

Appendix: The Teacher-Friendly Guides™, Virtual Fieldwork, and the NGSS's Three-Dimensional Science

The Next Generation Science Standards contain a set of learning goals that define and describe the ideas and practices that we need in order to think scientifically. The NGSS are not a curriculum. They tell teachers not how to teach, but rather, are tools to show what to teach. They also help families know what children are expected to learn, and help schools and teachers know what to assess. So, how do you teach in ways that align with NGSS, if NGSS itself doesn't tell you? The strategies, tools and resources associated with the Real Earth Inquiry project, like this *Teacher-Friendly Guide*™, are intended to offer a partial answer to that question.

The vision of NGSS differs in a number of important ways from current common practice in schools and classrooms across the country. Teaching about local and regional Earth and environmental science can and has worked well for many teachers under more traditional standards, but by attending to the three dimensions of the NGSS (see below), we believe it can work even better. Deep understandings of why your local environment looks the way it does requires understanding the local environment from multiple disciplinary perspectives, and understanding the connections

amongst these different disciplinary ideas. That is, to understand your local environment, a systems perspective is needed. Scientifically accurate meaningful understanding can and does come out of single lessons, single units, and single courses, but these understandings become richer, deeper, and more durable if they are connected across courses. The NGSS vision includes recognition that building a deep understanding of big ideas is both very important and a process that takes years of coordinated effort. Fortunately, the many processes that shape the local environment are part and parcel of existing curricula, and especially for Earth science, biology, and environmental science courses, nearly every unit has central aspects that play out on a human scale just outside the school door. A coordinated approach to the study of the local environment across units within a single course and across grade levels

Acronyms frequently used in *The Next Generation Science Standards* (NGSS):

PE: Performance Expectation
DCI: Disciplinary Core Idea
CC: Crosscutting Concept
**SEP: Scientific and Engineer-
ing Practice**
PS: Physical Sciences
LS: Life Sciences
ESS: Earth & Space Sciences
**ETS: Engineering, Technology,
and the Applications of
Science**

"ReaL Earth Inquiry" is the project name of the NSF grant (0733303) to the Paleontological Research Institution to develop teacher resources such as Teacher-Friendly Guides™ to regional Earth science and Virtual Fieldwork Experiences. "ReaL" refers to Regional and Local.

CHAPTER AUTHOR

Don Duggan-Haas

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and courses can be a fairly subtle change in each teacher's daily routines, but it has the potential for big returns in terms of the depth of student understanding. This deeper understanding pertains not only to the local environment and the way course topics are represented within it, but also to systems more generally, to the nature and importance of scale, and to much, much more.

NGSS builds upon the earlier work in the National Science Education Standards (NSES), but brings more of a systems approach not only to its representation of science, but to the standards themselves. NSES defined science not just as a body of ideas, but an evolving body of ideas extended by inquiry. NGSS continues this work by clarifying inquiry and the sciences as a set of relationships amongst three dimensions: Disciplinary Core Ideas (DCIs), Scientific and Engineering Practices, and Crosscutting Concepts. Each of the three dimensions is judged to be of roughly equal importance and they are seen as interdependent. To truly, deeply, understand science and how scientific understandings develop, learners must not only understand each dimension, but how the dimensions are related to one another—the whole is greater than the sum of the parts. By coming to understand these interconnections, teachers and students will also come to better understand the nature of both scientific inquiry and of complex systems.

A Perspective on Science Education Priorities

The bulk of the NGSS is a series of Standards, each a page or two in length, with "Performance Expectations" (PEs) at the top of the first page, followed "Foundation Boxes" and "Connection Boxes" supporting the PEs. It's tempting to jump into the discussion of NGSS by starting there. It's also tempting to start with the Disciplinary Core Ideas (DCIs), especially for those who specialize in a particular scientific discipline. But readers shouldn't do either of those things. Appendix K of NGSS notes, "The goal is not to teach the PEs, but rather to prepare students to be able to perform them by the end of the grade band course sequence." It's important to understand the basic three-dimensional structure of the NGSS before looking at the PEs or DCIs. We will give them both their due, but we won't start with either of them.

If you have a degree in a particular science, and this is the science that makes up the bulk of your teaching load, it's natural to go straight for your area of expertise in the NGSS, to see how that's addressed. But don't do that, or, if you already have, try to imagine that you haven't. Before considering the concepts and practices essential to being literate in your discipline, consider what you think everyone needs to know about science disciplines *outside your area of specialization*, and consider the ideas that are broadly applicable across all the sciences. That is, think about the fundamentals of science.

Imagine having magical powers that allowed you to make every American understand six or eight profound scientific ideas—ideas that, if everyone understood them, would help people make the world a better place because

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they would make better decisions. Imagine again that this power could also be used to give everyone a small set of well-developed scientific skills. What should these ideas and skills be? Ponder what these ideas and skills are before reading further, perhaps going so far as to put them down on paper. Ask your colleagues, and your former students the same question. What are the most important ideas and skills for everyone to understand or be able to do related to science?

The profound scientific ideas you thought of are likely to be something like NGSS's Crosscutting Concepts, and the scientific skills are likely to be something like the Scientific and Engineering Practices (*Table A.1*). In reviewing the NGSS, teachers at the secondary and college levels who specialize in a particular subject are often naturally drawn first to the Disciplinary Core Ideas for their discipline, and when they find a favorite topic that is not addressed to what they consider an appropriate depth, they are upset that NGSS is not providing the content necessary to prepare their students for the future. But, decades of educational practice teaching science courses with thousand-page textbooks and scores of key ideas has not yielded a scientifically literate populace. It is essential to focus on smaller sets of truly big ideas (see also the *Big Ideas* chapter) and work across grade-levels to build understandings over time. This may mean, however, that your favorite topics are no longer explicitly listed in the learning goals.

Table A.1 contains abbreviated versions of the Concepts, Practices, and Ideas. You can find longer descriptions within the NGSS, and we'll look at one as an illustrative example. Consider the full description of Crosscutting Concept #3:

Scale, proportion, and quantity. In considering phenomena, it is critical to recognize what is relevant at different measures of size, time, and energy and to recognize how changes in scale, proportion, or quantity affect a system's structure or performance.

It seems likely that most Americans do not have a good and durable understanding of this concept, yet it has relevance to many aspects of their daily lives. The same could be said of most, if not all, of the remaining concepts on the list.

The Crosscutting Concepts are described in some detail in Appendix G of NGSS, and the Scientific and Engineering Practices are described in Appendix F.

Such understandings are almost certainly more important than knowing particular facts about geologic history or the nature of disease (two topics not given deep attention in the NGSS). Indeed, it's only possible to understand geologic history or the nature of disease if you also understand these concepts!

While your favorite topics may not be explicitly mentioned in NGSS, that doesn't necessarily preclude them from being taught. There's a tremendous amount of content in these *Teacher-Friendly Guides™* that are not mentioned in NGSS, yet we believe that all of the contents of the Guides support teaching

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that is aligned with the NGSS. Different topics, such as glaciers or mineral resources, can serve as our pedagogical partners in building understandings of the Crosscutting Concepts, Scientific and Engineering Practices, and the Disciplinary Core Ideas that make up the NGSS. In other words, we can and should teach these topics, but understanding the particular topic isn't the primary goal. The primary goal is to use the teaching of these topics as a means to build an understanding of those bigger ideas.

It isn't clear if K–12 science curricula designed to bring the NGSS's vision to fruition will be more or less rigorous than today's common K–12 curricula, but rigor shouldn't be the goal of education. Education should develop citizens who can reason critically and use evidence to inform their actions. This isn't to say that schooling shouldn't be challenging, but rather that its challenges should be in the service of meeting other goals. Building deep and interconnected understandings of the three dimensions of NGSS will not be a simple task, but it has the potential to better prepare for students for citizenships, college, and careers.

Connecting "Why does this place look the way it does?" and Virtual Fieldwork to NGSS

This *Teacher-Friendly Guide™* is one part of a large project designed to help educators teach about Regional and Local (ReaL) Earth system science in an inquiry-based way. This ReaL Earth Inquiry Project, and all of its related resources, support educators and students in the investigation of the project's driving question: "*Why does this place look the way it does?*" The "place" of the question is anywhere you happen to be, but we hope and expect users of these materials will start by studying areas outside their backdoor or their classroom door. The *Fieldwork* chapter (Chapter 11) addresses both actual and Virtual Fieldwork, and we believe the coupling of virtual and actual fieldwork is an excellent way to teach and learn, and it's an approach that is fully three dimensional, in the NGSS's sense of that term.

Read through the Practices outlined in *Table A.1* with an eye toward engaging in and documenting fieldwork. See the graphic organizer and the question list in Chapter 11 and consider how these questions can be asked of any site, and how they can serve to inspire new questions that are site-specific. Then, consider the making of Virtual Fieldwork Experiences (VFEs) to document the site, allowing for continued investigation after leaving the field, and sharing findings with others in the community and beyond. This approach provides opportunities to engage *all* of the practices. To build rich explanations of the range of processes at play in a field site requires application of *all* of the Crosscutting Concepts. There are also opportunities for using field sites to build understandings of *all* of the DCIs, though selected ones from the Life and Earth & Space Sciences have the most direct correspondence. The use of virtual and actual fieldwork is scalable to fit the educational need, so a particular lesson or activity would be

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Scientific and Engineering Practices		Crosscutting Concepts	
<ol style="list-style-type: none"> Asking Questions and Defining Problems Developing and Using Models Planning and Carrying Out Investigations Analyzing and Interpreting Data Using Mathematics and Computational Thinking Constructing Explanations and Designing Solutions Engaging in Argument from Evidence Obtaining, Evaluating, and Communicating Information 		<ol style="list-style-type: none"> Patterns Cause and Effect Scale, Proportion, and Quantity Systems and System Models Energy and Matter Structure and Function Stability and Change Interdependence of Science, Engineering, and Technology Influence of Engineering, Technology, and Science on Society and the Natural World 	
Disciplinary Core Ideas			
<i>Physical Sciences</i>	<i>Life Sciences</i>	<i>Earth and Space Sciences</i>	<i>Engineering, Technology, and the Applications of Science</i>
<p>PS 1: Matter and its interactions</p> <p>PS 2: Motion and stability: Forces and interactions</p> <p>PS 3: Energy</p> <p>PS 4: Waves and their applications in technologies for information transfer</p>	<p>LS 1: From molecules to organisms: Structures and processes</p> <p>LS 2: Ecosystems: Interactions, energy, and dynamics</p> <p>LS 3: Heredity: Inheritance and variation of traits</p> <p>LS 4: Biological evolution: Unity and diversity</p>	<p>ESS 1: Earth's place in the universe</p> <p>ESS 2: Earth's systems</p> <p>ESS 3: Earth and human activity</p>	<p>ETS 1: Engineering design</p> <p>ETS 2: Links among engineering, technology, science, and society</p>

Table A.1: Summary of NGSS's Three Dimensions. For more detailed descriptions, see the relevant appendices in The Next Generation Science Standards.

expected to target just one or two, but a program of fieldwork across a course would allow for the addressing of many of the Concepts, Practices, and Ideas.

Look again to the graphic organizers from Chapter 11: Fieldwork. It is easy to see how, especially in Earth science, biology, or environmental science courses, most of the units in these courses play out in some meaningful way outside the classroom door. As the DCIs are akin to umbrellas relative to a course's units, these too largely play out in meaningful ways outside the classroom door. The

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NGSS recognizes that in order to understand big ideas, years of coordinated study are required. The coordinated study of the local and regional environment provides an excellent opportunity for this. A field site can be studied using increasingly sophisticated approaches across the K–12 experience, and for the students, this does not entail repetition, but rather the opportunity to study a site from different disciplinary vantage points across all or part of the K–12 continuum. If such an approach is adopted broadly, kids who move during the course of their schooling can bring in new eyes, and information, to compare and contrast the environment in their new school with the environment where they used to live.

How to Read the NGSS

Each standard in the NGSS includes multiple interconnected parts. They have an architecture that can be seen in *Figure A.1*. This diagram is taken directly from the NGSS website's page, "How to Read the Next Generation Science Standards." This page includes a short written overview and an accompanying video as well as links to more detailed information. The standards are designed to be read online, with features like pop-ups, choices for highlighting different parts of the text (the different dimensions) in different colors, and links to related content elsewhere within the NGSS. If you're not familiar with how they work, you should follow the link above and then explore around the NGSS a bit before reading further.

Know that the appearance of the Standards can be a bit intimidating, with all the abbreviations, acronyms, codes, and different colors, but after a bit of time working with the text, its logic does become understandable.

Example of Real Connections to Performance Expectations

Earth and Space Science Disciplinary Core Idea #2 is "Earth's Systems," and it has five supporting concepts:

- 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

In the middle school grade band of NGSS, there are six performance expectations associated with ESS2. All six are listed below, but not in their complete form. "Clarification Statements" and "Assessment Boundaries" are not included in the full list, but we'll look at one of the Performance Expectations in greater detail. See the full list (and the full standard) at <http://nextgenscience.org/msess2-earth-systems>.

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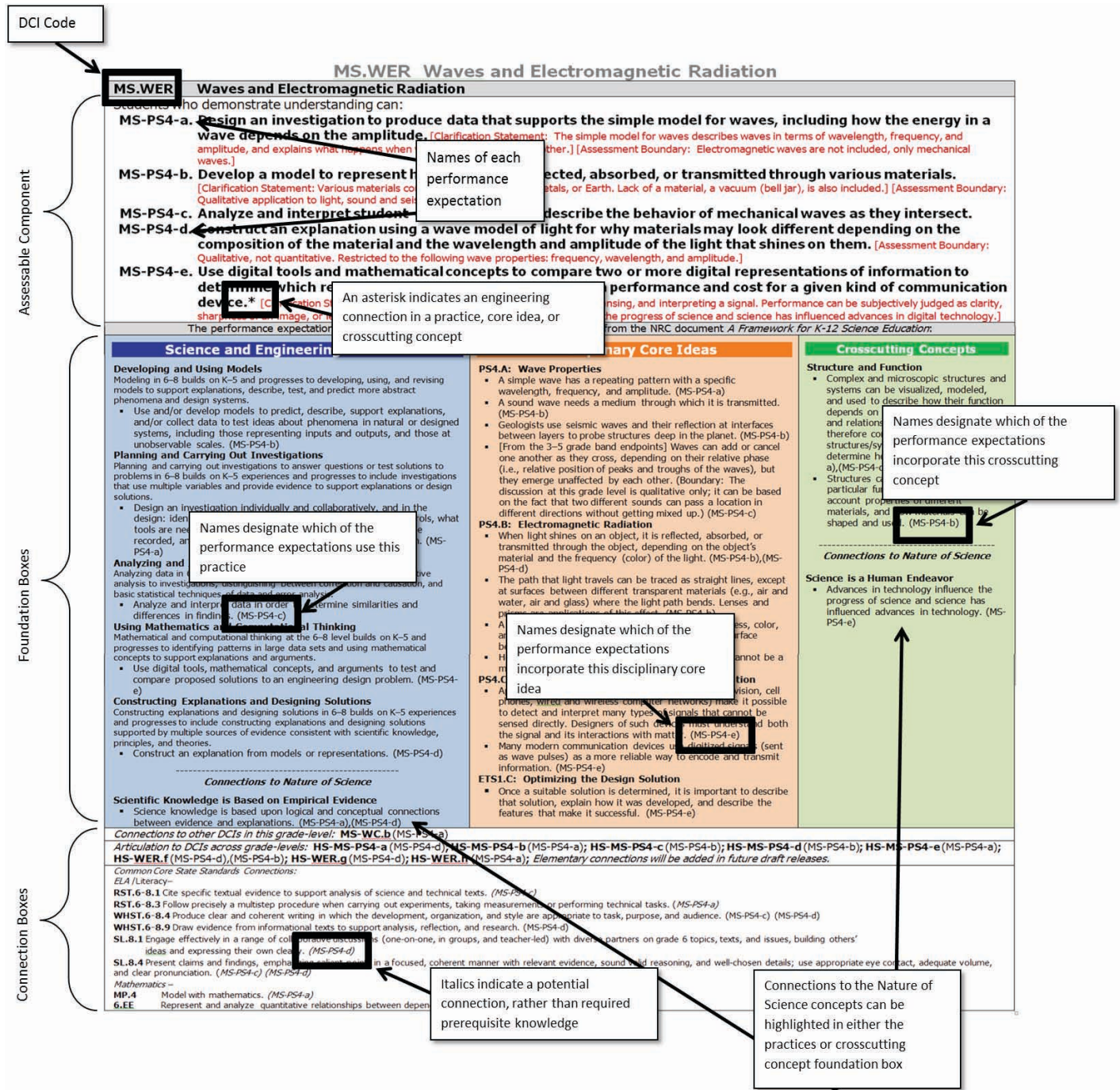


Figure A.1: The architecture of a standard. The NGSS is designed with the web in mind and features of its online architecture make it easier to understand than this diagram might indicate.

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MS-ESS2 Earth's Systems (Middle School-Earth System Science 2)
Students who demonstrate understanding can:

MS-ESS2-1. *Develop a model to describe the cycling of Earth's materials and the flow of energy that drives this process.*

MS-ESS2-2. *Construct an explanation based on evidence for how geoscience processes have changed Earth's surface at varying time and spatial scales.*

MS-ESS2-3. *Analyze and interpret data on the distribution of fossils and rocks, continental shapes, and seafloor structures to provide evidence of the past plate motions.*

MS-ESS2-4. *Develop a model to describe the cycling of water through Earth's systems driven by energy from the sun and the force of gravity.*

MS-ESS2-5. *Collect data to provide evidence for how the motions and complex interactions of air masses results in changes in weather conditions.*

MS-ESS2-6. *Develop and use a model to describe how unequal heating and rotation of the Earth cause patterns of atmospheric and oceanic circulation that determine regional climates.*

Each of the six above Performance Expectations (PEs) incorporates aspects of each of the three dimensions. The color-coding helps to reveal some of that. "Science and Engineering Practices" are shown in blue (*italics* here) and Crosscutting Concepts are shown in green (*underlined italics* here). Disciplinary Core Ideas are in black. This is one of the color-coding options in the online presentation. Pop-ups (which can be disabled) appear when the different colored parts of the PE are scrolled over with the mouse. *Figure A.2* is a screen grab of the first three PEs for ESS2, with a pop-up showing the Crosscutting Concepts related to "MS-ESS2-2."

All of these Performance Expectations directly aligns with "*Why does this place look the way it does?*" We'll take a closer look at MS-ESS2-2, which addresses how geoscience processes have shaped the Earth's surface at varying time and spatial scales. This Guide coupled with the development of a VFE of a site local to your school, provides rich opportunities for addressing both this particular PE, along with all of the others within this standard. The Clarification Statements often provide helpful examples, and Assessment Boundaries indicate what will not be addressed in the assessments now under development. Importantly, this is not an indication that these topics are out of bounds. These standards represent minimum expectations—exceeding these expectations is often appropriate.

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MS-ESS2 Earth's Systems

How to read the standards »
Go back to search results
Related Content »

Views: Disable Popups / Black and white / Practices and Core Ideas / Practices and Core Ideas / Practices and Crosscutting Concepts / PDF

Students who demonstrate understanding can

MS-ESS2-1. Develop a model to describe **Scale, Proportion, and Quantity**
[Clarification Statement: Emphasis is on how processes change Earth's surface at time and spatial scales that can be large (such as slow plate motions or the uplift of large mountain ranges) or small (such as rapid landslides or microscopic geochemical reactions), and how many geoscience processes (such as earthquakes, volcanoes, and meteor impacts) usually behave gradually but are punctuated by catastrophic events. Examples of geoscience processes include surface weathering and deposition by the movements of water, ice, and wind. Emphasis is on geoscience processes that shape local geographic features, where appropriate.]
• Time, space, and energy phenomena can be observed at various scales using models to study systems that are too large or too small.
does not include the identification, naming, or numbering of boundaries.
drives this process.
formation, and sedimentation,
ment Boundary: Assessment

MS-ESS2-2. Construct an explanation based on evidence for how geoscience processes have changed Earth's surface at varying time and spatial scales. [Clarification Statement: Emphasis is on how processes change Earth's surface at time and spatial scales that can be large (such as slow plate motions or the uplift of large mountain ranges) or small (such as rapid landslides or microscopic geochemical reactions), and how many geoscience processes (such as earthquakes, volcanoes, and meteor impacts) usually behave gradually but are punctuated by catastrophic events. Examples of geoscience processes include surface weathering and deposition by the movements of water, ice, and wind. Emphasis is on geoscience processes that shape local geographic features, where appropriate.]

MS-ESS2-3. Analyze and interpret data on the distribution of fossils and rocks, continental shapes, and seafloor structures to provide evidence of the past plate motions. [Clarification Statement: Examples of data include similarities of rock and fossil types on different continents, the shapes of the continents (including continental shelves), and the locations of ocean structures (such as ridges, fracture zones, and trenches).] [Assessment Boundary: Paleomagnetic anomalies in oceanic and continental crust are not assessed.]

MS-ESS2-4. Develop a model to describe the cycling of water through Earth's systems driven by energy from the sun and the force of gravity. [Clarification Statement: Emphasis is on the ways water changes its state as it moves through the multiple pathways of the hydrologic cycle. Examples of models can be conceptual or physical.] [Assessment Boundary: A quantitative understanding of the latent heats of vaporization and fusion is not assessed.]

MS-ESS2-5. Collect data to provide evidence for how the motions and complex interactions of air masses results in changes in weather conditions. [Clarification Statement: Emphasis is on how air masses flow from regions of high pressure to low pressure, causing weather (defined by temperature, pressure, humidity, precipitation, and wind) at a fixed location to change over time, and how sudden changes in weather can result when different air masses collide. Emphasis is on how weather can

Figure A.2: A screen-grab of part of the middle school standard on Earth Systems: MS-ESS2. Shown here are the first three PEs, with the first partially obscured by a pop-up related to the CC in the second.

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Figure A.2 only shows a piece of the standard—only the first few Performance Expectations. Like the example in the previous section, this PE also includes Foundation Boxes, which highlight what pieces of each of the three dimensions is addressed in the standard and Connection Boxes, which highlight connections to other disciplines and grade levels. Drawing these connections is important in helping fortify understandings of both the particular content and how that content is contextualized in broader human and natural systems.

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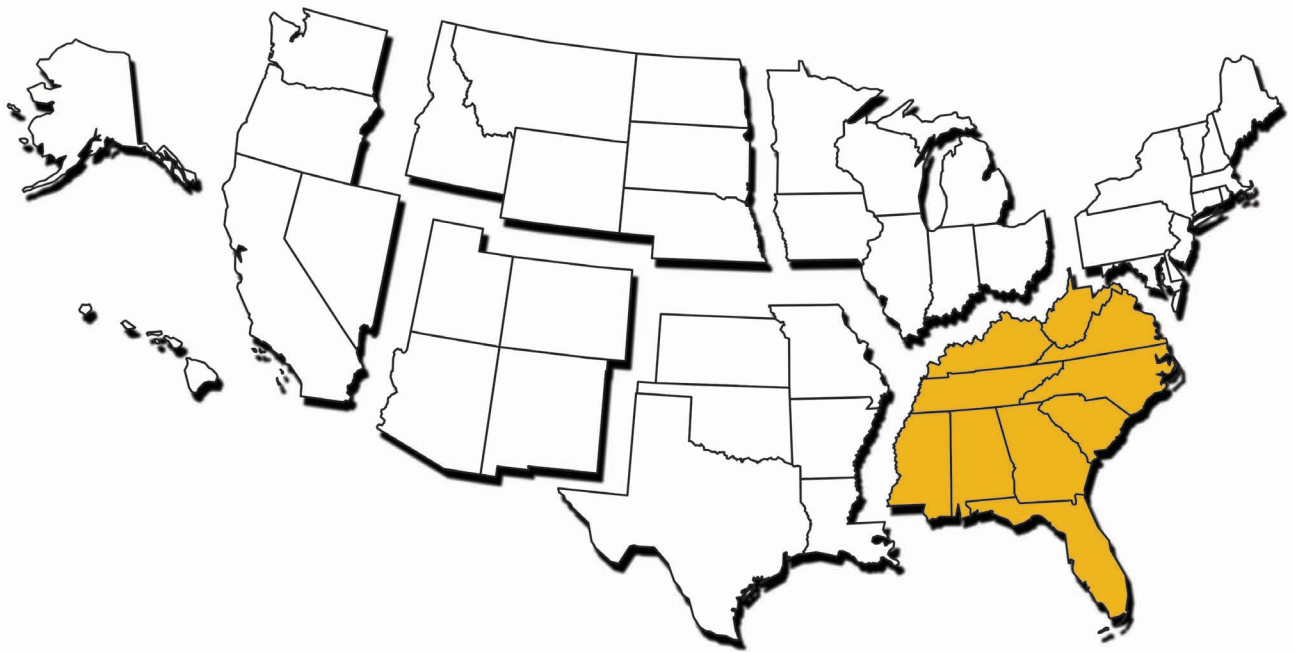
Resources

(Following are some of the most commonly used and cited publications on science education standards and bench-marks.)

- American Association for Advance of Science. 1993. *Benchmarks for Science Literacy*. Oxford University Press, <http://www/irpkeect2-61.org/publications/bsl/online/index.php>.
- Bransford, J. D., A. L. Brown, & R. R. Cocking, eds. 2000. *How People Learn: Brain, Mind, Experience, and School, expanded edition*. National Academies Press, Washington, DC, http://www.nap.edu/openbook.php?record_id=9853.
- Common Core State Standards Initiative*, <http://www.corestandards.org>. (While not focused on science education directly, standards on math and non-fiction reading impact are importantly related.)
- National Center for Science Education. 2013. *Evolution and Climate Change in the NGSS*, <http://ncse.com/news/2013/04/evolution-climate-change-ngss-0014800>.
- National Research Council. 1996. *National Science Education Standards*. National Academies Press, Washington, DC, http://www.nap.edu/openbook.php?record_id=4962. (NRC is a body of the National Academy of Sciences.)
- National Research Council. 2011. *Successful K-12 STEM Education: Identifying Effective Approaches in Science, Technology, Engineering, and Mathematics*. National Academies Press, Washington, DC, http://www.nap.edu/openbook.php?record_id=13158.
- National Research Council. 2012. *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. National Academies Press, Washington, DC, http://www.nap.edu/openbook.php?record_id=13165.
- National Research Council. 2013. *Next Generation Science Standards: For States, By States*. National Academies Press, Washington, DC, <http://www.nextgenscience.org>.
- NGSS@NSTA website, National Science Teacher Association, <http://ngss.nsta.org/>.
- Wysession, M. 2013. The Next Generation Science Standards and the Earth and Space Sciences. *The Science Teacher*, April/May issue, http://nstahosted.org/pdfs/ngss/resources/201304_NGSS-Wysession.pdf. (Duggan-Haas, author of this Appendix, worked with Wysession on NRC's Conceptual Framework for New Science Education Standards.)

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Teacher-Friendly
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Edited by Andrielle N. Swaby, Mark D. Lucas, & Robert M. Ross

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On the back cover: Blended geologic and digital elevation map of the Southeastern US. Each color represents the age of the bedrock at the surface. Adapted from Barton, K. E., Howell, D. G., Vigil, J. F., *The North America Tapestry of Time and Terrain*, US Geological Survey Geologic Investigations Series I-2781, <http://pubs.usgs.gov/imap/i2781>.