reasonably illustrated on the maps. Therefore, the threshold for displaying those connections on the maps is somewhat higher.

Every map is broken up into four **grade bands**. The bottom of the map features grades K–2 (primary). Then grades 3–5 (elementary), grades 6–8 (middle school), and grades 9–12 (high school) are stacked up the map in that order. How high or low an element box appears within a particular grade band is not an indicator of what grade it belongs in. In addition, unless two elements are connected by an arrow, nothing is implied by how high or low they are relative to one another. For example, just because one box is lower than another one does not mean that it should be taught before the other.

It should be noted that in the *NGSS,* the PEs in the elementary grade bands are broken up into specific grades K–5. While all of the practices and crosscutting concepts are intended for use in all grades, the assignment of PEs to specific grades means that the corresponding DCIs are also assigned to that grade. However, other standards that are based on the *Framework* may have decided that certain core ideas be taught at a different grade. For that reason, the maps do not presume that a given DCI is in a particular grade. In fact, it is possible that there are a few instances in which an arrow between two elements indicates a connection between something in a higher grade to something in a lower grade in the *NGSS*.

One of the most noticeable features of the maps are chains of connected elements that run up the map. These chains of elements are called **strands,** and they usually share a theme or involve the development of the same idea. The simplest strands are aligned in a vertical column connected by arrows, but sometimes a strand may fork or converge if it doesn't make sense to stack the elements in one straight line. The "Alternate Arrangement of the Practices Matrix" in Appendix F of the *NGSS* provided some guidance in planning strands on the maps of the practices in Chapter 1 (p. 2). In general, however, the strands emerged through the process of constructing the map. The vertical arrows in strands don't have any greater meaning than the other arrows on the map. In fact, two boxes connected by a vertical arrow on one map may not be arranged vertically on another map. Vertical arrows are more frequently cases in which the later idea is a more sophisticated version of the earlier idea. In addition, studying strands is often a good way to get a sense of some of the more important "stories" in a topic.

At the top of each map, enclosed in parentheses following the title for the map, is one or more **topic codes** identifying the topic(s) of the map. For example, the topic code for Developing and Using Models is MOD. For the DCIs, the topic code is the identifier for the component ideas (e.g., PS1.A, LS1.C & LS2.B, and ESS2.C). A list of all the topic codes can be found on page xxiii and on the inside front cover of the *NSTA Atlas*.

After the topic code is the **map code**, which is a unique identifier for the map that appears in the top right-hand corner of the map. The number before the period identifies which chapter the map comes from, and the number after the period identifies which number the map is within the chapter. Therefore, a map code of 3.2 indicates the second map in Chapter 3.

At the end of the text in every element box is an **element code**, which is a unique identifier for the element. The first part of the code (before the dash) is the topic code. After the dash, there is a letter and a number. The letter indicates the element's grade band: *P* for primary (grades K–2), *E* for elementary (grades 3–5), *M* for middle school (grades 6–8), and *H* for high school (grades 9–12). The number that appears after the letter indicates the bullet position of the element in that particular grade band (e.g., 1st, 2nd, or 3rd). Figure 5 (p. xiv) illustrates this structure.

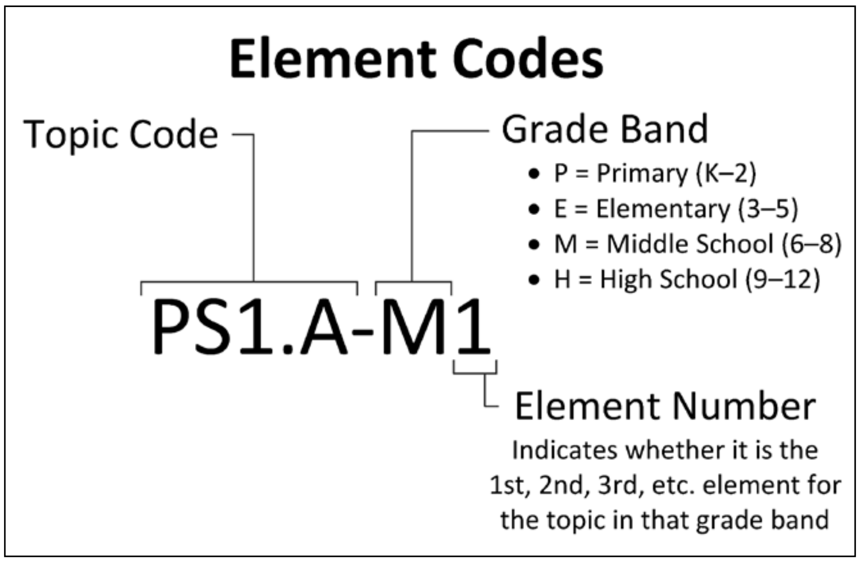


Figure 5. How to Read an Element Code

In addition to the element boxes, which have the full text of the element, there are also small boxes on the map that include only the element code (see Figure 6). These **off-map elements** provide a way to show connections to elements that are on other maps. An off-map element is somewhat relevant to the topic of the map, but not so much so that the element needs to be on the map. The off-map elements are color coded in the same way that the element boxes are so that it is easy to distinguish the different dimensions. During the process of identifying off-map elements for the core ideas, the connections boxes for each set of performance expectations in the *NGSS* were particularly useful for finding possible connections between different disciplines. Arrows connect the off-map elements to element boxes (and in some cases to other off-map elements). These arrows have the same meaning as the other arrows on the map. Because of design constraints, an off-map element may appear more than once on a map, and some connections to it may not be shown.

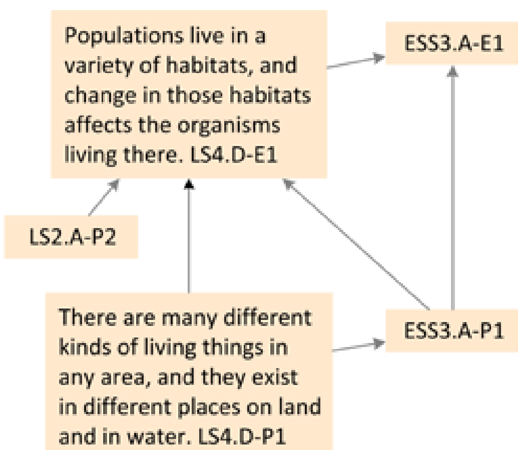
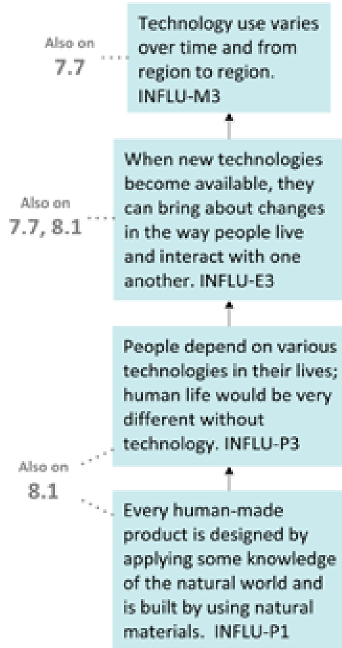


Figure 6. Excerpt From Map 4.4 Illustrating Off-Map Elements

An **Also on… Connection** is used to indicate when a given element box appears on more than one map (see Figure 7). The phrase *also on* is followed by one or more map codes to indicate that the connected element boxes also appear on those other maps. Also on… Connections are used only for element boxes. They don't indicate where off-map elements also appear. That information can be found in the index.



The Also on… Connections from this excerpt of Map 8.2 indicate the following:

- INFLU-M3 also appears on Map 7.7.
- INFLU-E3 appears on both Map 7.7 and Map 8.1.
- INFLU-P1 and INFU-P3 both appear on Map 8.1.

Figure 7. Excerpt From Map 8.2 Illustrating Also On… Connections

It is important to understand that no single map comprehensively shows all of the connections to a single element. The Also on… Connections and off-map elements provide only part of the picture. To get the full scope of connections for a particular element, readers should refer to the index and find all of the maps that contain that element.

Facing Pages

All of the maps appear on the right-hand side of a two-page spread. The page facing the map has additional information relevant to that map (see Figure 8).

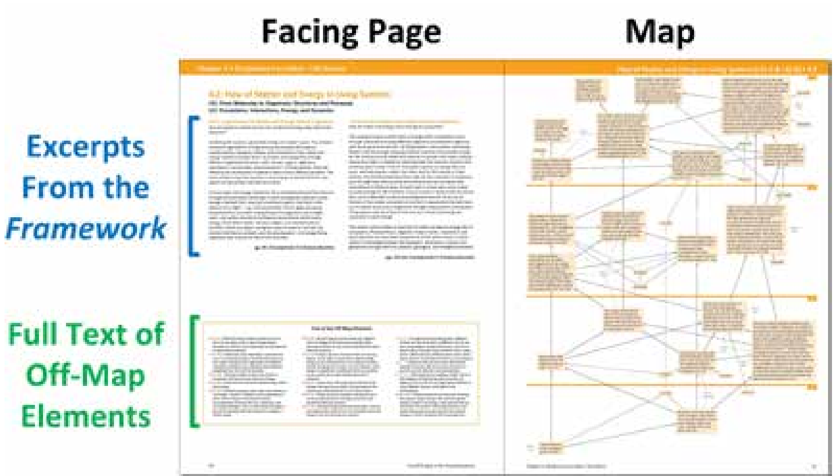


Figure 8. The Features of Facing Pages in Chapters 1–8

For the maps in Chapters 1–6 (pp. 2–89) and Chapter 8 (p. 108), the facing page contains excerpts from the *Framework* relevant to the topic of the map. Only the general description of the topic is shown. The progression descriptions for the practices and crosscutting concepts and the grade band endpoints for the DCIs are not included because there was insufficient space on the facing page and the maps themselves essentially convey the same information. The *Framework* does not have similar descriptions for the understandings of the nature of science because those elements were developed during the process of writing the *NGSS.* Therefore, the facing pages in Chapter 7 (p. 90) contain descriptions for each of the eight understandings of the nature of science that were contributed by Norman G. Lederman, Fouad Abd-El-Khalick, Ryan Summers, and Dawnne LePretre.

The facing pages in Chapters 1–8 (pp. 2–113) also include a list of the full text of the off-map elements that appear on the map, making it much easier to interpret the relationships shown on the map. In five cases, there wasn't enough room on the facing page to include this information, so the lists of off-map elements for the following maps are included in Appendix E (p. 181):

- **2.7:** Stability and Change (SC)
- **3.2:** Chemical Reactions and Nuclear Processes (PS1.B & PS1.C)
- **5.2:** Earth's Systems (ESS2.A & ESS2.E)
- **5.4:** Weather and Climate (ESS2.C & ESS2.D)
- **5.6:** Human Impacts on Earth Systems (ESS3.C & ESS3.D)

For the maps of the performance expectations in Chapter 9 (p. 114), the facing pages contain a description of the PEs at each grade level adapted from the introduction to various grades and grade bands in the *NGSS.* In addition, each facing page in Chapter 9 has a table that identifies the three-dimensional (3-D) elements that are integrated into each PE (see Figure 9).

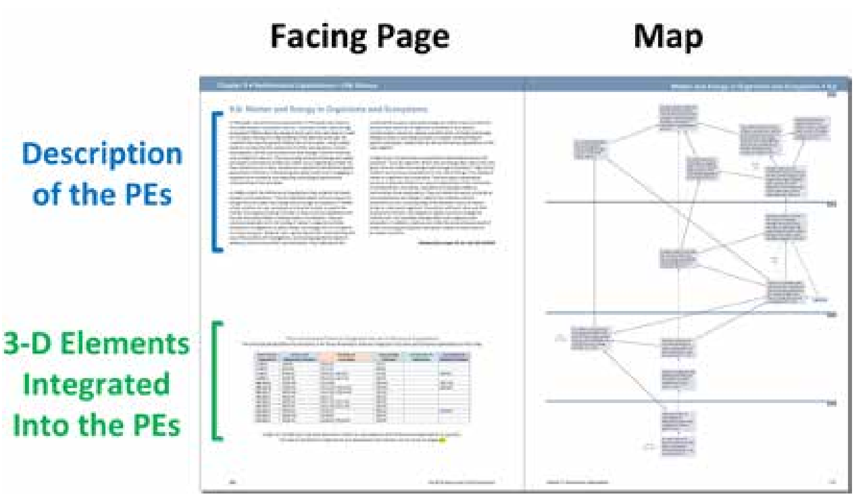


Figure 9. The Features of Facing Pages in Chapter 9

How the *NSTA Atlas* Is Organized

The *NSTA Atlas* is composed of nine chapters. There is one chapter for the practices and one chapter for the crosscutting concepts. The DCIs are broken out into four chapters—one for each of the four disciplines. There are also chapters for the connections to the nature of science and the connections to engineering, technology, and applications of science. Finally, Chapter 9 comprises the maps of the performance expectations.

Each chapter opener is a two-page spread. In most cases, the spread contains an excerpt from the *Framework* or *NGSS* that provides an overview of the topics covered in the chapter. For example, in Chapters 3–6, the chapter opener features descriptions from the *Framework* for each of the core ideas in the chapter.

When planning the maps for Chapters 1–8, the *Framework* and the *NGSS* provided guidance on how to break up the elements into different topics. For example, there is a map for each of the eight practices and each of the seven crosscutting concepts. There is also a map for each of the eight categories of understanding about the nature of science and the two types of connections to engineering. In all of these cases, the title of the map is derived directly from the title of the topic in the *NGSS.*

For the DCIs, the original plan was to have a map for each of the component ideas. However, there were many cases where a given component idea did not have a sufficient number of elements to be the backbone of a map. For example, PS1.C: Nuclear Processes contains only two elements. Therefore, when appropriate, two or three component ideas are combined to provide the core set of elements for a map. For example, whereas the first map in Chapter 3 focuses on the single component idea PS1.A: Structure and Properties of Matter, the second map in the chapter combines PS1.B: Chemical Reactions and PS1.C: Nuclear Processes.

An attempt was made to pair component ideas in ways that make sense conceptually. For example, LS2.C and LS4.D are combined because they both involve ecosystem dynamics. When a map focuses only on one component idea, the title is the same as the component idea. When a map combines two or more component ideas, the title combines the titles from those component ideas in a way that makes the focus of the map clear. For a map on a given topic, all of the elements for that topic appear on that map. In addition, most maps contain additional elements that are technically part of other topics but that are nonetheless relevant to the focus of the map.

For the maps of the PEs in Chapter 9, the *NGSS* provide less guidance on how to break things up, but the maps are roughly organized according to the topic arrangement of the *NGSS* and in most cases draw titles from that organizational structure. Three of the maps in Chapter 9 have the same titles as the maps of corresponding DCIs: Map 9.8: Inheritance and Variation of Traits, Map 9.9: Natural Selection and Evolution, and Map 9.12: Weather and Climate.

The appendixes of the *NSTA Atlas* contain several useful features. Appendix A (p. 145) is a list of all elements of the three dimensions. Appendix B (p. 163) is a list of all PEs, along with their clarification statements and assessment boundaries.

Appendix C (p. 173) contains a table that conveys all of the information from the connections boxes in the *NGSS.* It notes connections between the DCI elements for each PE and other DCI elements in the same grade band or in different grade bands, as well as connections between the DCI elements for each PE and the *Common Core State Standards* (NGAC and CCSSO 2010) for mathematics and English language arts and literacy.

Appendix D (p. 179) provides cross-references between PEs and DCI elements. At the end of the *NSTA Atlas* are indexes that can be used to identify the maps where each element and each PE appears. The index specifies whether the full text is shown on the map or whether it is an off-map element (or PE).

How the Maps Were Made

The maps in the *NSTA Atlas* were produced with flowcharting software called Microsoft Visio. As noted earlier, each map is focused on a particular topic. The first step in constructing the map is pasting the text of all of the elements in that topic into boxes on the map at the appropriate grade band. The text of all the elements and PEs, along with their codes, is pulled from an Excel file. (A Google Sheets version of this document can be found at this link: *http://tinyurl.com/ngsscodes*.)

Once those elements are on the map, I look for obvious connections between different elements, and work to organize the elements into strands that cross several grade bands. Appendix F of the *NGSS* provided some guidance in organizing the elements of practices, since one of the arrangements grouped them into strands of similar elements. For the other dimensions, I had to interpret the meaning of each element.

There were a few design constraints regarding the elements that I held myself to in working on the *NSTA Atlas.* One significant constraint was that I could not rewrite any of the statements. When I worked on the *Atlas of Science Literacy* for Project 2061, my colleagues and I had the freedom to reword benchmarks from *Benchmarks for Science Literacy* and even add or delete entire benchmarks because they were the intellectual property of Project 2061. I do not have similar authority with the *Framework*, *NGSS,* or other science standards based on the *Framework*. (This also meant that I had to ignore reviewer comments that suggested I change the text of the elements.) For similar reasons, I did not break up individual elements into smaller pieces or clump some together to make bigger pieces. I used the elements as they appeared in the *NGSS.*

I should also note that in many cases in the *NGSS,* the bulleted statement of a practice (and occasionally a crosscutting concept) in the foundation box is truncated compared with how it appears in the appendixes. I used only the full text versions from the appendixes.

As I identified relationships between elements, I connected them with arrows. Deciding which way an arrow should go was often difficult. When an arrow connects two elements that are in different grade bands, the direction of the arrow is simple. The arrow must run from the element in the lower grade band to the one in the upper grade band. But connecting two elements in the same grade band is more difficult. An argument can often be made for both directions. In fact, some people have suggested that I use double-headed arrows in many cases. The *Atlas of Science Literacy* had a few double-headed arrows, but I decided at the start of this mapping work not to use them.

The reason for this decision is that as tempting as double-headed arrows are, not using them pushes me to dig deeper into the meaning of each element and the relationships between them. In addition, my work with maps over the years has led me to conclude that double-headed arrows aren't particularly useful in guiding the educators using the maps. In almost every case of A → B (i.e., understanding A is useful in students learning B), it is also the case that learning B provides new insights into students' understanding of A. So nearly all arrows could be double-headed. But if every arrow in the *NSTA Atlas* were double-headed, that would ultimately lead to less information being conveyed. Instead, I suggest that whenever readers see A → B, they consider not only how A influences B but also how B could influence A. Ultimately, the maps are not a set of rules; they are a set of thinking tools.

The next step in developing the maps is to consider if other elements that aren't officially part of the topic in question should be included. I did this in a variety of ways. For example, to create Map 1.2: Developing and Using Models (MOD), I did a word search for any element that had the word *model* in it.

Work on one map inevitably ends up affecting other maps. For example, I held off on constructing Map 3.7: Energy in Chemical Processes and Everyday Life (PS3.D) until after I had made Map 4.2: Flow of Matter and Energy in Living Systems (LS1.C & LS2.B) because I knew that both maps would contain several ideas about photosynthesis. The full story about photosynthesis would appear on Map 4.2, so once it was completed, I could then figure out what aspects of that story could be shown on Map 3.7.

It's important to recognize the recursive nature of this work. Although I worked on Map 4.2 before I made Map 3.7, the work on Map 3.7 led me to modify Map 4.2. An extreme example of this process took place when I worked on the maps about the nature of science in Chapter 7. There were so many connections between the elements on those maps that I essentially worked on all of the maps simultaneously.

As more elements and more arrows are added to the maps, some design constraints begin to matter. The vertical space for each grade band is the same on all 62 maps. Each arrow is a straight line that appears to go from the center of one box to the center of the other. Arrows never go in front of or behind boxes. As a result, I frequently had to shift boxes up or down in a grade band to make things look right. In some cases, I needed to move a strand from one side of the map to the other. Clearly, many aspects of creating the maps were more art than science.

Part of the map-making process was also deciding whether a given element should appear with its full text in a box or whether it was more appropriate as an off-map element. While developing the *NSTA Atlas,* I promoted or demoted some elements based on other changes I made to the map or based on my rethinking of the elements' relative importance to the map.

After I had made at least one draft of every map, I conducted a detailed review of the connections boxes in the *NGSS.* A connections box describes two types of information:

1. Connections to Other DCIs in This Grade Band
2. Articulation Across Grade Bands

In both cases, the information indicates connections between a PE and a component idea at a particular grade band (or an individual grade in grades K–5). For example, the PE MS-PS1-1 is listed as being connected to ESS2.C in middle school, connected to PS1.A in fifth grade, and to PS1.A and ESS1.A in high school.

Comparing the connections made by the arrows in the *NSTA Atlas* with the ones described in the connections boxes of the *NGSS* was tricky because the connections are at different grain sizes. The arrows in the *NSTA Atlas* connect two specific elements, whereas a given PE and a component idea in a particular grade band may involve more than one element. For example, MS-PS1-1 is linked to two DCI elements (PS1.A-M1 and PS1.A-M5). The component idea PS1.A has three elements (PS1.A-E1, PS1.A-E2, and PS1.A-E3) in fifth grade. In high school, the component ideas PS1.A and ESS1.A each have four elements. So the three connections in the connections box of the *NGSS* are actually 32 possible arrows to consider in the *NSTA Atlas.*

To make these comparisons, I ended up creating an Excel spreadsheet, printing out the hundreds of pages it took up, and reviewing every possible connection suggested. In each case, I noted whether there was a direct connection between the two goals, an indirect connection, or no connection that I could identify. Thus, there are instances where a connections box indicates a relationship that is not represented in the *NSTA Atlas*. But by the same token, there are connections in the *NSTA Atlas* that are not reflected in any connections boxes. This is an inevitable outcome when different authors engage in different processes. Although comparing the maps and the connections boxes was laborious, it turned out to be very worthwhile. That process not only verified many connections I had already noted but also alerted me to some that I hadn't considered. In particular, I added a number of off-map elements to the maps as a result of this process.

At this stage, the first draft of the index was constructed. I needed the index at this point to add the Also on… Connections. The process of adding those connections also let me compare situations where the same element appears on more than one map and try to ensure that any and all connections to that element on one map were also found on all of the other maps that have that element.

Once maps were completed, I shared them with educators who volunteered to review them and provide me with feedback. The list of reviewers appears on page 183. I am indebted to each of these individuals for their critiques, suggestions, comments, and questions that improved the overall quality of the *NSTA Atlas.* They often led me to reevaluate my thinking and spend more time revising and fine-tuning the maps. I thank them for their help while acknowledging that the remaining errors and results of poor judgment are solely my responsibility.

As thorough as I have tried to be, I am certain that I have missed connections. In fact, I have probably missed some very important connections. A little bit of math makes clear why that is (see Figure 10).

Type of Element	Number of Elements				
	K–2	3–5	6–8	9–12	Total
Practices	36	41	51	50	**178**
Crosscutting Concepts	11	16	25	29	**81**
Disciplinary Core Ideas	38	58	90	98	**284**
Connections to the Nature of Science	12	16	26	32	**86**
Connections to Engineering	5	7	6	6	**24**
Total Number of Elements	**102**	**138**	**198**	**215**	**653**
Performance Expectations	**33**	**45**	**59**	**71**	**208**

Figure 10. A Count of the Number of Different Types of Elements

If an arrow could go from any element to any other element, there would be 468,812 possible connections to consider. However, there are some restrictions. For example, you can't have an arrow point from an element up in high school down to one in middle school, so that reduces the number of possible connections to "only" 269,990 between the 653 elements. A similar calculation for the 208 PEs adds an additional 27,242 connections to consider, meaning that there are theoretically 297,232 connections to consider in laying out the 62 maps in the *NSTA Atlas.*

As you might guess, I did not systematically review each of those nearly 300,000 possible connections. Instead, I strategically looked for connections where they seemed most likely. I am sure that as educators make use of the maps, they will identify connections that I have missed. They may also disagree with some of the connections I have made. As I will more clearly spell out next, I do not claim that these maps represent the definitive and only way to look at connections in the standards. I do, however, claim that I have done a great deal of thinking about the connections. I welcome others to study the maps and do some thinking of their own.

Using the Maps With Various State Standards

It is important to note that the maps in the *NSTA Atlas* are useful even if an educator is not in a state that has adopted the *NGSS.* More than 40 states have standards based on the *Framework*. About half of those states have adopted the *NGSS,* which means that their standards contain every PE word for word from the standards. Of the remaining states, some have standards that are nearly identical to the *NGSS,* whereas others have standards that are quite different. But all of those states include at least some of the three dimensions in their standards. Most include all three. Therefore, the educators in all of these states will find most of the maps in the *NSTA Atlas* quite useful.

For example, educators in many states use the elements of the three dimensions but not the PEs from the *NGSS* because their state standards have different PEs. Those educators may not find the maps in Chapter 9 very useful, but the maps in Chapters 1–8 will still be helpful in their work.

Another common situation is that some states added, deleted, or modified a few of the DCI elements. Educators from those states can still use the maps in the *NSTA Atlas,* but they will need to think about how to adapt the maps to account for differences between their standards and the *NGSS.*

Some states have standards that list the eight practices and seven crosscutting concepts but don't elaborate on them. The progressions of the practices and crosscutting concepts on the maps in the *NSTA Atlas* can provide educators in those states guidance on what their students should know and be able to do in a particular grade band.

Even educators in the few remaining states that have neither adopted the *NGSS* nor developed standards based on the *Framework* can find the maps useful. Many educators choose to incorporate science and engineering practices and crosscutting concepts into their instruction because it reflects current research on how students best learn science. The maps for these dimensions can certainly provide guidance. In addition, the science knowledge represented by the DCIs of the *Framework* and the *NGSS* is found in many standards. Students have been expected to learn about Newton's laws, the conservation of matter, the theory of evolution, and plate tectonics for many decades. Therefore, the maps of the DCIs can still help educators think about the ways students' learning can build over time.

How to Use the *NSTA Atlas*

Individual maps and the *NSTA Atlas* overall are powerful resources to aid educators in their work. In general, the maps help them understand the meaning of individual elements, which is essential for a host of educational activities. The maps are also particularly helpful for planning curricular sequences.

Despite the best efforts of the writers of the *Framework* and the *NGSS*, simply reading the text of an individual element by itself does not provide an educator with enough information to fully determine the writers' intent. This issue is not unique to the current set of standards; the same issues existed with *Benchmarks for Science Literacy*, the *National Science Education Standards* (NRC 1996), and earlier state standards. For both the previous generation of standards and the current standards, educators have developed processes for unpacking (or interpreting or clarifying) the standards to get a better sense of their meaning. The maps and other features in the *NSTA Atlas* can be an extremely valuable tool in that process.

When trying to unpack one of the elements, you should begin by looking at the home map for that element. When looking at the map, following these steps can be helpful:

1. Scan the strand the element is in and see how the expectations for student learning progress from one grade band to the next.
2. Examine all of the arrows that connect the element to other elements on the map. Think about what the arrows indicate as a relationship between the elements.
3. Study any off-map elements that feed into or out of the element you are unpacking. You can find the full text of the off-map elements on the page facing a given map.
4. Read the excerpts from the *Framework* that appear on the facing page. The *Framework* excerpts in the chapter opener may also be helpful.
5. Look for an Also on... Connection to see if the element appears on other maps, and see what you can learn about the element by studying those maps.
6. Check the index to see if the element appears as an off-map element on any other maps and review those maps.
7. Examine the PEs, as well as their clarification statements and assessment boundaries, that make use of the element. This step is particularly important when unpacking DCIs. You can find the list of PEs in Appendix B, and you can use Appendix D to identify the PE(s) that go with a particular DCI element.

As you review the maps and other resources in the *NSTA Atlas,* you will begin to get a better sense of what an element means. It is important to realize that the different dimensions require different approaches to unpacking. Figure 11 provides some guidance about what issues you should consider. This figure is based on procedures described in *Creating and Using Instructionally Supportive Assessments in* NGSS *Classrooms* (Harris, Krajcik, and Pellegrino, forthcoming). Figure 12 provides a set of questions you can use to guide your thinking about each of these issues.

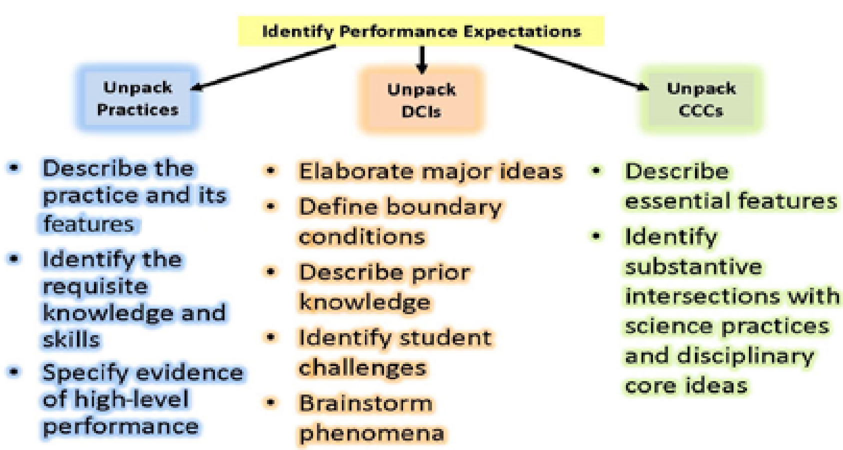


Figure 11. Examples of Using the Maps

Guiding Questions for Unpacking the Practices

Describe the practice and its features.

- *What does it mean to "do" the practice?*
- *What are the essential aspects of this practice?*
- *What possible intersections might there be with other practices?*

Identify the requisite knowledge and skills.

- *What knowledge and skills do students need to use in order to show that they can perform the practice?*

Specify evidence of high-level performance.

- *What evidence would you expect to see for each aspect of this practice?*
- *What are the different levels of performance for each aspect of this practice?*

Guiding Questions for Unpacking the Core Ideas

Elaborate major ideas.

- *What is the intended meaning of the element of the core idea?*
- *Is there one idea or several separate ideas in the statement?*
- *What terminology is explicitly used in the core idea?*

Define boundary conditions.

- *What peripheral ideas or terms are not essential for understanding the core idea?*

Describe prior knowledge.

- *What other knowledge and skills (both from this topic and from other topics) do students need in order to understand this core idea?*

Identify student challenges.

- *Are there any commonly held ideas that differ in important ways from the scientifically accepted understanding?*
- *What methods can be used to determine students' current understandings?*
- *In what ways can instruction directly address or leverage students' current understandings?*

Brainstorm phenomena.

- *What phenomena would provide examples of this core idea?*

Guiding Questions for Unpacking the Crosscutting Concepts

Describe essential features.

- *What are the key aspects of this crosscutting concept?*
- *What explanatory value does this crosscutting concept have?*
- *How might students' understanding of this crosscutting concept grow over time?*

Identify substantive intersections with science practices and disciplinary core ideas.

- *Which practices provide unforced and meaningful connections with this crosscutting concept?*
- *What are some concepts or contexts in life, Earth, and physical science that would provide good opportunities for students to explore this crosscutting concept?*

Figure 12. Guiding Questions for Unpacking the Three Dimensions

Examples of Using the Maps

The rest of this section illustrates some ways in which reviewing a map can help educators in their work. For example, an educator reading the K–2 element ESS1.A-P1 in Figure 13 by itself might mistakenly think that students should be expected to understand how the motion of the Sun, Earth, and Moon relative to one another explains the patterns that students observe. However, the causes of those patterns are explicitly mentioned in ESS1.B-E1 for grades 3–5 but not mentioned in ESS1.A-P1, so the true intent of ESS1.A-P1 is much clearer if the educator reads ESS1.B-E1 first.

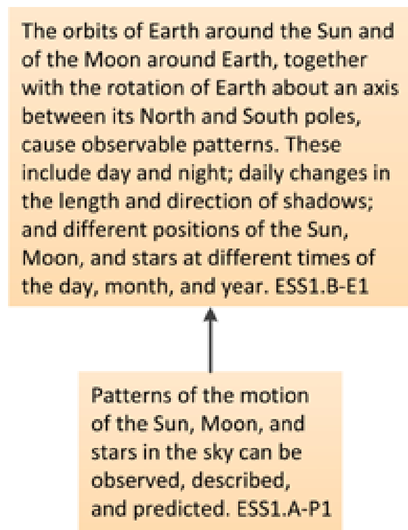


Figure 13. Excerpt From Map 5.1

In addition, sometimes studying a map can give educators ideas about instruction. For example, a teacher who wants to help students learn LS4.A-E1 could look at the connections to it on Map 4.6 (excerpted in Figure 14) and think about how she or he could use students' understanding of LS4.C-E1 and LS4.A-E2 to help them learn LS4.A-E1.

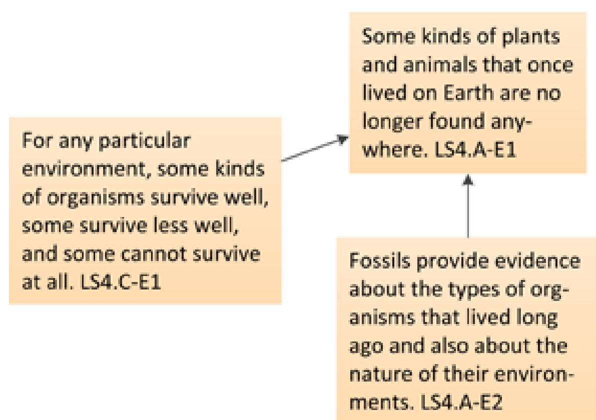


Figure 14. Excerpt From Map 4.6

One possibility would be to take the idea in LS4.C-E1 that some organisms cannot survive at all in a particular environment and extend it to imagine what would happen if there were no hospitable environments for a particular organism. Another approach would be to take the idea in LS4.A-E2 that fossils provide evidence of organisms that lived long ago and consider the fossils of an organism that has no modern equivalent.

At the same time, it is important to keep in mind that maps are meant only to suggest instructional sequences—not mandate particular ones. For example, an arrow leading from LS4.C-E1 to LS4.A-E1 does not mean that LS4.C-E1 must be taught first. There could be other instructional reasons to teach them in the other order.

What has worked best for educators is to use the maps to stimulate thinking and discussion about the relationships between different ideas. Any instance of A → B can stimulate thinking and discussion about the following questions:

1. What do each of these elements mean?
2. How would students' competency with element A be useful in learning element B?
3. How might students learning element B deepen their learning of element A?
4. How should the relationship between elements A and B affect the sequencing of instruction?
5. How should the answers to the above questions influence instructional decisions?

In addition, each of these questions could be considered reversing the arrow and trading A for B in the questions above.

When reviewing the maps, I encourage you to not just blindly accept the guidance that the arrows in the *NSTA Atlas* provide. Instead, use the maps to sharpen your own thinking. Make different choices if you wish, but be thoughtful and deliberate in doing so. Don't ignore what a map suggests just because you have always done things a different way. But if you have a clear rationale for diverging from what the maps suggest, then by all means use your professional judgment to do what is best for your students.

The next example of how reviewing a map can help educators in their work involves the excerpt of Map 5.3 in Figure 15.

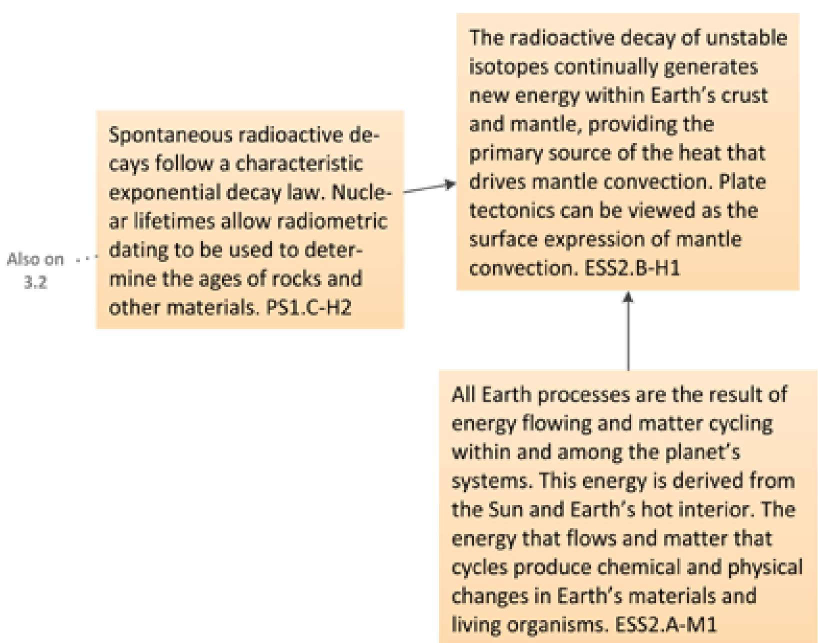


Figure 15. Excerpt From Map 5.3

A high school Earth science teacher who is planning instruction targeting ESS2.B-H1 should consider what students may have learned in middle school on this topic. She might want to assess students' understanding of ESS2.A-M1. She might even use the phenomenon of the Earth's hot interior to stimulate the driving question (Why is the Earth's interior hot?) that would lead them to learn about radioactive decay in the interior of the Earth.

The appearance of PS1.C-H2 on the map and its connection to ESS2.B-H1 leads to the possibility of making a connection to ideas that students learned in a physical science class, assuming that students took physical science before taking this Earth science class. If students haven't already learned about radioactive decay, the teacher may need to help them understand this topic before tackling ESS2.B-H1.

Although PS1.C-H2 is technically a physical science core idea, a school might even intentionally choose to have it addressed in an Earth science class rather than a physical science class because of its relevance to ESS2.B-H1 and other ideas in Earth science. As this example illustrates, the maps can help educators make decisions about the order in which courses should be taught and how ideas should be put together within a course.

One of the significant challenges with the *NGSS* and many other standards based on the *Framework* is that the standards in middle school and high school do not specify elements at each grade level, thus leaving it to districts, schools, or even individual teachers to plan multiyear course sequences. The connections and dependencies defined in the *NSTA Atlas* provide a great deal of guidance for educators making those decisions.

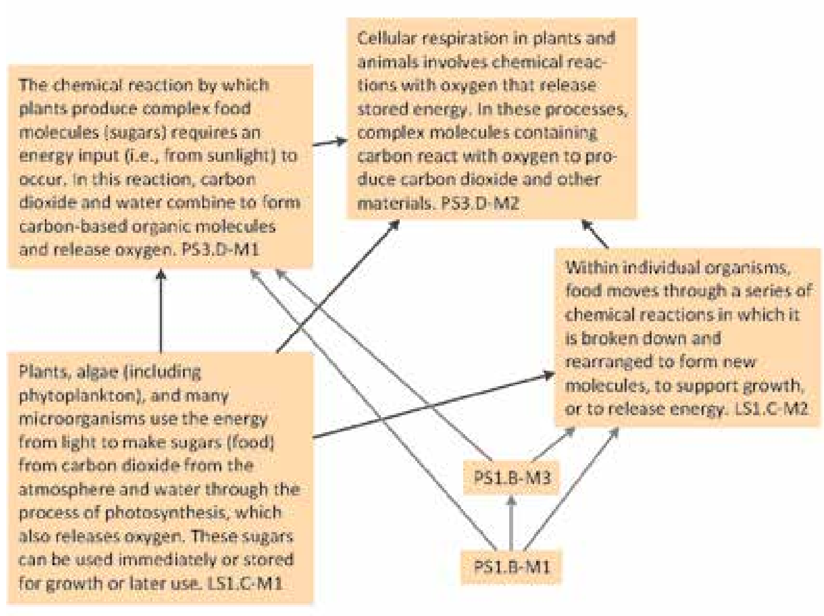


Figure 16. Excerpt From Map 4.2

The off-map elements between different disciplines, or different topics within a discipline, are particularly useful to examine when thinking about sequencing. For example, Figure 16 shows an excerpt from Map 4.2: Flow of Matter and Energy in Living Systems (LS1.C & LS2.B). Several elements in the middle school grade band on the map have off-map elements from PS1.B: Chemical Reactions supporting them. These connections suggest that it would be a good idea to have an instructional sequence where students learn about chemical reactions before learning about the flow of matter and energy in living systems. At the same time, there are two physical science core ideas (PS3.D-M1 and PS3.D-M2) that might make sense to teach in a biology class.

Conclusion

The maps that follow will help educators better understand the meaning of individual elements, the relationships between elements, and the sequencing of elements across a variety of time intervals from a series of lessons to a multiyear curriculum. Therefore, they are valuable tools for planning curriculum and instruction and developing instructional materials and assessments.

I believe this quote from the first volume of the *Atlas of Science Literacy* also applies to the purpose of the *NSTA Atlas*:

> Atlas *is intended to help educators understand what students can be expected to learn in different grades and to help them design coherent and comprehensive curricula, instruction, and assessment. Unless educators understand how ideas and skills develop over time and how they relate to one another, students will be left with nothing more than a heap of unrelated, poorly understood, and quickly forgotten facts, algorithms, and technical terms. (AAAS 2001, p. 3)*

Creating these maps has deepened my understanding of the standards, and I hope that using them will deepen your understanding as well.

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MAP KEY

Maps organize all of the elements from standards on a particular topic (e.g., Models, Patterns, or Definitions of Energy) on a single page. The elements from grades K–2 are at the bottom of the page and elements from grades 9–12 are at the top. Arrows connect elements to indicate how competency in one element can be useful in learning another. Thus, the map is a useful tool to help educators think about what each element means and how elements build on one another over time in order to plan curriculum, instruction, and assessment. This Map Key provides further details about all of the features on the maps.

Topic Code*: One or more codes in parentheses next to the title that identifies the topic of the map. For example, the topic code for Developing and Using Models is MOD. For the disciplinary core ideas (DCIs), the topic code is the identifier for the component ideas (e.g., PS1.A, LS1.C & LS2.B, and ESS2.C).

Title: The name of the map (topic) is featured at the top of the page.

Element Box: A rectangle on a map that contains the text of one of the bulleted statements (called "elements") from the foundation boxes and the *NGSS* appendixes.

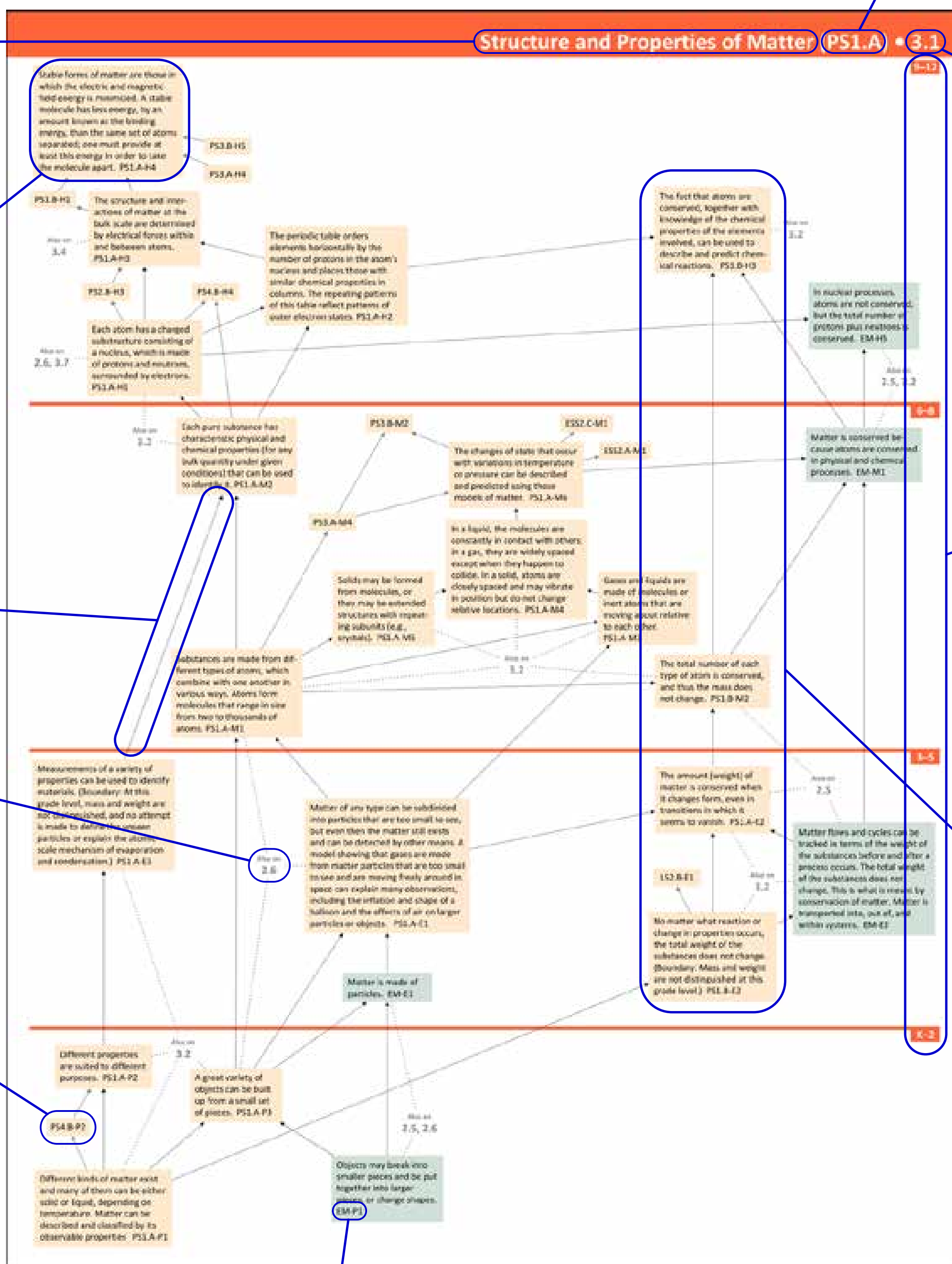
The color of a box indicates what type of element it is.

Blue = Practices
Green = Crosscutting Concepts
Orange = Core Ideas
Purple = Connections to the Nature of Science
Teal = Connections to Engineering
Gray = Performance Expectations

Arrow: A connection between two element boxes indicates that competency in one element is useful in learning to achieve the other element. Arrows always point at least somewhat upward.

Also On... Connection: This phrase followed by one or more map codes indicates that the connected element boxes also appear on those other maps.

Off-Map Element: An element code in a very small box on the map. It represents an element that can be found on other maps that is somewhat relevant to the topic of the map, but not so much so that the element needs to be on the map. Due to design constraints, an off-map element may appear more than once on a map and some connections to it may not be shown. The full text of it can be found on the page facing the map.



Map Code: A unique identifier for the map that appears in the top right-hand corner of the map. The number before the period identifies which chapter the map comes from, and the number after the period identifies which map it is in that chapter.

Grade Bands: The map is broken up into four grade bands. Grades K–2 (primary) is at the bottom of the map, with grades 3–5 (elementary), grades 6–8 (middle school), and grades 9–12 (high school) stacked up in order. How high or low an element appears within a grade band is **not** an indicator of what grade it belongs in or whether learning it should precede or follow learning other ideas in that grade band.

Strand: A chain of connected elements that run up the map and share a theme or involve the development of the same idea. The simplest strands are aligned in a vertical column connected by arrows, but sometimes a strand may fork and/or converge if it doesn't make sense to stack the elements in one straight line.

Element Code*: A unique identifier for an element. The first part of the code (before the dash) is the topic code. The second part of the code (after the dash) is a letter and a number. The letter indicates the element's grade band: *P* for primary (grades K–2), *E* for elementary (grades 3–5), *M* for middle school (grades 6–8), and *H* for high school (grades 9–12). The number that appears after the letter indicates the bullet position of the element in that particular grade band (1st, 2nd, 3rd, etc.). The code for an element appears in every box after the text for that element.

*** Note for Chapter 9:** This chapter contains maps of performance expectations (PEs). The boxes in these maps contain PEs instead of elements and use the PE code instead of an element code. In addition, these maps do not have a topic code.

LIST OF TOPIC CODES

Science and Engineering Practices

AQDP: Asking Questions and Defining Problems
MOD: Developing and Using Models
INV: Planning and Carrying Out Investigations
DATA: Analyzing and Interpreting Data
MATH: Using Mathematics and Computational Thinking
CEDS: Constructing Explanations and Designing Solutions
ARG: Engaging in Argument From Evidence
INFO: Obtaining, Evaluating, and Communicating Information

Crosscutting Concepts

PAT: Patterns
CE: Cause and Effect: Mechanism and Explanation
SPQ: Scale, Proportion, and Quantity
SYS: Systems and System Models
EM: Energy and Matter: Flows, Cycles, and Conservation
SF: Structure and Function
SC: Stability and Change

Disciplinary Core Ideas in Physical Science

PS1: Matter and Its Interactions

PS1.A: Structure and Properties of Matter
PS1.B: Chemical Reactions
PS1.C: Nuclear Processes

PS2: Motion and Stability: Forces and Interactions

PS2.A: Forces and Motion
PS2.B: Types of Interactions
PS2.C: Stability and Instability in Physical Systems

PS3: Energy

PS3.A: Definitions of Energy
PS3.B: Conservation of Energy and Energy Transfer
PS3.C: Relationship Between Energy and Forces
PS3.D: Energy in Chemical Processes and Everyday Life

PS4: Waves and Their Applications in Technologies for Information Transfer

PS4.A: Wave Properties
PS4.B: Electromagnetic Radiation
PS4.C: Information Technologies and Instrumentation

Disciplinary Core Ideas in Life Science

LS1: From Molecules to Organisms: Structures and Processes

LS1.A: Structure and Function
LS1.B: Growth and Development of Organisms
LS1.C: Organization for Matter and Energy Flow in Organisms
LS1.D: Information Processing

LS2: Ecosystems: Interactions, Energy, and Dynamics

LS2.A: Interdependent Relationships in Ecosystems
LS2.B: Cycles of Matter and Energy Transfer in Ecosystems
LS2.C: Ecosystem Dynamics, Functioning, and Resilience
LS2.D: Social Interactions and Group Behavior

LS3: Heredity: Inheritance and Variation of Traits

LS3.A: Inheritance of Traits
LS3.B: Variation of Traits

LS4: Biological Evolution: Unity and Diversity

LS4.A: Evidence of Common Ancestry and Diversity
LS4.B: Natural Selection
LS4.C: Adaptation
LS4.D: Biodiversity and Humans

Disciplinary Core Ideas in Earth and Space Science

ESS1: Earth's Place in the Universe

ESS1.A: The Universe and Its Stars
ESS1.B: Earth and the Solar System
ESS1.C: The History of Planet Earth

ESS2: Earth's Systems

ESS2.A: Earth Materials and Systems
ESS2.B: Plate Tectonics and Large-Scale System Interactions
ESS2.C: The Roles of Water in Earth's Surface Processes
ESS2.D: Weather and Climate
ESS2.E: Biogeology

ESS3: Earth and Human Activity

ESS3.A: Natural Resources
ESS3.B: Natural Hazards
ESS3.C: Human Impacts on Earth Systems
ESS3.D: Global Climate Change

Disciplinary Core Ideas in Engineering, Technology, and Applications of Science

ETS1: Engineering Design

ETS1.A: Defining and Delimiting an Engineering Problem
ETS1.B: Developing Possible Solutions
ETS1.C: Optimizing the Design Solution

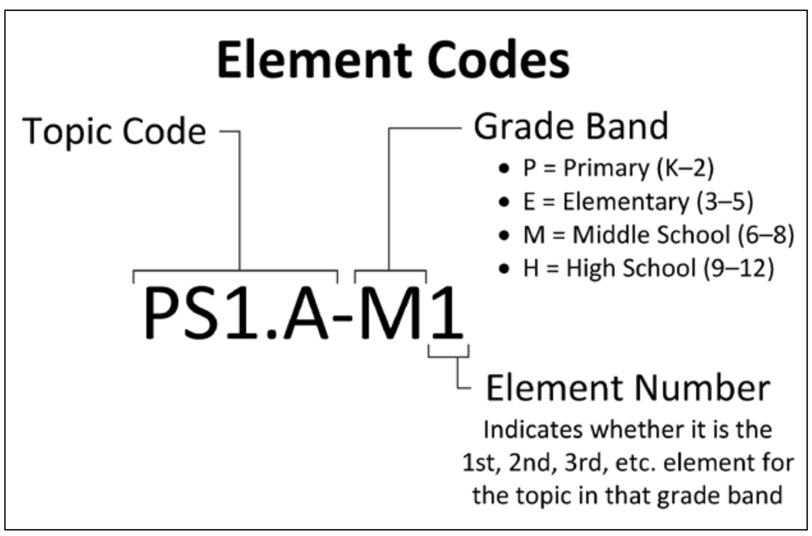
Connections to the Nature of Science

VOM: Scientific Investigations Use a Variety of Methods
BEE: Scientific Knowledge Is Based on Empirical Evidence
OTR: Scientific Knowledge Is Open to Revision in Light of New Evidence
ENP: Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena
WOK: Science Is a Way of Knowing
AOC: Scientific Knowledge Assumes an Order and Consistency in Natural Systems
HE: Science Is a Human Endeavor
AQAW: Science Addresses Questions About the Natural and Material World

Connections to Engineering, Technology, and Applications of Science

INTER: Interdependence of Science, Engineering, and Technology

INFLU: Influence of Science, Engineering, and Technology on Society and the Natural World



1.2: Developing and Using Models

Scientists construct mental and conceptual models of phenomena. Mental models are internal, personal, idiosyncratic, incomplete, unstable, and essentially functional. They serve the purpose of being a tool for thinking with, making predictions, and making sense of experience. Conceptual models, the focus of this section, are, in contrast, explicit representations that are in some ways analogous to the phenomena they represent. Conceptual models allow scientists and engineers to better visualize and understand a phenomenon under investigation or develop a possible solution to a design problem. Used in science and engineering as either structural, functional, or behavioral analogs, albeit simplified, conceptual models include diagrams, physical replicas, mathematical representations, analogies, and computer simulations. Although they do not correspond exactly to the more complicated entity being modeled, they do bring certain features into focus while minimizing or obscuring others. Because all models contain approximations and assumptions that limit the range of validity of their application and the precision of their predictive power, it is important to recognize their limitations.

Conceptual models are in some senses the external articulation of the mental models that scientists hold and are strongly interrelated with mental models. Building an understanding of models and their role in science helps students to construct and revise mental models of phenomena. Better mental models, in turn, lead to a deeper understanding of science and enhanced scientific reasoning.

Scientists use models (from here on, for the sake of simplicity, we use the term “models” to refer to conceptual models rather than mental models) to represent their current understanding of a system (or parts of a system) under study, to aid in the development of questions and explanations, and to communicate ideas to others. Some of the models used by scientists are mathematical; for example, the ideal gas law is an equation derived from the model of a gas as a set of point masses engaged in perfectly elastic collisions with each other and the walls of the container—which is a simplified model based on the atomic theory of matter. For more complex systems, mathematical representations of physical systems are used to create computer simulations, which enable scientists to predict the behavior of otherwise intractable systems—for example, the effects of increasing atmospheric levels of carbon dioxide on agriculture in different regions of the world. Models can be evaluated and refined through an iterative cycle of comparing their predictions with the real world and then adjusting them, thereby potentially yielding insights into the phenomenon being modeled.

Engineering makes use of models to analyze existing systems; this allows engineers to see where or under what conditions flaws might develop or to test possible solutions to a new problem. Engineers also use models to visualize a design and take it to a higher level of refinement, to communicate a design’s features to others, and as prototypes for testing design performance. Models, particularly modern computer simulations that encode relevant physical laws and properties of materials, can be especially helpful both in realizing and testing designs for structures, such as buildings, bridges, or aircraft, that are expensive to construct and that must survive extreme conditions that occur only on rare occasions. Other types of engineering problems also benefit from use of specialized computer-based simulations in their design and testing phases. But as in science, engineers who use models must be aware of their intrinsic limitations and test them against known situations to ensure that they are reliable.

(from *A Framework for K–12 Science Education,* pp. 56–58)

Text of the Off-Map Elements

AQDP-M3: Ask questions to determine relationships between independent and dependent variables and relationships in models.

INV-E3: Make observations and/or measurements to produce data to serve as the basis for evidence for an explanation of a phenomenon or test a design solution.

INV-E5: Test two different models of the same proposed object, tool, or process to determine which better meets criteria for success.

INV-H1: Plan an investigation or test a design individually and collaboratively to produce data to serve as the basis for evidence as part of building and revising models, supporting explanations for phenomena, or testing solutions to problems. Consider possible variables or effects and evaluate the confounding investigation’s design to ensure variables are controlled.

INV-H2: Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly.

INV-H6: Manipulate variables and collect data about a complex model of a proposed process or system to identify failure points or improve performance relative to criteria for success or other variables.

DATA-H1: Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution.

MATH-H1: Create and/or revise a computational model or simulation of a phenomenon, designed device, process, or system.

CEDS-E5: Generate and compare multiple solutions to a problem based on how well they meet the criteria and constraints of the design solution.

CEDS-M7: Undertake a design project, engaging in the design cycle, to construct and/or implement a solution that meets specific design criteria and constraints.

INFO-P4: Communicate information or design ideas and/or solutions with others in oral and/or written forms using models, drawings, writing, or numbers that provide detail about scientific ideas, practices, and/or design ideas.

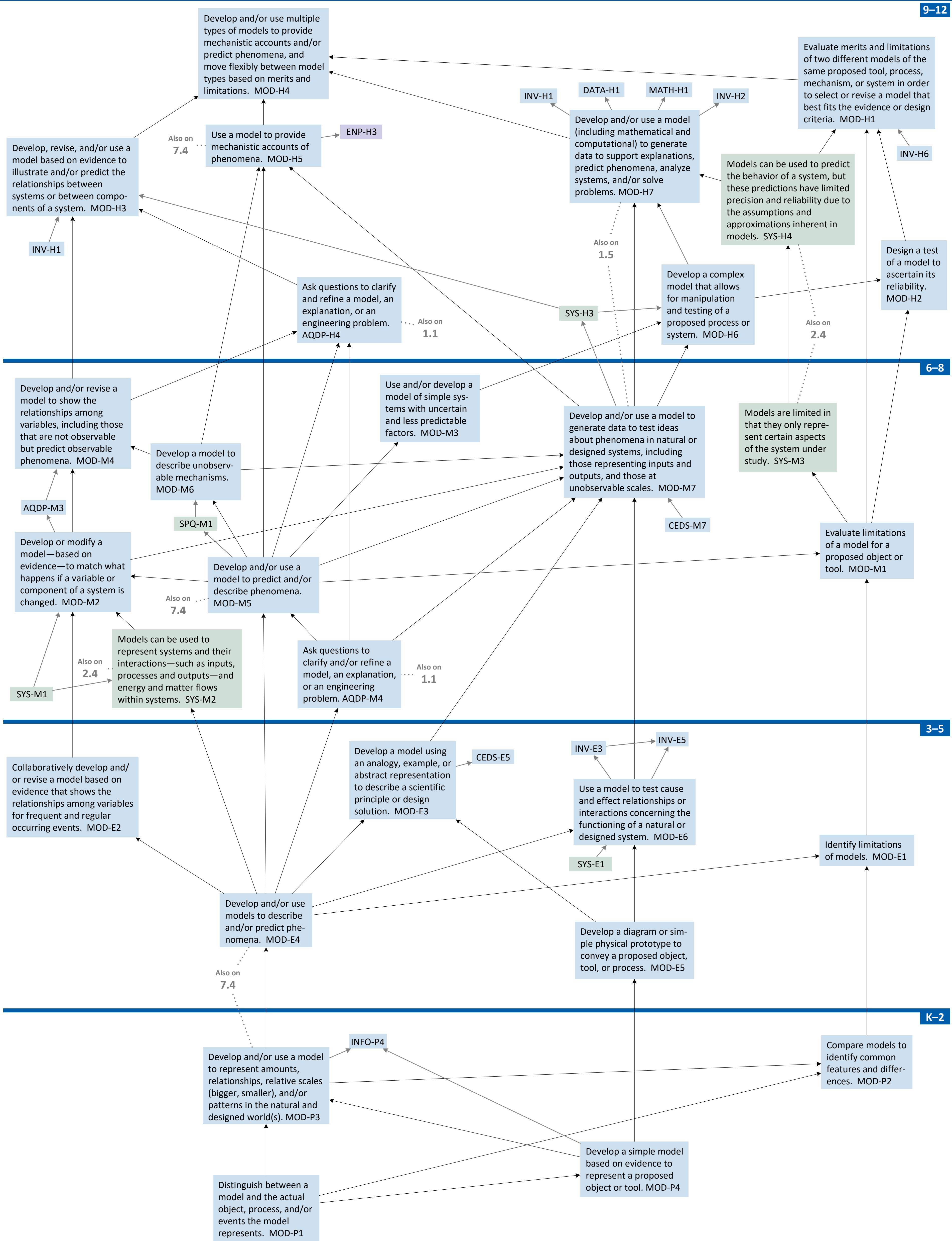
SPQ-M1: Time, space, and energy phenomena can be observed at various scales using models to study systems that are too large or too small.

SYS-E1: A system is a group of related parts that make up a whole and can carry out functions its individual parts cannot.

SYS-M1: Systems may interact with other systems; they may have sub-systems and be a part of larger complex systems.

SYS-H3: Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales.

ENP-H3: Models, mechanisms, and explanations collectively serve as tools in the development of a scientific theory.


9–12
Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena, and move flexibly between model types based on merits and limitations. MOD-H4
Evaluate merits and limitations of two different models of the same proposed tool, process, mechanism, or system in order to select or revise a model that best fits the evidence or design criteria. MOD-H1
INV-H1
DATA-H1
MATH-H1
INV-H2
Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems. MOD-H7
Also on 7.4
Use a model to provide mechanistic accounts of phenomena. MOD-H5
ENP-H3
Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. MOD-H3
INV-H6
Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models. SYS-H4
INV-H1
Also on 1.5
Design a test of a model to ascertain its reliability. MOD-H2
Ask questions to clarify and refine a model, an explanation, or an engineering problem. AQDP-H4
Also on 1.1
SYS-H3
Develop a complex model that allows for manipulation and testing of a proposed process or system. MOD-H6
Also on 2.4
6–8
Develop and/or revise a model to show the relationships among variables, including those that are not observable but predict observable phenomena. MOD-M4
Use and/or develop a model of simple systems with uncertain and less predictable factors. MOD-M3
Develop and/or use a model to generate data to test ideas about phenomena in natural or designed systems, including those representing inputs and outputs, and those at unobservable scales. MOD-M7
Models are limited in that they only represent certain aspects of the system under study. SYS-M3
Develop a model to describe unobservable mechanisms. MOD-M6
AQDP-M3
SPQ-M1
CEDS-M7
Develop or modify a model—based on evidence—to match what happens if a variable or component of a system is changed. MOD-M2
Develop and/or use a model to predict and/or describe phenomena. MOD-M5
Also on 7.4
Evaluate limitations of a model for a proposed object or tool. MOD-M1
Models can be used to represent systems and their interactions—such as inputs, processes and outputs—and energy and matter flows within systems. SYS-M2
Also on 2.4
SYS-M1
Ask questions to clarify and/or refine a model, an explanation, or an engineering problem. AQDP-M4
Also on 1.1
3–5
Develop a model using an analogy, example, or abstract representation to describe a scientific principle or design solution. MOD-E3
CEDS-E5
INV-E3
INV-E5
Collaboratively develop and/or revise a model based on evidence that shows the relationships among variables for frequent and regular occurring events. MOD-E2
Use a model to test cause and effect relationships or interactions concerning the functioning of a natural or designed system. MOD-E6
SYS-E1
Identify limitations of models. MOD-E1
Develop and/or use models to describe and/or predict phenomena. MOD-E4
Develop a diagram or simple physical prototype to convey a proposed object, tool, or process. MOD-E5
Also on 7.4
K–2
INFO-P4
Develop and/or use a model to represent amounts, relationships, relative scales (bigger, smaller), and/or patterns in the natural and designed world(s). MOD-P3
Compare models to identify common features and differences. MOD-P2
Develop a simple model based on evidence to represent a proposed object or tool. MOD-P4
Distinguish between a model and the actual object, process, and/or events the model represents. MOD-P1

2.5: Energy and Matter: Flows, Cycles, and Conservation

One of the great achievements of science is the recognition that, in any system, certain conserved quantities can change only through transfers into or out of the system. Such laws of conservation provide limits on what can occur in a system, whether human built or natural. This section focuses on two such quantities, matter and energy, whose conservation has important implications for the disciplines of science in this framework. The supply of energy and of each needed chemical element restricts a system's operation—for example, without inputs of energy (sunlight) and matter (carbon dioxide and water), a plant cannot grow. Hence, it is very informative to track the transfers of matter and energy within, into, or out of any system under study.

In many systems there also are cycles of various types. In some cases, the most readily observable cycling may be of matter—for example, water going back and forth between Earth's atmosphere and its surface and subsurface reservoirs. Any such cycle of matter also involves associated energy transfers at each stage, so to fully understand the water cycle, one must model not only how water moves between parts of the system but also the energy transfer mechanisms that are critical for that motion.

Consideration of energy and matter inputs, outputs, and flows or transfers within a system or process are equally important for engineering. A major goal in design is to maximize certain types of energy output while minimizing others, in order to minimize the energy inputs needed to achieve a desired task.

The ability to examine, characterize, and model the transfers and cycles of matter and energy is a tool that students can use across virtually all areas of science and engineering. And studying the *interactions* between matter and energy supports students in developing increasingly sophisticated conceptions of their role in any system. However, for this development to occur, there needs to be a common use of language about energy and matter across the disciplines in science instruction.

(from *A Framework for K–12 Science Education,* pp. 94–95)

Text of the Off-Map Elements

SPQ-P1: Relative scales allow objects and events to be compared and described (e.g., bigger and smaller; hotter and colder; faster and slower).

SYS-E2: A system can be described in terms of its components and their interactions.

SYS-M2: Models can be used to represent systems and their interactions—such as inputs, processes and outputs—and energy and matter flows within systems.

SYS-H2: When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models.

SYS-H3: Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales.

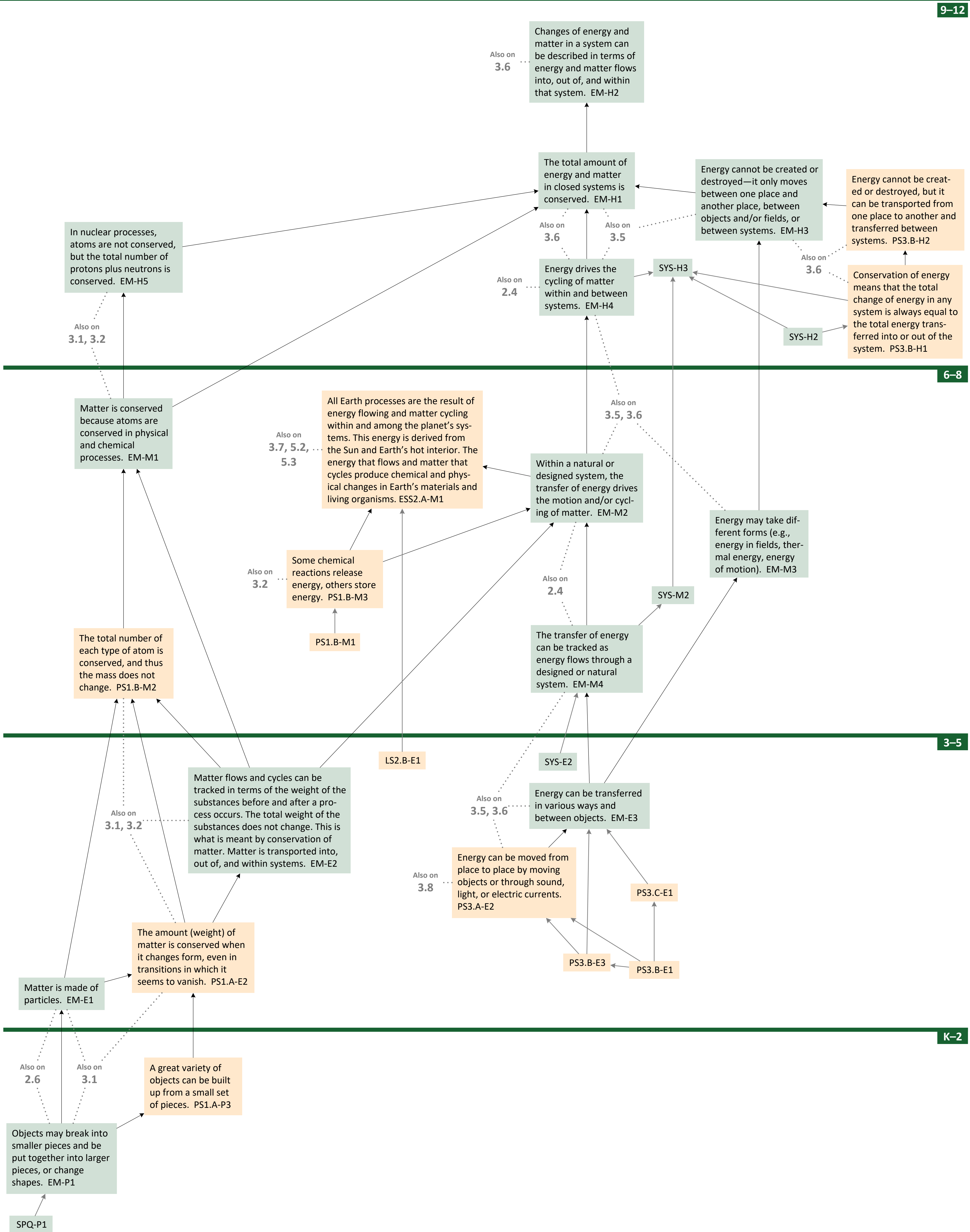
PS1.B-M1: Substances react chemically in characteristic ways. In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants.

PS3.B-E1: Energy is present whenever there are moving objects, sound, light, or heat. When objects collide, energy can be transferred from one object to another, thereby changing their motion. In such collisions, some energy is typically also transferred to the surrounding air; as a result, the air gets heated and sound is produced.

PS3.B-E3: Energy can also be transferred from place to place by electric currents, which can then be used locally to produce motion, sound, heat, or light. The currents may have been produced to begin with by transforming the energy of motion into electrical energy.

PS3.C-E1: When objects collide, the contact forces transfer energy so as to change the objects' motions.

LS2.B-E1: Matter cycles between the air and soil and among plants, animals, and microbes as these organisms live and die. Organisms obtain gases and water from the environment and release waste matter (gas, liquid, or solid) back into the environment.


9–12
Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. EM-H2
Also on 3.6
The total amount of energy and matter in closed systems is conserved. EM-H1
Also on 3.6
Also on 3.5
Energy cannot be created or destroyed—it only moves between one place and another place, between objects and/or fields, or between systems. EM-H3
Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. PS3.B-H2
Also on 3.6
In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved. EM-H5
Also on 3.1, 3.2
Also on 2.4
Energy drives the cycling of matter within and between systems. EM-H4
SYS-H3
Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system. PS3.B-H1
SYS-H2
6–8
Matter is conserved because atoms are conserved in physical and chemical processes. EM-M1
Also on 3.7, 5.2, 5.3
All Earth processes are the result of energy flowing and matter cycling within and among the planet's systems. This energy is derived from the Sun and Earth's hot interior. The energy that flows and matter that cycles produce chemical and physical changes in Earth's materials and living organisms. ESS2.A-M1
Also on 3.5, 3.6
Within a natural or designed system, the transfer of energy drives the motion and/or cycling of matter. EM-M2
Energy may take different forms (e.g., energy in fields, thermal energy, energy of motion). EM-M3
Also on 3.2
Some chemical reactions release energy, others store energy. PS1.B-M3
PS1.B-M1
Also on 2.4
SYS-M2
The total number of each type of atom is conserved, and thus the mass does not change. PS1.B-M2
The transfer of energy can be tracked as energy flows through a designed or natural system. EM-M4
3–5
LS2.B-E1
SYS-E2
Matter flows and cycles can be tracked in terms of the weight of the substances before and after a process occurs. The total weight of the substances does not change. This is what is meant by conservation of matter. Matter is transported into, out of, and within systems. EM-E2
Also on 3.1, 3.2
Also on 3.5, 3.6
Energy can be transferred in various ways and between objects. EM-E3
Also on 3.8
Energy can be moved from place to place by moving objects or through sound, light, or electric currents. PS3.A-E2
PS3.C-E1
The amount (weight) of matter is conserved when it changes form, even in transitions in which it seems to vanish. PS1.A-E2
Matter is made of particles. EM-E1
PS3.B-E3
PS3.B-E1
K–2
Also on 2.6
Also on 3.1
A great variety of objects can be built up from a small set of pieces. PS1.A-P3
Objects may break into smaller pieces and be put together into larger pieces, or change shapes. EM-P1
SPQ-P1

3.1: Structure and Properties of Matter

PS1: Matter and Its Interactions

PS1.A: Structure and Properties of Matter

How do particles combine to form the variety of matter one observes?

While too small to be seen with visible light, atoms have substructures of their own. They have a small central region or nucleus—containing protons and neutrons—surrounded by a larger region containing electrons. The number of protons in the atomic nucleus (atomic number) is the defining characteristic of each element; different isotopes of the same element differ in the number of neutrons only. Despite the immense variation and number of substances, there are only some 100 different stable elements.

Each element has characteristic chemical properties. The periodic table, a systematic representation of known elements, is organized horizontally by increasing atomic number and vertically by families of elements with related chemical properties. The development of the periodic table (which occurred well before atomic substructure was understood) was a major advance, as its patterns suggested and led to the identification of additional elements with particular properties. Moreover, the table's patterns are now recognized as related to the atom's outermost electron patterns, which play an important role in explaining chemical reactivity and bond formation, and the periodic table continues to be a useful way to organize this information.

The substructure of atoms determines how they combine and rearrange to form all of the world's substances. Electrical attractions and repulsions between charged particles (i.e., atomic nuclei and electrons) in matter explain the structure of atoms and the forces between atoms that cause them to form molecules (via chemical bonds), which range in size from two to thousands of atoms (e.g., in biological molecules such as proteins). Atoms also combine due to these forces to form extended structures, such as crystals or metals. The varied properties (e.g., hardness, conductivity) of the materials one encounters, both natural and manufactured, can be understood in terms of the atomic and molecular constituents present and the forces within and between them.

Within matter, atoms and their constituents are constantly in motion. The arrangement and motion of atoms vary in characteristic ways, depending on the substance and its current state (e.g., solid, liquid). Chemical composition, temperature, and pressure affect such arrangements and motions of atoms, as well as the ways in which they interact. Under a given set of conditions, the state and some properties (e.g., density, elasticity, viscosity) are the same for different bulk quantities of a substance, whereas other properties (e.g., volume, mass) provide measures of the size of the sample at hand.

Materials can be characterized by their intensive measureable properties. Different materials with different properties are suited to different uses. The ability to image and manipulate placement of individual atoms in tiny structures allows for the design of new types of materials with particular desired functionality (e.g., plastics, nanoparticles). Moreover, the modern explanation of how particular atoms influence the properties of materials or molecules is critical to understanding the physical and chemical functioning of biological systems.

(from *A Framework for K–12 Science Education*, pp. 106–107)

Text of the Off-Map Elements

PS1.B-H1: Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy.

PS2.B-H3: Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects.

PS3.A-M3: The term "heat" as used in everyday language refers both to thermal energy (the motion of atoms or molecules within a substance) and the transfer of that thermal energy from one object to another. In science, heat is used only for this second meaning; it refers to the energy transferred due to the temperature difference between two objects.

PS3.A-M4: The temperature of a system is proportional to the average internal kinetic energy and potential energy per atom or molecule (whichever is the appropriate building block for the system's material). The details of that relationship depend on the type of atom or molecule and the interactions among the atoms in the material. Temperature is not a direct measure of a system's total thermal energy. The total thermal energy (sometimes called the total internal energy) of a system depends jointly on the temperature, the total number of atoms in the system, and the state of the material.

PS3.A-H4: These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space.

PS3.B-M2: The amount of energy transfer needed to change the temperature of a matter sample by a given amount depends on the nature of the matter, the size of the sample, and the environment.

PS3.B-H5: Uncontrolled systems always evolve toward more stable states—that is, toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down).

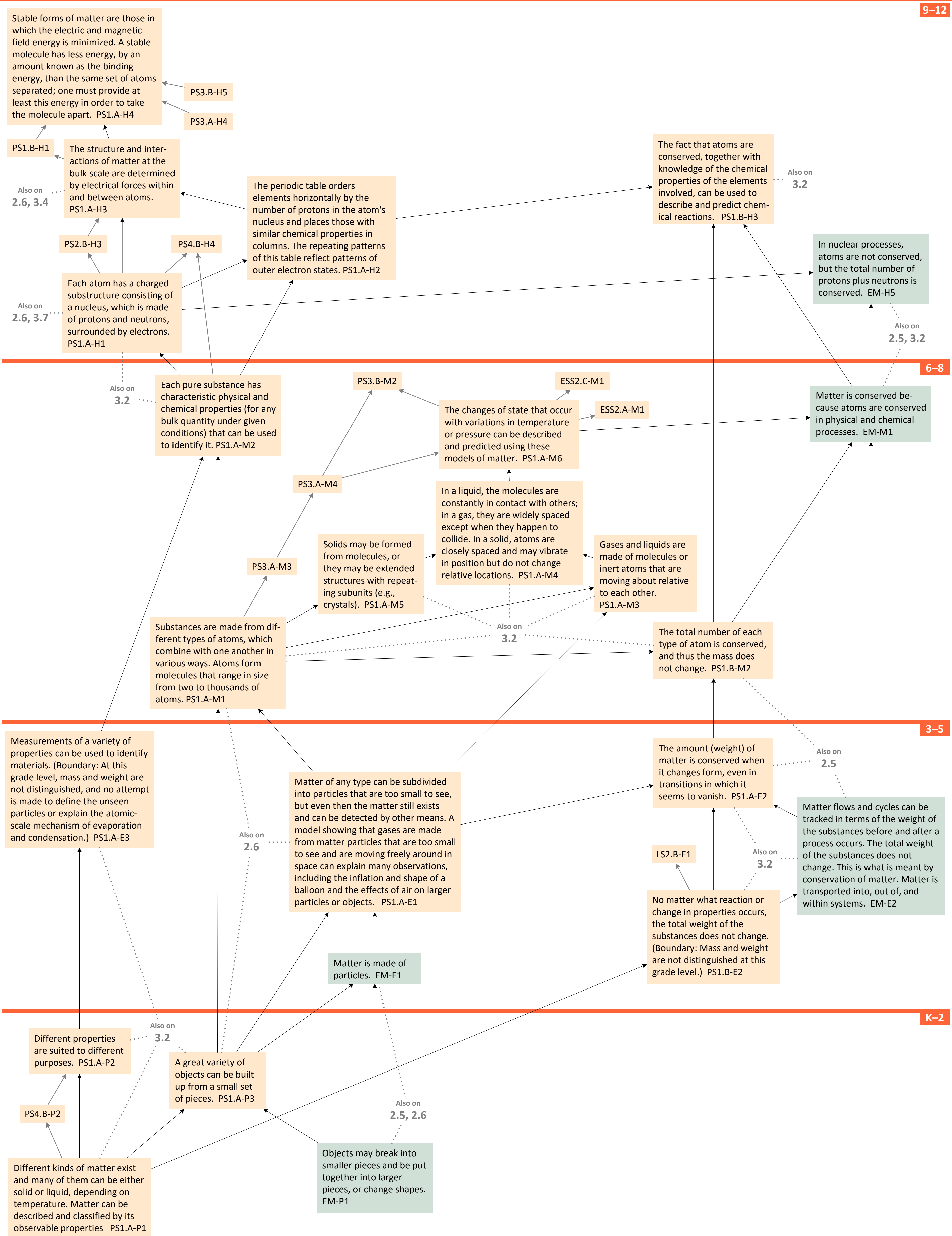
PS4.B-P2: Some materials allow light to pass through them, others allow only some light through, and still others block all the light and create a dark shadow on any surface beyond them, where the light cannot reach. Mirrors can be used to redirect a light beam. (Boundary: The idea that light travels from place to place is developed through experiences with light sources, mirrors, and shadows, but no attempt is made to discuss the speed of light.)

PS4.B-H4: Atoms of each element emit and absorb characteristic frequencies of light. These characteristics allow identification of the presence of an element, even in microscopic quantities.

LS2.B-E1: Matter cycles between the air and soil and among plants, animals, and microbes as these organisms live and die. Organisms obtain gases and water from the environment and release waste matter (gas, liquid, or solid) back into the environment.

ESS2.A-M1: All Earth processes are the result of energy flowing and matter cycling within and among the planet's systems. This energy is derived from the Sun and Earth's hot interior. The energy that flows and matter that cycles produce chemical and physical changes in Earth's materials and living organisms.

ESS2.C-M1: Water continually cycles among land, ocean, and atmosphere via transpiration, evaporation, condensation and crystallization, and precipitation, as well as downhill flows on land.


9–12
Stable forms of matter are those in which the electric and magnetic field energy is minimized. A stable molecule has less energy, by an amount known as the binding energy, than the same set of atoms separated; one must provide at least this energy in order to take the molecule apart. PS1.A-H4
PS3.B-H5
PS3.A-H4
PS1.B-H1
The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. PS1.A-H3
Also on 2.6, 3.4
The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states. PS1.A-H2
The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions. PS1.B-H3
Also on 3.2
PS2.B-H3
PS4.B-H4
In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved. EM-H5
Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons. PS1.A-H1
Also on 2.6, 3.7
Also on 2.5, 3.2
6–8
Also on 3.2
Each pure substance has characteristic physical and chemical properties (for any bulk quantity under given conditions) that can be used to identify it. PS1.A-M2
PS3.B-M2
ESS2.C-M1
The changes of state that occur with variations in temperature or pressure can be described and predicted using these models of matter. PS1.A-M6
ESS2.A-M1
Matter is conserved because atoms are conserved in physical and chemical processes. EM-M1
PS3.A-M4
In a liquid, the molecules are constantly in contact with others; in a gas, they are widely spaced except when they happen to collide. In a solid, atoms are closely spaced and may vibrate in position but do not change relative locations. PS1.A-M4
Solids may be formed from molecules, or they may be extended structures with repeating subunits (e.g., crystals). PS1.A-M5
PS3.A-M3
Gases and liquids are made of molecules or inert atoms that are moving about relative to each other. PS1.A-M3
Also on 3.2
Substances are made from different types of atoms, which combine with one another in various ways. Atoms form molecules that range in size from two to thousands of atoms. PS1.A-M1
The total number of each type of atom is conserved, and thus the mass does not change. PS1.B-M2
3–5
Measurements of a variety of properties can be used to identify materials. (Boundary: At this grade level, mass and weight are not distinguished, and no attempt is made to define the unseen particles or explain the atomic-scale mechanism of evaporation and condensation.) PS1.A-E3
Matter of any type can be subdivided into particles that are too small to see, but even then the matter still exists and can be detected by other means. A model showing that gases are made from matter particles that are too small to see and are moving freely around in space can explain many observations, including the inflation and shape of a balloon and the effects of air on larger particles or objects. PS1.A-E1
Also on 2.6
The amount (weight) of matter is conserved when it changes form, even in transitions in which it seems to vanish. PS1.A-E2
Also on 2.5
Matter flows and cycles can be tracked in terms of the weight of the substances before and after a process occurs. The total weight of the substances does not change. This is what is meant by conservation of matter. Matter is transported into, out of, and within systems. EM-E2
LS2.B-E1
Also on 3.2
No matter what reaction or change in properties occurs, the total weight of the substances does not change. (Boundary: Mass and weight are not distinguished at this grade level.) PS1.B-E2
Matter is made of particles. EM-E1
K–2
Also on 3.2
Different properties are suited to different purposes. PS1.A-P2
A great variety of objects can be built up from a small set of pieces. PS1.A-P3
PS4.B-P2
Also on 2.5, 2.6
Objects may break into smaller pieces and be put together into larger pieces, or change shapes. EM-P1
Different kinds of matter exist and many of them can be either solid or liquid, depending on temperature. Matter can be described and classified by its observable properties PS1.A-P1

4.2: Flow of Matter and Energy in Living Systems

LS1: From Molecules to Organisms: Structures and Processes

LS1.C: Organization for Matter and Energy Flow in Organisms

How do organisms obtain and use the matter and energy they need to live and grow?

Sustaining life requires substantial energy and matter inputs. The complex structural organization of organisms accommodates the capture, transformation, transport, release, and elimination of the matter and energy needed to sustain them. As matter and energy flow through different organizational levels—cells, tissues, organs, organisms, populations, communities, and ecosystems—of living systems, chemical elements are recombined in different ways to form different products. The result of these chemical reactions is that energy is transferred from one system of interacting molecules to another.

In most cases, the energy needed for life is ultimately derived from the sun through photosynthesis (although in some ecologically important cases, energy is derived from reactions involving inorganic chemicals in the absence of sunlight—e.g., chemosynthesis). Plants, algae (including phytoplankton), and other energy fixing microorganisms use sunlight, water, and carbon dioxide to facilitate photosynthesis, which stores energy, forms plant matter, releases oxygen, and maintains plants' activities. Plants and algae—being the resource base for animals, the animals that feed on animals, and the decomposers—are energy-fixing organisms that sustain the rest of the food web.

(from A *Framework for K–12 Science Education,* p. 147)

LS2: Ecosystems: Interactions, Energy, and Dynamics

LS2.B: Cycles of Matter and Energy Transfer in Ecosystems

How do matter and energy move through an ecosystem?

The cycling of matter and the flow of energy within ecosystems occur through interactions among different organisms and between organisms and the physical environment. All living systems need matter and energy. Matter fuels the energy releasing chemical reactions that provide energy for life functions and provides the material for growth and repair of tissue. Energy from light is needed for plants because the chemical reaction that produces plant matter from air and water requires an energy input to occur. Animals acquire matter from food, that is, from plants or other animals. The chemical elements that make up the molecules of organisms pass through food webs and the environment and are combined and recombined in different ways. At each level in a food web, some matter provides energy for life functions, some is stored in newly made structures, and much is discarded to the surrounding environment. Only a small fraction of the matter consumed at one level is captured by the next level up. As matter cycles and energy flows through living systems and between living systems and the physical environment, matter and energy are conserved in each change.

The carbon cycle provides an example of matter cycling and energy flow in ecosystems. Photosynthesis, digestion of plant matter, respiration, and decomposition are important components of the carbon cycle, in which carbon is exchanged between the biosphere, atmosphere, oceans, and geosphere through chemical, physical, geological, and biological processes.

(from *A Framework for K–12 Science Education*, pp. 152–153)

Text of the Off-Map Elements

PS1.A-P1: Different kinds of matter exist and many of them can be either solid or liquid, depending on temperature. Matter can be described and classified by its observable properties.

PS1.B-M1: Substances react chemically in characteristic ways. In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants.

PS1.B-M2: The total number of each type of atom is conserved, and thus the mass does not change.

PS1.B-M3: Some chemical reactions release energy, others store energy.

PS1.B-H1: Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy.

PS1.B-H3: The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.

PS3.B-E1: Energy is present whenever there are moving objects, sound, light, or heat. When objects collide, energy can be transferred from one object to another, thereby changing their motion. In such collisions, some energy is typically also transferred to the surrounding air; as a result, the air gets heated and sound is produced.

PS3.B-H1: Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system.

PS3.B-H2: Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems.

PS3.D-H4: Although energy cannot be destroyed, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment.

LS1.A-P1: All organisms have external parts. Different animals use their body parts in different ways to see, hear, grasp objects, protect themselves, move from place to place, and seek, find, and take in food, water, and air. Plants also have different parts (roots, stems, leaves, flowers, fruits) that help them survive and grow.

LS1.A-E1: Plants and animals have both internal and external structures that serve various functions in growth, survival, behavior, and reproduction.

LS1.A-M1: All living things are made up of cells, which is the smallest unit that can be said to be alive. An organism may consist of one single cell (unicellular) or many different numbers and types of cells (multicellular).

ESS2.A-M1: All Earth processes are the result of energy flowing and matter cycling within and among the planet's systems. This energy is derived from the Sun and Earth's hot interior. The energy that flows and matter that cycles produce chemical and physical changes in Earth's materials and living organisms.

9–12

Photosynthesis and cellular respiration (including anaerobic processes) provide most of the energy for life processes. LS2.B-H1

Photosynthesis and cellular respiration are important components of the carbon cycle, in which carbon is exchanged among the biosphere, atmosphere, oceans, and geosphere through chemical, physical, geologic, and biological processes. LS2.B-H3

Plants or algae form the lowest level of the food web. At each link upward in a food web, only a small fraction of the matter consumed at the lower level is transferred upward, to produce growth and release energy in cellular respiration at the higher level. Given this inefficiency, there are generally fewer organisms at higher levels of a food web. Some matter reacts to release energy for life functions, some matter is stored in newly made structures, and much is discarded. The chemical elements that make up the molecules of organisms pass through food webs and into and out of the atmosphere and soil, and they are combined and recombined in different ways. At each link in an ecosystem, matter and energy are conserved. LS2.B-H2

PS3.D-H4

Also on 4.3

PS3.B-H2

The main way that solar energy is captured and stored on Earth is through the complex chemical process known as photosynthesis. PS3.D-H2

Also on 3.7

As a result of these chemical reactions, energy is transferred from one system of interacting molecules to another. Cellular respiration is a chemical process in which the bonds of food molecules and oxygen molecules are broken and new compounds are formed that can transport energy to muscles. Cellular respiration also releases the energy needed to maintain body temperature despite ongoing energy transfer to the surrounding environment. LS1.C-H4

PS3.B-H1

The process of photosynthesis converts light energy to stored chemical energy by converting carbon dioxide plus water into sugars plus released oxygen. LS1.C-H1

The sugar molecules thus formed contain carbon, hydrogen, and oxygen; their hydrocarbon backbones are used to make amino acids and other carbon-based molecules that can be assembled into larger molecules (such as proteins or DNA), used for example to form new cells. LS1.C-H2

PS1.B-H1

PS1.B-H3

As matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products. LS1.C-H3

6–8

ESS2.A-M1

The chemical reaction by which plants produce complex food molecules (sugars) requires an energy input (i.e., from sunlight) to occur. In this reaction, carbon dioxide and water combine to form carbon-based organic molecules and release oxygen. PS3.D-M1

Cellular respiration in plants and animals involves chemical reactions with oxygen that release stored energy. In these processes, complex molecules containing carbon react with oxygen to produce carbon dioxide and other materials. PS3.D-M2

LS1.A-M1

Within individual organisms, food moves through a series of chemical reactions in which it is broken down and rearranged to form new molecules, to support growth, or to release energy. LS1.C-M2

Food webs are models that demonstrate how matter and energy are transferred between producers, consumers, and decomposers as the three groups interact within an ecosystem. Transfers of matter into and out of the physical environment occur at every level. Decomposers recycle nutrients from dead plant or animal matter back to the soil in terrestrial environments or to the water in aquatic environments. The atoms that make up the organisms in an ecosystem are cycled repeatedly between the living and nonliving parts of the ecosystem. LS2.B-M1

Also on 4.3

PS1.B-M2

Plants, algae (including phytoplankton), and many microorganisms use the energy from light to make sugars (food) from carbon dioxide from the atmosphere and water through the process of photosynthesis, which also releases oxygen. These sugars can be used immediately or stored for growth or later use. LS1.C-M1

Also on 3.7

PS1.B-M3

PS1.B-M1

3–5

Matter cycles between the air and soil and among plants, animals, and microbes as these organisms live and die. Organisms obtain gases and water from the environment and release waste matter (gas, liquid, or solid) back into the environment. LS2.B-E1

Also on 5.2

The energy released [from] food was once energy from the Sun that was captured by plants in the chemical process that forms plant matter (from air and water). PS3.D-E2

The food of almost any kind of animal can be traced back to plants. Organisms are related in food webs in which some animals eat plants for food and other animals eat the animals that eat plants. Some organisms, such as fungi and bacteria, break down dead organisms (both plants or plant parts and animals) and therefore operate as "decomposers." Decomposition eventually restores (recycles) some materials back to the soil. Organisms can survive only in environments in which their particular needs are met. A healthy ecosystem is one in which multiple species of different types are each able to meet their needs in a relatively stable web of life. Newly introduced species can damage the balance of an ecosystem. LS2.A-E1

Also on 4.3

Also on 4.4

Plants acquire their material for growth chiefly from air and water. LS1.C-E2

Food provides animals with the materials they need for body repair and growth and the energy they need to maintain body warmth and for motion. LS1.C-E1

LS1.A-E1

PS3.B-E1

K–2

LS1.A-P1

Also on 3.7, 4.3

PS1.A-P1

All animals need food in order to live and grow. They obtain their food from plants or from other animals. Plants need water and light to live and grow. LS1.C-P1

Also on 4.3

Plants depend on water and light to grow. LS2.A-P1

5.4: Weather and Climate

ESS2: Earth's Systems

ESS2.C: The Roles of Water in Earth's Surface Processes

How do the properties and movements of water shape Earth's surface and affect its systems?

Earth is often called the water planet because of the abundance of liquid water on its surface and because water's unique combination of physical and chemical properties is central to Earth's dynamics. These properties include water's exceptional capacity to absorb, store, and release large amounts of energy as it changes state; to transmit sunlight; to expand upon freezing; to dissolve and transport many materials; and to lower the viscosities and freezing points of the material when mixed with fluid rocks in the mantle. Each of these properties plays a role in how water affects other Earth systems (e.g., ice expansion contributes to rock erosion, ocean thermal capacity contributes to moderating temperature variations).

Water is found almost everywhere on Earth, from high in the atmosphere (as water vapor and ice crystals) to low in the atmosphere (precipitation, droplets in clouds) to mountain snowcaps and glaciers (solid) to running liquid water on the land, ocean, and underground. Energy from the sun and the force of gravity drive the continual cycling of water among these reservoirs. Sunlight causes evaporation and propels oceanic and atmospheric circulation, which transports water around the globe. Gravity causes precipitation to fall from clouds and water to flow downward on the land through watersheds.

About 97 percent of Earth's water is in the ocean, and most fresh water is contained in glaciers or underground aquifers; only a tiny fraction of Earth's water is found in streams, lakes, and rivers. The relative availability of water is a major factor in distinguishing habitats for different living organisms.

Water participates both in the dissolution and formation of Earth's materials. The downward flow of water, both in liquid and solid form, shapes landscapes through the erosion, transport, and deposition of sediment. Shoreline waves in the ocean and lakes are powerful agents of erosion. Over millions of years, coastlines have moved back and forth over continents by hundreds of kilometers, largely due to the rise and fall of sea level as the climate changed (e.g., ice ages).

(from *A Framework for K–12 Science Education,* pp. 184)

ESS2.D: Weather and Climate

What regulates weather and climate?

Weather, which varies from day to day and seasonally throughout the year, is the condition of the atmosphere at a given place and time. Climate is longer term and location sensitive; it is the range of a region's weather over 1 year or many years, and, because it depends on latitude and geography, it varies from place to place. Weather and climate are shaped by complex interactions involving sunlight, the ocean, the atmosphere, ice, landforms, and living things. These interactions can drive changes that occur over multiple time scales—from days, weeks, and months for weather to years, decades, centuries, and beyond—for climate.

The ocean exerts a major influence on weather and climate. It absorbs and stores large amounts of energy from the sun and releases it very slowly; in that way, the ocean moderates and stabilizes global climates. Energy is redistributed globally through ocean currents (e.g., the Gulf Stream) and also through atmospheric circulation (winds). Sunlight heats Earth's surface, which in turn heats the atmosphere. The resulting temperature patterns, together with Earth's rotation and the configuration of continents and oceans, control the large-scale patterns of atmospheric circulation. Winds gain energy and water vapor content as they cross hot ocean regions, which can lead to tropical storms.

The "greenhouse effect" keeps Earth's surface warmer than it would be otherwise. To maintain any average temperature over time, energy inputs from the sun and from radioactive decay in Earth's interior must be balanced by energy loss due to radiation from the upper atmosphere. However, what determines the temperature at which this balance occurs is a complex set of absorption, reflection, transmission, and redistribution processes in the atmosphere and oceans that determine how long energy stays trapped in these systems before being radiated away. Certain gases in the atmosphere (water vapor, carbon dioxide, methane, and nitrous oxides), which absorb and retain energy that radiates from Earth's surface, essentially insulate the planet. Without this phenomenon, Earth's surface would be too cold to be habitable. However, changes in the atmosphere, such as increases in carbon dioxide, can make regions of Earth too hot to be habitable by many species.

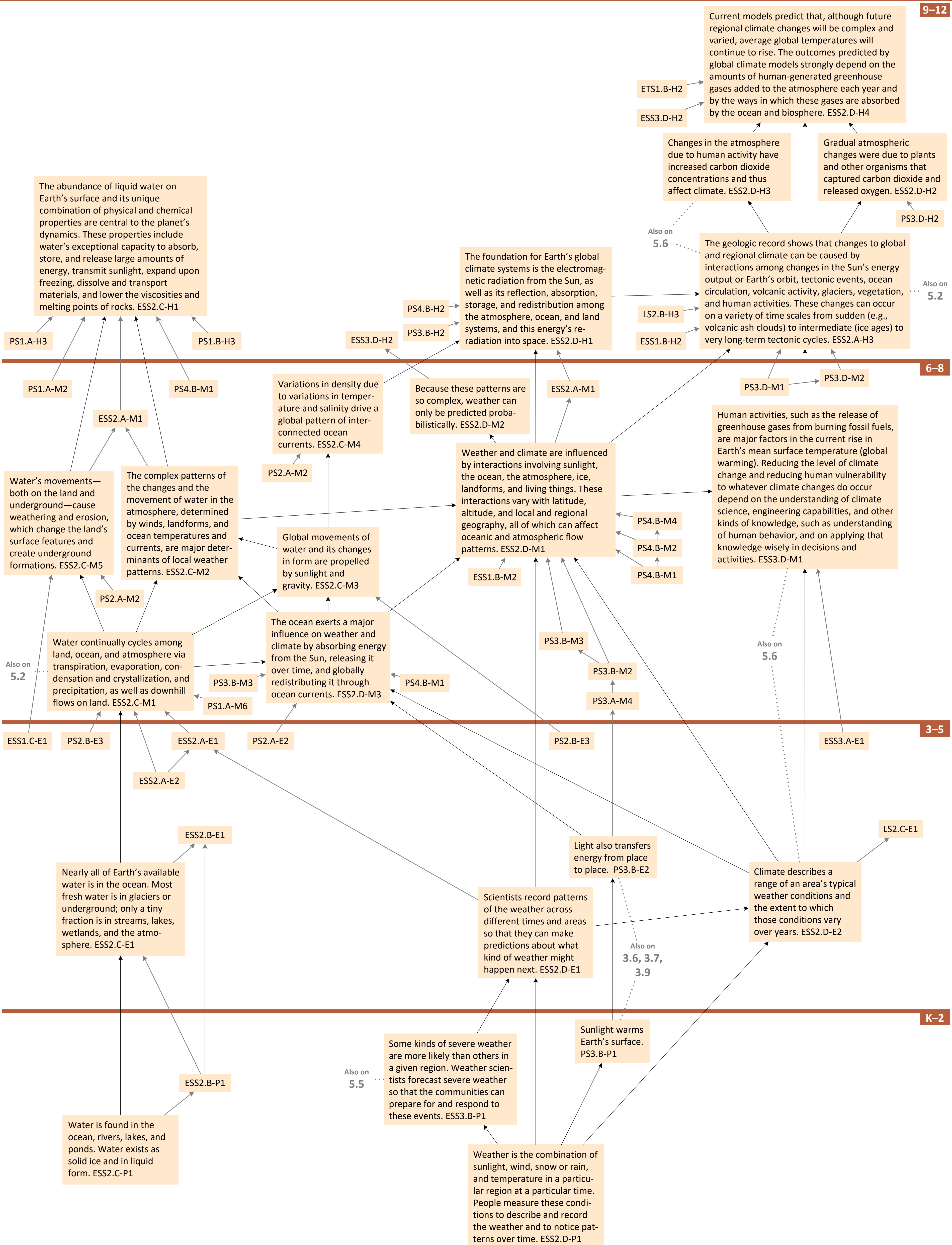
Climate changes, which are defined as significant and persistent changes in an area's average or extreme weather conditions, can occur if any of Earth's systems change (e.g., composition of the atmosphere, reflectivity of Earth's surface). Positive feedback loops can amplify the impacts of these effects and trigger relatively abrupt changes in the climate system; negative feedback loops tend to maintain stable climate conditions.

Some climate changes in Earth's history were rapid shifts (caused by events, such as volcanic eruptions and meteoric impacts, that suddenly put a large amount of particulate matter into the atmosphere or by abrupt changes in ocean currents); other climate changes were gradual and longer term—due, for example, to solar output variations, shifts in the tilt of Earth's axis, or atmospheric change due to the rise of plants and other life forms that modified the atmosphere via photosynthesis. Scientists can infer these changes from geological evidence.

Natural factors that cause climate changes over human time scales (tens or hundreds of years) include variations in the sun's energy output, ocean circulation patterns, atmospheric composition, and volcanic activity. (See ESS3.D for a detailed discussion of human activities and global climate change.) When ocean currents change their flow patterns, such as during El Niño Southern Oscillation conditions, some global regions become warmer or wetter and others become colder or drier. Cumulative increases in the atmospheric concentration of carbon dioxide and other greenhouse gases, whether arising from natural sources or human industrial activity (see ESS3.D), increase the capacity of Earth to retain energy. Changes in surface or atmospheric reflectivity change the amount of energy from the sun that enters the planetary system. Icy surfaces, clouds, aerosols, and larger particles in the atmosphere, such as from volcanic ash, reflect sunlight and thereby decrease the amount of solar energy that can enter the weather/climate system. Conversely, dark surfaces (e.g., roads, most buildings) absorb sunlight and thus increase the energy entering the system.

(from *A Framework for K–12 Science Education,* pp. 186–187)

The text of the off-map elements for this map can be found on page 182.


9–12
Current models predict that, although future regional climate changes will be complex and varied, average global temperatures will continue to rise. The outcomes predicted by global climate models strongly depend on the amounts of human-generated greenhouse gases added to the atmosphere each year and by the ways in which these gases are absorbed by the ocean and biosphere. ESS2.D-H4
ETS1.B-H2
ESS3.D-H2
Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate. ESS2.D-H3
Gradual atmospheric changes were due to plants and other organisms that captured carbon dioxide and released oxygen. ESS2.D-H2
PS3.D-H2
Also on 5.6
The geologic record shows that changes to global and regional climate can be caused by interactions among changes in the Sun's energy output or Earth's orbit, tectonic events, ocean circulation, volcanic activity, glaciers, vegetation, and human activities. These changes can occur on a variety of time scales from sudden (e.g., volcanic ash clouds) to intermediate (ice ages) to very long-term tectonic cycles. ESS2.A-H3
Also on 5.2
LS2.B-H3
ESS1.B-H2
The abundance of liquid water on Earth's surface and its unique combination of physical and chemical properties are central to the planet's dynamics. These properties include water's exceptional capacity to absorb, store, and release large amounts of energy, transmit sunlight, expand upon freezing, dissolve and transport materials, and lower the viscosities and melting points of rocks. ESS2.C-H1
PS1.A-H3
PS1.B-H3
The foundation for Earth's global climate systems is the electromagnetic radiation from the Sun, as well as its reflection, absorption, storage, and redistribution among the atmosphere, ocean, and land systems, and this energy's reradiation into space. ESS2.D-H1
PS4.B-H2
PS3.B-H2
ESS3.D-H2
6–8
PS1.A-M2
PS4.B-M1
ESS2.A-M1
Variations in density due to variations in temperature and salinity drive a global pattern of interconnected ocean currents. ESS2.C-M4
Because these patterns are so complex, weather can only be predicted probabilistically. ESS2.D-M2
ESS2.A-M1
PS3.D-M1
PS3.D-M2
Human activities, such as the release of greenhouse gases from burning fossil fuels, are major factors in the current rise in Earth's mean surface temperature (global warming). Reducing the level of climate change and reducing human vulnerability to whatever climate changes do occur depend on the understanding of climate science, engineering capabilities, and other kinds of knowledge, such as understanding of human behavior, and on applying that knowledge wisely in decisions and activities. ESS3.D-M1
Water's movements—both on the land and underground—cause weathering and erosion, which change the land's surface features and create underground formations. ESS2.C-M5
The complex patterns of the changes and the movement of water in the atmosphere, determined by winds, landforms, and ocean temperatures and currents, are major determinants of local weather patterns. ESS2.C-M2
PS2.A-M2
Global movements of water and its changes in form are propelled by sunlight and gravity. ESS2.C-M3
Weather and climate are influenced by interactions involving sunlight, the ocean, the atmosphere, ice, landforms, and living things. These interactions vary with latitude, altitude, and local and regional geography, all of which can affect oceanic and atmospheric flow patterns. ESS2.D-M1
PS4.B-M4
PS4.B-M2
PS4.B-M1
ESS1.B-M2
PS2.A-M2
Also on 5.2
Water continually cycles among land, ocean, and atmosphere via transpiration, evaporation, condensation and crystallization, and precipitation, as well as downhill flows on land. ESS2.C-M1
PS3.B-M3
PS1.A-M6
The ocean exerts a major influence on weather and climate by absorbing energy from the Sun, releasing it over time, and globally redistributing it through ocean currents. ESS2.D-M3
PS4.B-M1
PS3.B-M3
PS3.B-M2
PS3.A-M4
Also on 5.6
3–5
ESS1.C-E1
PS2.B-E3
ESS2.A-E1
PS2.A-E2
PS2.B-E3
ESS3.A-E1
ESS2.A-E2
ESS2.B-E1
LS2.C-E1
Nearly all of Earth's available water is in the ocean. Most fresh water is in glaciers or underground; only a tiny fraction is in streams, lakes, wetlands, and the atmosphere. ESS2.C-E1
Light also transfers energy from place to place. PS3.B-E2
Climate describes a range of an area's typical weather conditions and the extent to which those conditions vary over years. ESS2.D-E2
Scientists record patterns of the weather across different times and areas so that they can make predictions about what kind of weather might happen next. ESS2.D-E1
Also on 3.6, 3.7, 3.9
K–2
Sunlight warms Earth's surface. PS3.B-P1
Some kinds of severe weather are more likely than others in a given region. Weather scientists forecast severe weather so that the communities can prepare for and respond to these events. ESS3.B-P1
Also on 5.5
ESS2.B-P1
Water is found in the ocean, rivers, lakes, and ponds. Water exists as solid ice and in liquid form. ESS2.C-P1
Weather is the combination of sunlight, wind, snow or rain, and temperature in a particular region at a particular time. People measure these conditions to describe and record the weather and to notice patterns over time. ESS2.D-P1

6.1: Defining and Delimiting an Engineering Problem

ETS1: Engineering Design

ETS1.A: Defining and Delimiting an Engineering Problem

What is a design for?
What are the criteria and constraints of a successful solution?

The engineering design process begins with the identification of a problem to solve and the specification of clear goals, or criteria, that the final product or system must meet. Criteria, which typically reflect the needs of the expected end-user of a technology or process, address such things as how the product or system will function (what job it will perform and how), its durability, and its cost. Criteria should be quantifiable whenever possible and stated so that one can tell if a given design meets them.

Engineers must contend with a variety of limitations, or constraints, when they engage in design. Constraints, which frame the salient conditions under which the problem must be solved, may be physical, economic, legal, political, social, ethical, aesthetic, or related to time and place. In terms of quantitative measurements, constraints may include limits on cost, size, weight, or performance, for example. And although constraints place restrictions on a design, not all of them are permanent or absolute.

(from *A Framework for K–12 Science Education,* pp. 204–205)

Text of the Off-Map Element

ETS1.C-P1: Because there is always more than one possible solution to a problem, it is useful to compare and test designs.

9–12

Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities. ETS1.A-H2

Also on 8.2

Evaluate competing design solutions to a real-world problem based on scientific ideas and principles, empirical evidence, and logical arguments regarding relevant factors (e.g. economic, societal, environmental, ethical considerations). ARG-H6

Design, evaluate, and/or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. CEDS-H5

Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. ETS1.A-H1

When evaluating solutions it is important to take into account a range of constraints including cost, safety, reliability, and aesthetics and to consider social, cultural, and environmental impacts. ETS1.B-H1

Also on 1.7

Also on 6.2

Also on 8.1

Define a design problem that involves the development of a process or system with interacting components and criteria and constraints that may include social, technical and/or environmental considerations. AQDP-H8

Manipulate variables and collect data about a complex model of a proposed process or system to identify failure points or improve performance relative to criteria for success or other variables. INV-H6

Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. ETS1.C-H1

6–8

Evaluate competing design solutions based on jointly developed and agreed-upon design criteria. ARG-M5

The iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution. ETS1.C-M2

There are systematic processes for evaluating solutions with respect to how well they meet criteria and constraints of a problem. ETS1.B-M2

Also on 1.1, 1.6

Also on 1.6, 6.2

Optimize performance of a design by prioritizing criteria, making tradeoffs, testing, revising, and re-testing. CEDS-M8

Also on 1.3

Also on 6.2

The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that is likely to limit possible solutions. ETS1.A-M1

Undertake a design project, engaging in the design cycle, to construct and/or implement a solution that meets specific design criteria and constraints. CEDS-M7

Define a design problem that can be solved through the development of an object, tool, process or system and includes multiple criteria and constraints, including scientific knowledge that may limit possible solutions. AQDP-M8

Also on 8.1

Collect data about the performance of a proposed object, tool, process, or system under a range of conditions. INV-M5

A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. ETS1.B-M1

3–5

Make a claim about the merit of a solution to a problem by citing relevant evidence about how it meets the criteria and constraints of the problem. ARG-E6

Possible solutions to a problem are limited by available materials and resources (constraints). The success of a designed solution is determined by considering the desired features of a solution (criteria). Different proposals for solutions can be compared on the basis of how well each one meets the specified criteria for success or how well each takes the constraints into account. ETS1.A-E1

Tests are often designed to identify failure points or difficulties, which suggest the elements of the design that need to be improved. ETS1.B-E2

Also on 6.2

Generate and compare multiple solutions to a problem based on how well they meet the criteria and constraints of the design solution. CEDS-E5

Define a simple design problem that can be solved through the development of an object, tool, process, or system and includes several criteria for success and constraints on materials, time, or cost. AQDP-E5

Also on 1.7

Test two different models of the same proposed object, tool, or process to determine which better meets criteria for success. INV-E5

Research on a problem should be carried out before beginning to design a solution. Testing a solution involves investigating how well it performs under a range of likely conditions. ETS1.B-E1

Also on 1.6

K–2

Generate and/or compare multiple solutions to a problem. CEDS-P3

Also on 1.6, 6.2, 8.1

Also on 1.1, 1.6

Make a claim about the effectiveness of an object, tool, or solution that is supported by relevant evidence. ARG-P7

Also on 1.3

ETS1.C-P1

Asking questions, making observations, and gathering information are helpful in thinking about problems. ETS1.A-P2

Use tools and/or materials to design and/or build a device that solves a specific problem or a solution to a specific problem. CEDS-P2

Make observations (first-hand or from media) and/or measurements of a proposed object or tool or solution to determine if it solves a problem or meets a goal. INV-P5

Before beginning to design a solution, it is important to clearly understand the problem. ETS1.A-P3

Also on 1.3

Define a simple problem that can be solved through the development of a new or improved object or tool. AQDP-P3

A situation that people want to change or create can be approached as a problem to be solved through engineering. Such problems may have many acceptable solutions. ETS1.A-P1

Also on 6.2

7.4: Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena

Science models, laws, mechanisms, and theories explain natural phenomena and provide us with our understandings of the natural world. These types of knowledge are different but equally important, and they should be consistent with each other. Of particular importance is the nature and relationship between theories and laws. *Laws* are statements or descriptions of the relationships among observable phenomena. Boyle's law, which relates the pressure of a gas to its volume at a constant temperature, is a case in point. *Theories,* by contrast, are inferred explanations for observable phenomena. The kinetic molecular theory, which explains Boyle's law, is one example. At a very basic level, theories and laws are more sophisticated versions of observations and inferences, which are critical components in the development of all scientific knowledge. Scientists do not usually formulate theories in the hope that one day they will acquire the status of a scientific law. Indeed, Boyle's law existed at least 50 years before the emergence of kinetic molecular theory. A more contemporary example is the law of inertia, which still has no established theory to explain the observed natural phenomena. The understanding of the difference between theories and laws and that one does not mature into the other is especially important when hearing language such as "evolution is just a theory, not a law." That statement implies that the theory has not yet developed into a scientific law or is regarded as lesser than a law. Theories, laws, models, and mechanisms are different types of knowledge, but they are all very important to science.

(contributed by Norman G. Lederman, Fouad Abd-El-Khalick, Ryan Summers, and Dawnne LePretre)

Text of the Off-Map Elements

MOD-P4: Develop a simple model based on evidence to represent a proposed object or tool.

MOD-H4: Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena, and move flexibly between model types based on merits and limitations.

CE-P1: Simple tests can be designed to gather evidence to support or refute student ideas about causes.

SPQ-M4: Scientific relationships can be represented through the use of algebraic expressions and equations.

SYS-M2: Models can be used to represent systems and their interactions—such as inputs, processes and outputs—and energy and matter flows within systems.

SYS-H3: Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales.

PS2.A-M1: For any pair of interacting objects, the force exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first, but in the opposite direction (Newton's third law).

PS2.A-M2: The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion.

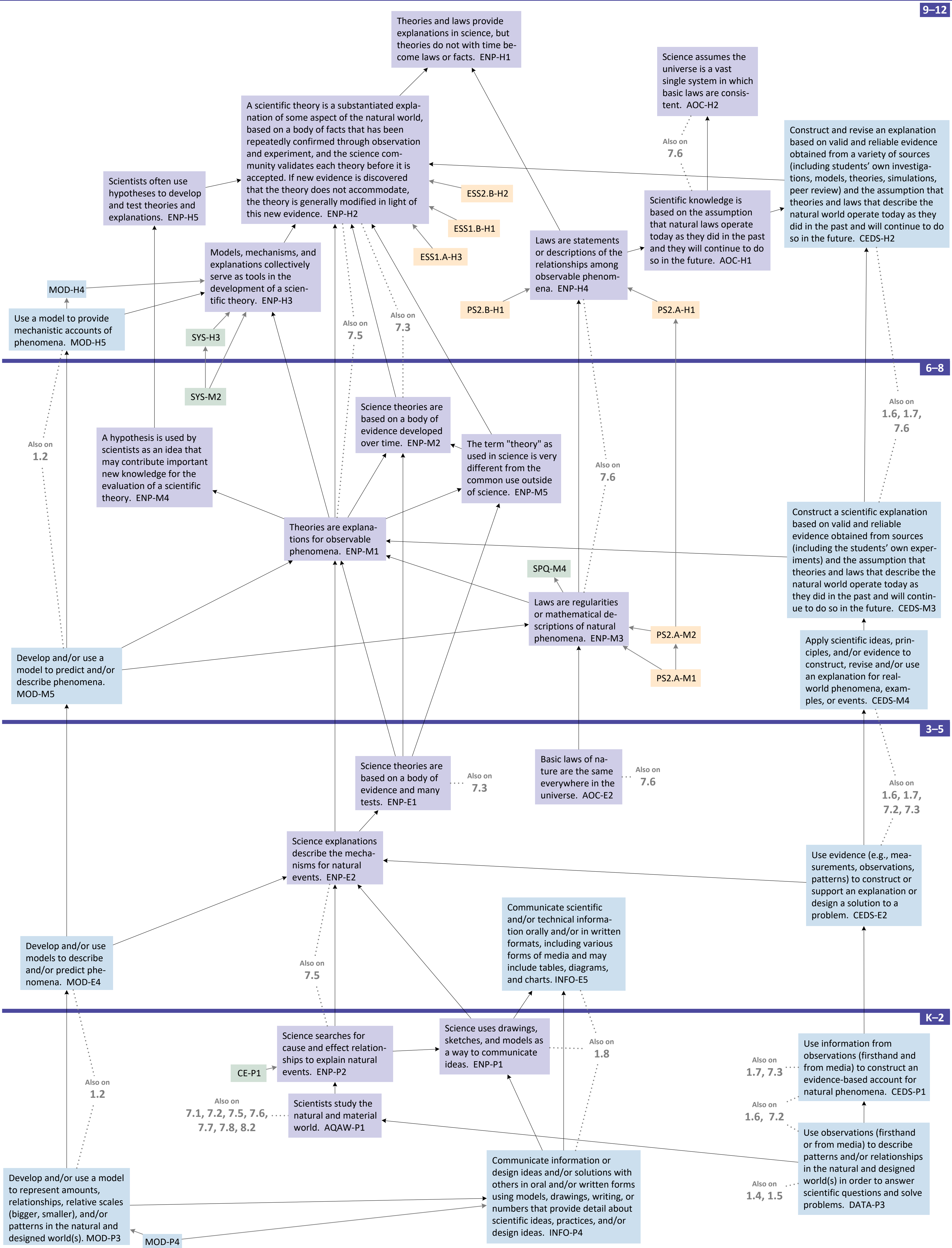
PS2.A-H1: Newton's second law accurately predicts changes in the motion of macroscopic objects.

PS2.B-H1: Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects.

ESS1.A-H3: The big bang theory is supported by observations of distant galaxies receding from our own, of the measured composition of stars and nonstellar gases, and of the maps of spectra of the primordial radiation (cosmic microwave background) that still fills the universe.

ESS1.B-H1: Kepler's laws describe common features of the motions of orbiting objects, including their elliptical paths around the Sun. Orbits may change due to the gravitational effects from, or collisions with, other objects in the solar system.

ESS2.B-H2: Plate tectonics is the unifying theory that explains the past and current movements of the rocks at Earth's surface and provides a framework for understanding its geologic history.


9–12
Theories and laws provide explanations in science, but theories do not with time become laws or facts. ENP-H1
Science assumes the universe is a vast single system in which basic laws are consistent. AOC-H2
A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that has been repeatedly confirmed through observation and experiment, and the science community validates each theory before it is accepted. If new evidence is discovered that the theory does not accommodate, the theory is generally modified in light of this new evidence. ENP-H2
Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. CEDS-H2
Also on 7.6
Scientists often use hypotheses to develop and test theories and explanations. ENP-H5
ESS2.B-H2
ESS1.B-H1
Scientific knowledge is based on the assumption that natural laws operate today as they did in the past and they will continue to do so in the future. AOC-H1
Models, mechanisms, and explanations collectively serve as tools in the development of a scientific theory. ENP-H3
ESS1.A-H3
Laws are statements or descriptions of the relationships among observable phenomena. ENP-H4
MOD-H4
Use a model to provide mechanistic accounts of phenomena. MOD-H5
PS2.B-H1
PS2.A-H1
SYS-H3
Also on 7.5
Also on 7.3
6–8
SYS-M2
Also on 1.6, 1.7, 7.6
Science theories are based on a body of evidence developed over time. ENP-M2
A hypothesis is used by scientists as an idea that may contribute important new knowledge for the evaluation of a scientific theory. ENP-M4
The term "theory" as used in science is very different from the common use outside of science. ENP-M5
Also on 1.2
Also on 7.6
Construct a scientific explanation based on valid and reliable evidence obtained from sources (including the students' own experiments) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. CEDS-M3
Theories are explanations for observable phenomena. ENP-M1
SPQ-M4
Laws are regularities or mathematical descriptions of natural phenomena. ENP-M3
PS2.A-M2
Apply scientific ideas, principles, and/or evidence to construct, revise and/or use an explanation for real-world phenomena, examples, or events. CEDS-M4
Develop and/or use a model to predict and/or describe phenomena. MOD-M5
PS2.A-M1
3–5
Science theories are based on a body of evidence and many tests. ENP-E1
Also on 7.3
Basic laws of nature are the same everywhere in the universe. AOC-E2
Also on 7.6
Also on 1.6, 1.7, 7.2, 7.3
Science explanations describe the mechanisms for natural events. ENP-E2
Use evidence (e.g., measurements, observations, patterns) to construct or support an explanation or design a solution to a problem. CEDS-E2
Communicate scientific and/or technical information orally and/or in written formats, including various forms of media and may include tables, diagrams, and charts. INFO-E5
Develop and/or use models to describe and/or predict phenomena. MOD-E4
Also on 7.5
K–2
Science searches for cause and effect relationships to explain natural events. ENP-P2
Science uses drawings, sketches, and models as a way to communicate ideas. ENP-P1
Also on 1.8
Use information from observations (firsthand and from media) to construct an evidence-based account for natural phenomena. CEDS-P1
Also on 1.7, 7.3
CE-P1
Also on 1.2
Also on 7.1, 7.2, 7.5, 7.6, 7.7, 7.8, 8.2
Scientists study the natural and material world. AQAW-P1
Also on 1.6, 7.2
Use observations (firsthand or from media) to describe patterns and/or relationships in the natural and designed world(s) in order to answer scientific questions and solve problems. DATA-P3
Also on 1.4, 1.5
Communicate information or design ideas and/or solutions with others in oral and/or written forms using models, drawings, writing, or numbers that provide detail about scientific ideas, practices, and/or design ideas. INFO-P4
Develop and/or use a model to represent amounts, relationships, relative scales (bigger, smaller), and/or patterns in the natural and designed world(s). MOD-P3
MOD-P4

8.1: Interdependence of Science, Engineering, and Technology

What are the relationships among science, engineering, and technology?

The fields of science and engineering are mutually supportive, and scientists and engineers often work together in teams, especially in fields at the borders of science and engineering. Advances in science offer new capabilities, new materials, or new understanding of processes that can be applied through engineering to produce advances in technology. Advances in technology, in turn, provide scientists with new capabilities to probe the natural world at larger or smaller scales; to record, manage, and analyze data; and to model ever more complex systems with greater precision. In addition, engineers' efforts to develop or improve technologies often raise new questions for scientists' investigation.

(from *A Framework for K–12 Science Education*, pp. 210–211)

Text of the Off-Map Elements

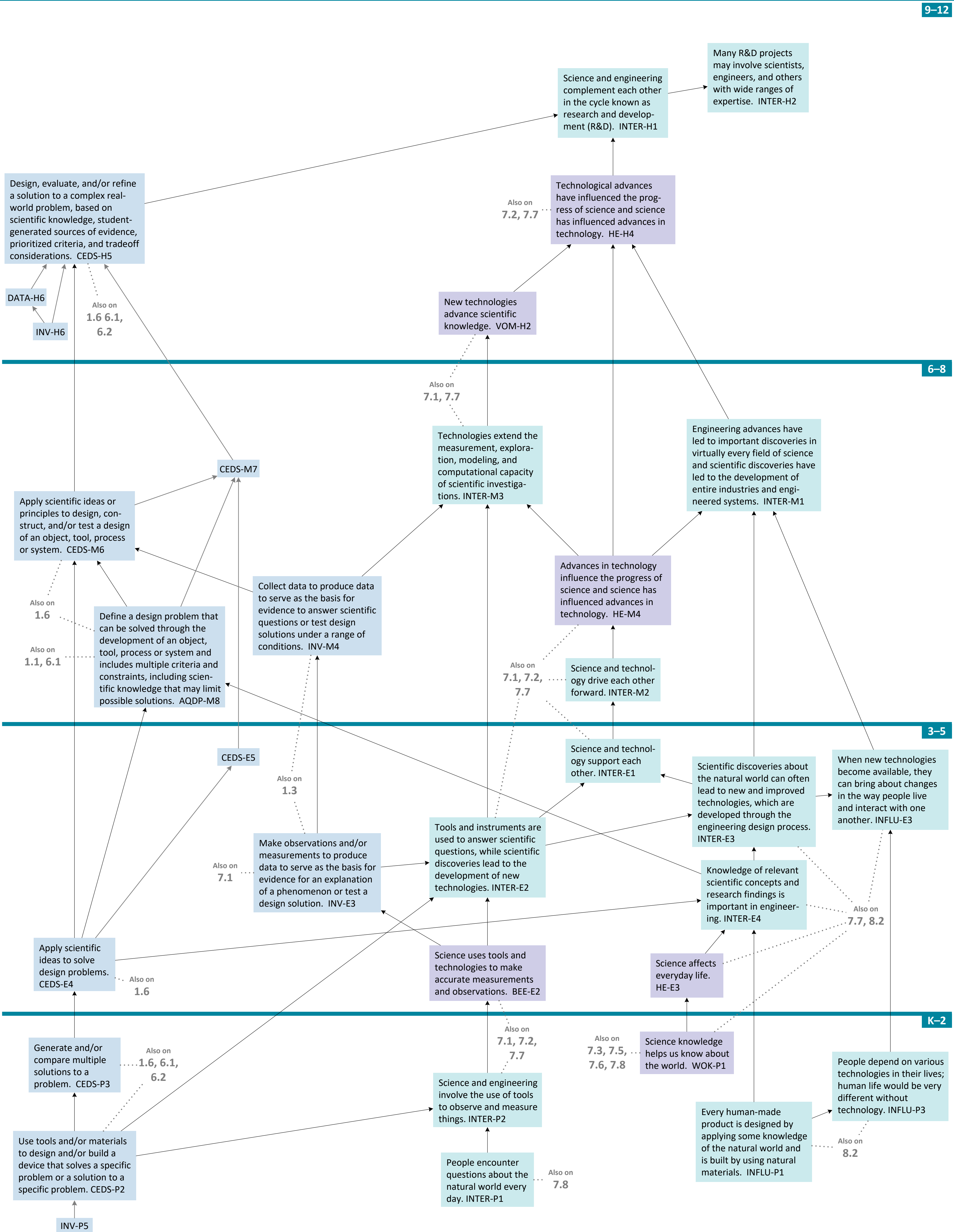
INV-P5: Make observations (firsthand or from media) and/or measurements of a proposed object or tool or solution to determine if it solves a problem or meets a goal.

INV-H6: Manipulate variables and collect data about a complex model of a proposed process or system to identify failure points or improve performance relative to criteria for success or other variables.

DATA-H6: Analyze data to identify design features or characteristics of the components of a proposed process or system to optimize it relative to criteria for success.

CEDS-E5: Generate and compare multiple solutions to a problem based on how well they meet the criteria and constraints of the design solution.

CEDS-M7: Undertake a design project, engaging in the design cycle, to construct and/or implement a solution that meets specific design criteria and constraints.


9–12
Many R&D projects may involve scientists, engineers, and others with wide ranges of expertise. INTER-H2
Science and engineering complement each other in the cycle known as research and development (R&D). INTER-H1
Design, evaluate, and/or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. CEDS-H5
Also on 7.2, 7.7
Technological advances have influenced the progress of science and science has influenced advances in technology. HE-H4
DATA-H6
INV-H6
Also on 1.6 6.1, 6.2
New technologies advance scientific knowledge. VOM-H2
6–8
Also on 7.1, 7.7
Technologies extend the measurement, exploration, modeling, and computational capacity of scientific investigations. INTER-M3
Engineering advances have led to important discoveries in virtually every field of science and scientific discoveries have led to the development of entire industries and engineered systems. INTER-M1
CEDS-M7
Apply scientific ideas or principles to design, construct, and/or test a design of an object, tool, process or system. CEDS-M6
Collect data to produce data to serve as the basis for evidence to answer scientific questions or test design solutions under a range of conditions. INV-M4
Advances in technology influence the progress of science and science has influenced advances in technology. HE-M4
Also on 1.6
Define a design problem that can be solved through the development of an object, tool, process or system and includes multiple criteria and constraints, including scientific knowledge that may limit possible solutions. AQDP-M8
Also on 1.1, 6.1
Also on 7.1, 7.2, 7.7
Science and technology drive each other forward. INTER-M2
3–5
CEDS-E5
Science and technology support each other. INTER-E1
Scientific discoveries about the natural world can often lead to new and improved technologies, which are developed through the engineering design process. INTER-E3
When new technologies become available, they can bring about changes in the way people live and interact with one another. INFLU-E3
Also on 1.3
Tools and instruments are used to answer scientific questions, while scientific discoveries lead to the development of new technologies. INTER-E2
Make observations and/or measurements to produce data to serve as the basis for evidence for an explanation of a phenomenon or test a design solution. INV-E3
Also on 7.1
Knowledge of relevant scientific concepts and research findings is important in engineering. INTER-E4
Also on 7.7, 8.2
Apply scientific ideas to solve design problems. CEDS-E4
Also on 1.6
Science uses tools and technologies to make accurate measurements and observations. BEE-E2
Science affects everyday life. HE-E3
K–2
Also on 7.1, 7.2, 7.7
Also on 7.3, 7.5, 7.6, 7.8
Science knowledge helps us know about the world. WOK-P1
Generate and/or compare multiple solutions to a problem. CEDS-P3
Also on 1.6, 6.1, 6.2
Science and engineering involve the use of tools to observe and measure things. INTER-P2
People depend on various technologies in their lives; human life would be very different without technology. INFLU-P3
Every human-made product is designed by applying some knowledge of the natural world and is built by using natural materials. INFLU-P1
Use tools and/or materials to design and/or build a device that solves a specific problem or a solution to a specific problem. CEDS-P2
People encounter questions about the natural world every day. INTER-P1
Also on 7.8
Also on 8.2
INV-P5

9.1: Matter and Its Interactions

In second grade, students are expected to answer questions such as: "How are materials similar and different from one another, and how do the properties of the materials relate to their use?" An understanding of observable properties of materials is developed by students at this level through analysis and classification of different materials. Students are expected to demonstrate grade-appropriate proficiency in the crosscutting concepts of patterns; cause and effect; and energy and matter and the practices of analyzing and interpreting data; constructing explanations and designing solutions; and engaging in argument from evidence.

In fifth grade, students are expected to answer questions such as: "When matter changes, does its weight change? Can new substances be created by combining other substances?" Students are able to describe that matter is made of particles too small to be seen through the development of a model. Students develop an understanding of the idea that regardless of the type of change that matter undergoes, the total weight of matter is conserved. Students determine whether the mixing of two or more substances results in new substances. Students are expected to demonstrate grade-appropriate proficiency in the crosscutting concepts of cause and effect and scale, proportion, and in the practices of developing and using models, planning and carrying out investigations, and using mathematics and computational thinking.

In middle school, students are expected to answer questions such as: "How can particles combine to produce a substance with different properties? How does thermal energy affect particles? What happens when new materials are formed? What stays the same and what changes?" They build understanding of what occurs at the atomic and molecular scales, including during chemical reactions. Students will be able to apply an understanding that pure substances have characteristic properties and are made from a single type of atom or molecule. They will be able to provide molecular-level accounts to explain states of matter and changes between states as well as that chemical reactions involve regrouping of atoms to form new substances, and that atoms rearrange during chemical reactions. Students are also able to apply an understanding of the design and process of optimization in engineering to chemical reaction systems. Students are expected to demonstrate proficiency in crosscutting concepts of patterns; cause and effect; scale, proportion and quantity; energy and matter; and structure and function and in the practices of developing and using models and in obtaining, analyzing, and interpreting data, designing solutions, and evaluating and communicating information.

In high school, students are expected to answer questions such as the following: "How can one explain the structure and properties of matter? How do substances combine or change (react) to make new substances? How does one characterize and explain these reactions and make predictions about them?" Chemical reactions, including rates of reactions and energy changes, can be understood in terms of the collisions of molecules and the rearrangements of atoms. Using this expanded knowledge of chemical reactions, students are able to explain important biological and geophysical phenomena. They are also able to apply an understanding of the process of optimization in engineering design to chemical reaction systems. Students develop an understanding of the substructure of atoms and provide more mechanistic explanations of the properties of substances. They use the periodic table as a tool to explain and predict the properties of elements. Phenomena involving nuclei are also important to understand, as they explain the formation and abundance of the elements, radioactivity, the release of energy from the sun and other stars, and the generation of nuclear power. The crosscutting concepts of patterns, energy and matter, structure and function, and stability and change are called out for these disciplinary core ideas. Students are expected to demonstrate proficiency in the crosscutting concepts of patterns, energy and matter, structure and function, and stability and change and in the practices of developing and using models, planning and conducting investigations, using mathematical thinking, constructing explanations and designing solutions, and communicating scientific and technical information.

(adapted from *Next Generation Science Standards,* pp. 15, 42, 54, and 88)

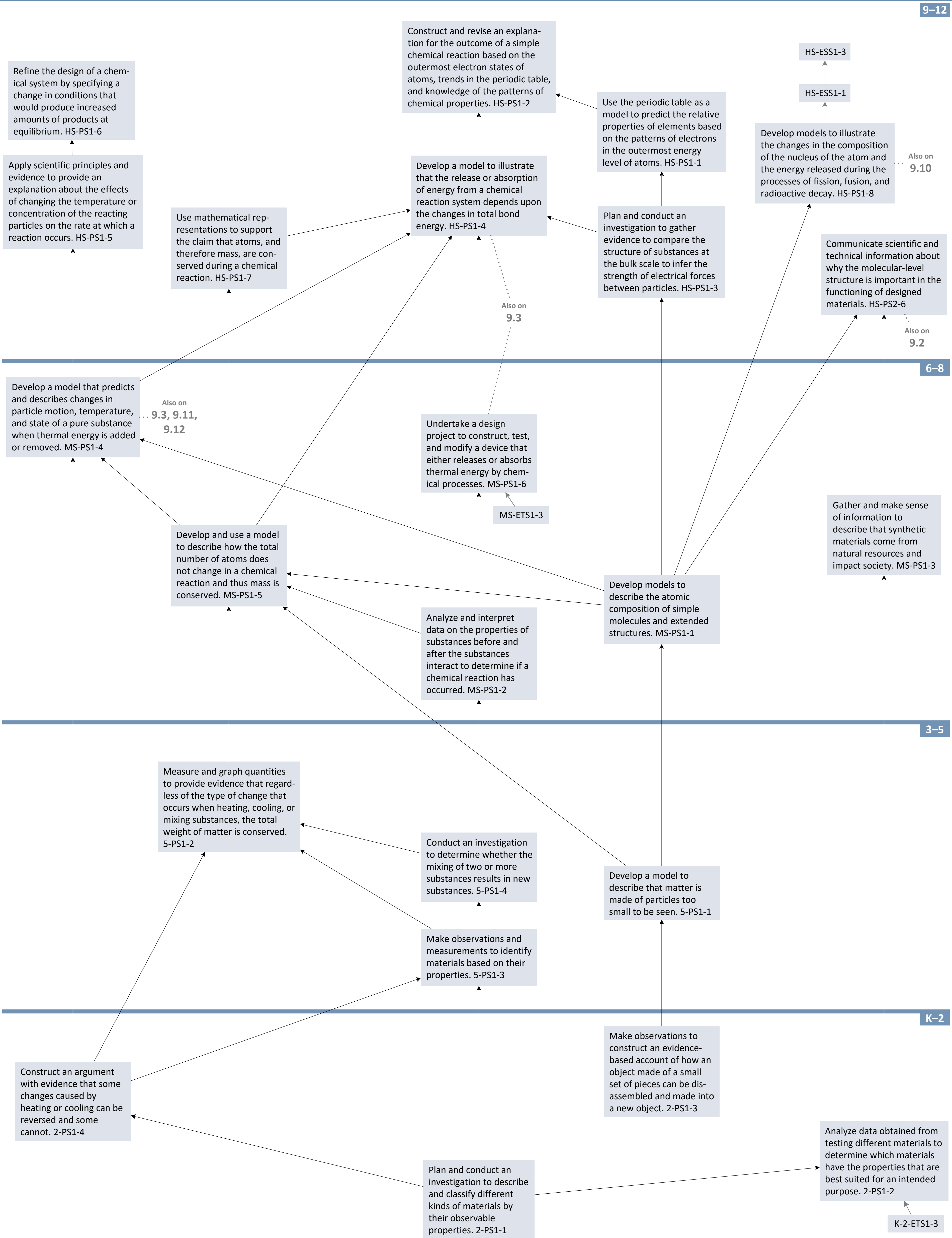
Three-Dimensional Elements Integrated Into the Performance Expectations

The chart below identifies the elements of all three dimensions that are integrated into each performance expectation on this map.

Performance Expectations	Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts	Connections to Engineering	Connections to the Nature of Science
2-PS1-1	INV-P2	PS1.A-P1	PAT-P1		
2-PS1-2	DATA-P5	PS1.A-P2	CE-P1	INFLU-P1	
2-PS1-3	CEDS-P1	PS1.A-P2, PS1.A-P3	EM-P1		
2-PS1-4	ARG-P6	PS1.B-P1	CE-P2		ENP-P2
5-PS1-1	MOD-E4	PS1.A-E1	SPQ-E1		
5-PS1-2	MATH-E3	PS1.A-E2, PS1.B-E2	SPQ-E2		AOC-E1
5-PS1-3	INV-E3	PS1.A-E3	SPQ-E2		
5-PS1-4	INV-E1	PS1.A-E1	CE-E1		
MS-PS1-1	MOD-M5	PS1.A-M1, PS1.A-M5	SPQ-M1		
MS-PS1-2	DATA-M7	PS1.A-M2, PS1.B-M1	PAT-M1		BEE-M1
MS-PS1-3	INFO-M3	PS1.A-M2, PS1.B-M1	SF-M2	INFLU-M2, INTER-M1	
MS-PS1-4	MOD-M5	PS1.A-M3, PS1.A-M4, PS1.A-M6 , *PS3.A-M3, PS3.A-M4*	CE-M2		
MS-PS1-5	MOD-M6	PS1.B-M1, PS1.B-M2	EM-M1		ENP-M3
MS-PS1-6	CEDS-M7	PS1.B-M3, *ETS1.B-M1, ETS1.C-M1, ETS1.C-M2*	EM-M4		
HS-PS1-1	MOD-H3	PS1.A-H1, PS1.A-H2, *PS2.B-H3*	PAT-H1		
HS-PS1-2	CEDS-H2	PS1.A-H2, PS1.B-H3	PAT-H1		
HS-PS1-3	INV-H2	PS1.A-H3, *PS2.B-H3*	PAT-H1		
HS-PS1-4	MOD-H3	PS1.A-H4, PS1.B-H1	EM-H2		
HS-PS1-5	CEDS-H3	PS1.B-H1	PAT-H1		
HS-PS1-6	CEDS-H5	PS1.B-H2, *ETS1.C-H1*	SC-H1		
HS-PS1-7	MATH-H2	PS1.B-H3	EM-H1		AOC-H2
HS-PS1-8	MOD-H3	PS1.C-H1	EM-H5		
HS-PS2-6	INFO-H5	PS2.B-H3, *PS1.A-H3*	SF-H1		

Codes for disciplinary core idea elements in *blue italic* are secondary to the given performance expectation.

The text of all performance expectations with their clarification statements and assessment boundaries can be found in Appendix B (p. 163).


9–12
Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties. HS-PS1-2
HS-ESS1-3
HS-ESS1-1
Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium. HS-PS1-6
Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms. HS-PS1-1
Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay. HS-PS1-8
Also on 9.10
Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs. HS-PS1-5
Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy. HS-PS1-4
Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction. HS-PS1-7
Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles. HS-PS1-3
Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials. HS-PS2-6
Also on 9.3
Also on 9.2
6–8
Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed. MS-PS1-4
Also on 9.3, 9.11, 9.12
Undertake a design project to construct, test, and modify a device that either releases or absorbs thermal energy by chemical processes. MS-PS1-6
MS-ETS1-3
Gather and make sense of information to describe that synthetic materials come from natural resources and impact society. MS-PS1-3
Develop and use a model to describe how the total number of atoms does not change in a chemical reaction and thus mass is conserved. MS-PS1-5
Develop models to describe the atomic composition of simple molecules and extended structures. MS-PS1-1
Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred. MS-PS1-2
3–5
Measure and graph quantities to provide evidence that regardless of the type of change that occurs when heating, cooling, or mixing substances, the total weight of matter is conserved. 5-PS1-2
Conduct an investigation to determine whether the mixing of two or more substances results in new substances. 5-PS1-4
Develop a model to describe that matter is made of particles too small to be seen. 5-PS1-1
Make observations and measurements to identify materials based on their properties. 5-PS1-3
K–2
Make observations to construct an evidence-based account of how an object made of a small set of pieces can be disassembled and made into a new object. 2-PS1-3
Construct an argument with evidence that some changes caused by heating or cooling can be reversed and some cannot. 2-PS1-4
Analyze data obtained from testing different materials to determine which materials have the properties that are best suited for an intended purpose. 2-PS1-2
Plan and conduct an investigation to describe and classify different kinds of materials by their observable properties. 2-PS1-1
K-2-ETS1-3

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AQDP-P2	1.1, 1.3, 7.1, 7.8	1.4, 1.5
AQDP-P3	1.1, 1.3, 1.6, 6.1	1.5
AQDP-E1	1.1	1.3, 1.7
AQDP-E2	1.1	
AQDP-E3	1.1, 7.1, 7.8	1.3, 1.5
AQDP-E4	1.1	
AQDP-E5	1.1, 1.6, 6.1	1.3, 1.4, 1.5
AQDP-M1	1.1	
AQDP-M2	1.1	1.3
AQDP-M3	1.1	1.2, 1.3
AQDP-M4	1.1, 1.2	
AQDP-M5	1.1	
AQDP-M6	1.1, 7.8	1.3, 1.5
AQDP-M7	1.1	1.7
AQDP-M8	1.1, 1.6, 6.1, 8.1	1.5
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AQDP-H2	1.1	
AQDP-H3	1.1	1.4
AQDP-H4	1.1, 1.2	1.8
AQDP-H5	1.1	
AQDP-H6	1.1	1.3
AQDP-H7	1.1	1.6, 1.7
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MOD-P4	1.2	1.8, 7.4
MOD-E1	1.2	
MOD-E2	1.2	1.7
MOD-E3	1.2	1.6
MOD-E4	1.2, 7.4	2.4
MOD-E5	1.2	
MOD-E6	1.2	1.3, 6.2
MOD-M1	1.2	2.4
MOD-M2	1.2	1.1, 2.4
MOD-M3	1.2	
MOD-M4	1.2	1.1
MOD-M5	1.2, 7.4	2.3
MOD-M6	1.2	2.3
MOD-M7	1.2, 1.5	1.3, 1.6
MOD-H1	1.2	1.3, 2.4
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MOD-H3	1.2	1.3
MOD-H4	1.2	7.4
MOD-H5	1.2, 7.4	
MOD-H6	1.2	2.4
MOD-H7	1.2, 1.5	1.3, 1.6

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INV-P3	1.3	
INV-P4	1.3, 7.1, 7.8	1.4, 1.6
INV-P5	1.3, 6.1	1.4, 1.6, 8.1
INV-P6	1.3	1.4, 8.1
INV-E1	1.3, 7.1	1.1, 1.4, 7.8
INV-E2	1.3	
INV-E3	1.3, 7.1, 7.8, 8.1	1.2, 1.4, 1.6
INV-E4	1.3	1.1, 2.2
INV-E5	1.3, 6.1	1.1, 1.2
INV-M1	1.3, 7.1	1.1, 1.6, 1.7
INV-M2	1.3	1.4
INV-M3	1.3	
INV-M4	1.3, 7.8, 8.1	1.1, 1.4, 1.6
INV-M5	1.3, 6.1	1.4, 1.6
INV-H1	1.3	1.2, 1.4
INV-H2	1.3	1.1, 1.2, 1.4
INV-H3	1.3	
INV-H4	1.3	1.4
INV-H5	1.3	
INV-H6	1.3, 6.1	1.2, 1.4, 1.6, 8.1

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DATA-E1	1.4, 1.5, 1.8	1.3
DATA-E2	1.4	
DATA-E3	1.4	
DATA-E4	1.4	1.1, 1.3
DATA-E5	1.4	1.3, 1.7
DATA-M1	1.4, 1.5, 1.8	1.3, 1.6
DATA-M2	1.4	
DATA-M3	1.4	
DATA-M4	1.4	
DATA-M5	1.4	
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DATA-M8	1.4	1.1, 1.3
DATA-H1	1.4, 1.5, 1.8	1.2, 1.3, 1.7
DATA-H2	1.4	1.1
DATA-H3	1.4	
DATA-H4	1.4	
DATA-H5	1.4	
DATA-H6	1.4	1.1, 1.3, 1.6, 8.1

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MATH-P4	1.5	
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MATH-E2	1.5, 2.1	
MATH-E3	1.5	2.3
MATH-E4	1.5	1.4
MATH-M1	1.5	
MATH-M2	1.5	2.3
MATH-M3	1.5	
MATH-M4	1.5	1.1, 2.3
MATH-M5	1.5	1.4
MATH-H1	1.5	1.2, 1.4
MATH-H2	1.5	1.4, 2.3
MATH-H3	1.5	
MATH-H4	1.5	
MATH-H5	1.5	
MATH-H6	1.5	

Code	Appears on Map	Off-Map Element
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CEDS-P3	1.6, 6.1, 6.2, 8.1	1.1, 1.5
CEDS-E1	1.6	
CEDS-E2	1.6, 1.7, 7.2, 7.3, 7.4	1.1, 1.3, 1.5, 1.7, 1.8, 2.1
CEDS-E3	1.6, 7.2	1.5
CEDS-E4	1.6, 8.1	
CEDS-E5	1.6, 6.1, 6.2	1.1, 1.2, 1.5, 1.7, 8.1
CEDS-M1	1.6	
CEDS-M2	1.6	1.5
CEDS-M3	1.6, 1.7, 7.4, 7.6	1.8
CEDS-M4	1.6, 1.7, 7.2, 7.3, 7.4	
CEDS-M5	1.6, 7.2	
CEDS-M6	1.6, 8.1	
CEDS-M7	1.6, 6.1, 6.2	1.1, 1.2, 1.3, 1.5, 1.7, 8.1

Code	Appears on Map	Off-Map Element
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CEDS-H1	1.6	
CEDS-H2	1.6, 1.7, 7.4, 7.6	1.3, 1.4
CEDS-H3	1.6, 7.2	
CEDS-H4	1.6, 7.2	1.8
CEDS-H5	1.6, 6.1, 6.2, 8.1	1.1, 1.3, 1.4, 1.5
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ARG-P3	1.1, 1.7	
ARG-P4	1.7	
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ARG-P7	1.7, 6.1	1.4, 1.6
ARG-E1	1.7, 7.2, 7.3	
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ARG-M1	1.7, 7.3	
ARG-M2	1.7	1.3, 1.6
ARG-M3	1.7, 7.3	
ARG-M4	1.7	
ARG-M5	1.7, 6.1	1.6
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ARG-H5	1.7	
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INFO-P3	1.8	1.4
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INFO-E3	1.8	1.4
INFO-E4	1.8	1.6
INFO-E5	1.8, 7.4	6.2
INFO-M1	1.8	
INFO-M2	1.8	1.4, 1.6
INFO-M3	1.8	
INFO-M4	1.8	
INFO-M5	1.8	
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Code	Appears on Map	Off-Map Element
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INFO-H3	1.8	
INFO-H4	1.8	1.6
INFO-H5	1.8	
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PAT-E1	2.1, 2.7	
PAT-E2	2.1, 2.2, 2.7	1.3
PAT-E3	2.1, 7.2, 7.6	1.6
PAT-M1	2.1, 2.3	
PAT-M2	2.1, 2.7	
PAT-M3	2.1, 2.2	1.4
PAT-M4	1.4, 1.5, 2.1	
PAT-H1	2.1, 2.3	
PAT-H2	2.1, 2.3	
PAT-H3	2.1, 2.2, 2.4	
PAT-H4	2.1	
PAT-H5	2.1, 2.2	
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CE-E1	2.2	1.7
CE-E2	2.1, 2.2	
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SPQ-P2	2.3	1.5
SPQ-E1	2.3	
SPQ-E2	2.3	1.5
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SPQ-M2	2.3, 2.4	
SPQ-M3	2.3	1.5
SPQ-M4	2.3	1.5
SPQ-M5	2.1, 2.3	
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SPQ-H2	2.3, 2.4	
SPQ-H3	2.1, 2.3	
SPQ-H4	2.3	
SPQ-H5	2.3	1.5

Code	Appears on Map	Off-Map Element
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SYS-E2	2.4	2.5, 3.5
SYS-M1	2.2, 2.3, 2.4	1.2, 2.6
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EM-E2	2.5, 3.1, 3.2	
EM-E3	2.5, 3.5, 3.6	
EM-M1	2.5, 3.1, 3.2	
EM-M2	2.4, 2.5, 3.5, 3.6	3.7, 5.2
EM-M3	2.5, 3.5, 3.6	3.7, 3.8, 5.2
EM-M4	2.4, 2.5, 3.5, 3.6	
EM-H1	2.5, 3.5, 3.6	3.2
EM-H2	2.5, 3.6	
EM-H3	2.5, 3.5, 3.6	3.7
EM-H4	2.4, 2.5, 3.5, 3.6	
EM-H5	2.5, 3.1, 3.2	3.7
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SF-E1	2.6	
SF-E2	2.6	4.1
SF-M1	2.6	4.1
SF-M2	2.6	
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SC-P1	2.7	
SC-P2	2.7	
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PS1.A-P3	2.5, 2.6, 3.1, 3.2	4.3
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PS1.A-E2	2.5, 3.1, 3.2	
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PS1.A-M1	2.6, 3.1, 3.2	2.7, 3.6, 3.7, 4.5, 5.5
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PS1.A-H2	3.1	5.1
PS1.A-H3	2.6, 3.1, 3.4	3.2, 3.5, 5.4
PS1.A-H4	3.1	3.2, 3.4, 3.5, 3.6
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LS1.A-H3	4.1	
LS1.A-H4	4.1	2.7
LS1.B-P1	4.1, 4.5, 4.6	2.6, 4.3, 4.6
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Code	Appears on Map	Off-Map Element
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Code	Appears on Map	Off-Map Element
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The NSTA Atlas of the THREE DIMENSIONS

A key aspect of learning in K–12 education is the idea that what students know and are able to do grows and evolves over time. Simple ideas learned in the early elementary grades gain levels of detail and complexity as students progress in their education. Connections between different topics and disciplines are made.

Therefore, a key feature of setting standards for students is to describe learning progressions. Simply put, a learning progression is an articulation of the "steps along the way" that a student might go through as he or she works toward mastery of something. Although one path does not apply to all students, some paths are more common than others.

A Framework for K–12 Science Education (the *Framework*) provides specific grade-band endpoints for the disciplinary core ideas and describes progressions for the science and engineering practices and crosscutting concepts. The *Next Generation Science Standards (NGSS)* and other standards based on the *Framework* contain tables of progressions for all three dimensions.

What's missing is a way to illustrate these connections. That's where *The NSTA Atlas of the Three Dimensions* comes in. It's your user-friendly guide to understanding how ideas build on each other and relate to each other. With the *NSTA Atlas*, you'll be able to trace the prerequisites for understanding science in every grade, make the appropriate connections to support science content, and show the way to the next steps in your students' science education—all in the context of today's standards.

The 62 maps in the *NSTA Atlas* organize all of the elements from standards on a particular topic (e.g., modeling, patterns, or definitions of energy) on a single page. The elements from grades K–2 are at the bottom of the page, and those from grades 9–12 are at the top. Arrows connect elements to indicate how ideas in a particular topic build on each other and how elements in different topics connect to one another. Because the maps prompt you to think about ways student learning can build over time, the *NSTA Atlas* is useful even if you teach in a state that hasn't adopted the *NGSS*.

By studying the maps in the *NSTA Atlas* and the additional resources in the appendixes, you'll gain new insights about the standards and have a powerful navigational tool to help you plan curriculum, instruction, and assessment.

What Others Are Saying About the *NSTA Atlas*

"Ted has put forward a way of thinking about the *NGSS* that will foster great discussion and guide teachers as they plan individually and in teams."

—from the foreword by **Stephen Pruitt,** president of the Southern Regional Education Board, former coordinator of the development of the *NGSS* as senior vice president of Achieve

"Navigating and realizing the vision of the *Framework* and *NGSS* can be a daunting challenge. Ted Willard, in creating *The NSTA Atlas of the Three Dimensions*, provides an exceptional resource to navigate this new world of science education. The *NSTA Atlas* provides a thoughtful and systematic guide that shows the meaning of the elements of the three dimensions at various grade levels. But more important, the *NSTA Atlas* illustrates how the elements develop over time. As such, the *NSTA Atlas* will serve as an indispensable resource to support the science education community as we work together to bring this vision into reality."

—**Joe Krajcik,** Lappan-Phillips Professor of Science Education; director, CREATE for STEM, Michigan State University; *NGSS* writing team leader

"The *NSTA Atlas* is a one-of-a-kind, exceptional resource that moves the three dimensions from a list of learning goals on a page to a visual map that thoughtfully portrays the steps along the way to achieving a coherent understanding of science. It's a 'must have' resource for every teacher and those who support teachers as they transition to new visions of achieving science literacy."

—**Page Keeley,** bestselling author and science education consultant, former president of the National Science Teaching Association

"Science educators can use this important tool in their own planning and in multiple professional learning opportunities to ensure that their instructional practices are in sync with a child's grade-level learning progression. The *NSTA Atlas* has the potential to be an important equity lever to assist educators as they select and implement new standards."

—**Ellen Ebert,** director, Learning and Teaching Science, Office of the Superintendent of Public Instruction, State of Washington; former president, Council of State Science Supervisors

"The *NSTA Atlas* is a critical and incredibly useful tool to visually map how scientific concepts, practices, and crosscutting concepts build vertically across grade bands and connect horizontally to each other across disciplines. These maps will provide an indispensable guide to educators."

—**Maria Chiara Simani,** executive director, California Science Project

"I am excited for teachers, curriculum designers, science supervisors, superintendents, and school committees to see three-dimensional standards in a new light as can only be shown by *The NSTA Atlas of the Three Dimensions*."

—**James Blake,** K–12 science curriculum specialist, Lincoln Public Schools, Lincoln, Nebraska; president, National Science Education Leadership Association

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